Educator Perceptions on the Utility of Musical Sonification

An Interactive Qualifying Project submitted to the Faculty of Worcester Polytechnic Institute in partial fulfilment of the requirements for the degree of Bachelor of Science.

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December 15, 2021

Abstract

The use of sonification for auditory representation of data in educational contexts has been investigated a number of times and often has produced interesting – though inconclusive – results. The research done as a basis of this report research sought to explore opinions of academic instructors on the educational utility of Sonify, an application that facilitates the creation of musical sonification from Ramen spectroscopy data. Educators from Worcester Polytechnic Institute and Mass Academy were asked to watch a short demonstration of the use of Sonify before completing a short survey. The eight participants on average did not find that the music created by Sonify to be educationally valuable, and did not express interest in using Sonify. While these results would be more valuable if they followed first-hand experience using Sonify from a larger sample, the results of this report will likely be helpful to someone looking to continue developing Sonify or create their own musical sonification tool for educational purposes.

Acknowledgements

Special thanks to Professor Michael Timko and Professor Vincent Manzo for their long-term advisement and support. Thanks also to Matthew Pietrucha for the time and work spent in the development of Sonify and for contributing research to the use of sonification in education. Lastly, thanks to the instructors who took time out of their busy schedules to participate in this survey and provide thoughtful responses.

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Introduction

Sonification

Sonification is the representation of data as sound (Vines et al. (2019)). Useful applications of sonification can be as simple as a clock that chimes every hour, or a metronome that assigns different sounds to various divisions of time. Other more complex examples include tools like Geiger counters which produce audible clicks as they approach radioactive substances, and the electrocardiographic heart monitors commonly heard beeping in hospitals.

Sonification has many useful purposes in modern society. As Madhyastha and Reed (1995) aptly points out, a car with a manual transmission can not be safely driven if the driver has to divert their eyes to monitor the tachometer of their car. Instead, drivers listen to the sound of the engine to know when to shift gears.

Sonify

Sonify is an application that was developed by Worcester Polytechnic Institute (WPI) graduate student Matthew Pietrucha to facilitate the sonification of Ramen spectroscopy data. Pietrucha (2019) describes the aims in the development of Sonify as follows:

"*[Sonify] was developed to audify spectroscopy data, with the purpose of better understanding how multi-purpose systems can be modified to suit a particular need. Since all sonification systems may become context specific to the data they audify, we developed a system in the programming language Max that is both modular and responsive to the parameterization of data to create musical outcomes. The trends and phenomena of spectral data in the field of spectroscopy plot musically through the system and further enhanced by processes that associate descriptors of said data with compositional idioms such as rhythm, melody, and harmony.*"

Regarding the *particular need* mentioned in the above excerpt, Pietrucha (2019) gets into further detail when describing the methodology of the application's development, where it is stated that Sonify was intended to be used as an educational tool.

Using this information from the developer, Sonify can be said to be a tool that creates music from data for the purposes of being simultaneously entertaining and educational. It is important that engagement is considered for sonification applications, as repetitive auditory cues tend to be tuned out (Seagull and Sanderson 1998). If the sonification of data strikes the right balance of entertaining and informative, however, the result will be an engaging alternative to traditional methods of data representation.

This research therefore seeks to get impressions from instructors on the viability of using Sonify to translate data into sound in educational contexts.

Background

Information and Sound

People understand information about the world around them using their five major senses – touch, taste, smell, sight, and sound. Sight and sound in particular play important roles in human perception and awareness of who and what is in their immediate surroundings. To perceive and be aware is to use sensory information to understand the details of one's surroundings. Sound, in particular, is useful to locate resources and danger, as it can travel long distances, permeate through materials, and reflect off walls and around corners.

Taking advantage of these properties, sound can be utilized to gain information that would be difficult to ascertain via the use of the other senses:

- A physician can use a stethoscope to learn whether a person has an abnormal or typical heartbeat and to learn if their heart rate is fast or slow.
- A mechanic can rev the engine of a car and listen to the sound to identify certain problems with the engine belt or the exhaust.
- A musician can listen to a chord progression to determine what notes they can play over it while improvising, or they can use a reference pitch to know if their instrument is sharp or flat and tune it accordingly.

These are examples of the conveyance of information via *sonification* – the representation of information in the form of non-speech audio.

Barrass and Kramer (1999) found that '*Sounds can be very useful in circumstances where the need to move the eyes to acquire information is risky and a bottleneck for performance (Ballas 1994), such as driving an emergency vehicle or piloting a plane.*' and further discuss the benefit of a sonified instrument panel to pilots in training.

The applications above show that the sonification of data can often provide great utility. Oftentimes it is used by the listener to be able to continuously monitor something in the environment while they are working on a task nearby that requires visual attention. However, sonification has also been used in applications designed to entertain or engage – such as the sonification of gravitational waves observed in 2016 by the Laser Interferometer Gravitational-wave Observatory (LIGO 2016), sometimes referred to as the LIGO chirp[1].

[1] Fig. 1 shows an example plot of a gravitational wave, where it can be seen that the frequency rapidly increases. It is this rapid increase that is eponymous to the *chirp* given to its sound.

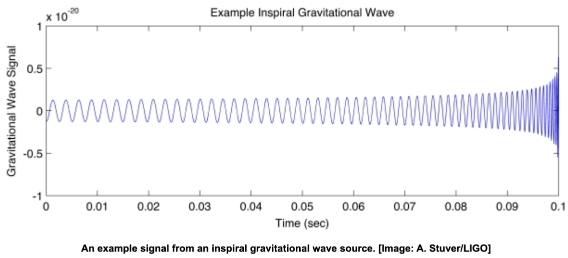


Figure 1: A graph showing how the frequency of a gravitational wave signal changes over a period of time. (Stuver/LIGO 2016)

LIGO translated gravitational wave data into sound as part of an effort to help others grasp what the data represented. The orbital frequency produced by the merging of two massive astral bodies – particularly how the frequency changes as they spiral closer together – is an abstract concept to those that are not involved in the field of astronomy. The LIGO chirp is a result of mapping the orbital frequency into sound waves that are within the audible range of human hearing. The sonification of this data, therefore, translated something complicated and foreign into a form that could be intuitively understood by *listening to the data.*

The dis-abstraction performed by LIGO begs an intriguing question: can other complex concepts be made simpler and more engaging through the sonification of data? The LIGO chirp conveyed information about gravitational waves without relying on scientific jargon which may be difficult for a student or layperson to understand. With the right tools and presentation, sonification could prove to be a useful educational aid.

Sonification in Education

Sound plays an important role in education, particularly for auditory learners. The primary method by which sound is utilized in an academic setting is the conveyance of information using speech – lectures. The effectiveness of a lecture will be determined by the ability of the lecturer to convey information in a way that their audience can understand. Additionally, there are many data-based concepts that can not be effectively conveyed through speech alone.

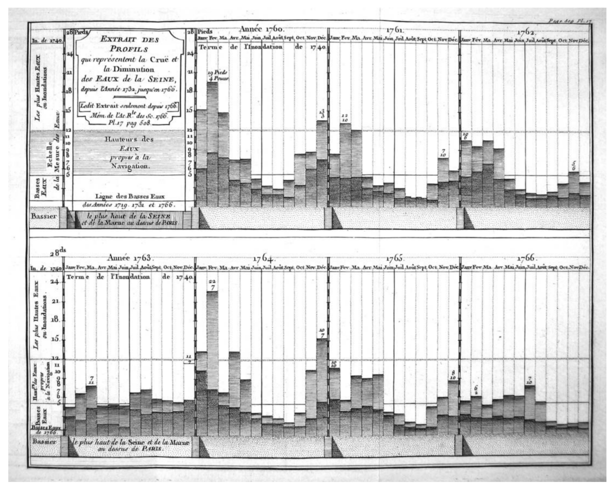


Figure 2: A bar graph published in 1770. (Smeltzer 2010)

For example, relationships between sets of data are often presented using charts, graphs, plots, and diagrams – data representations that work well for those with a visual learning style. Those who learn best by listening, however, do not have a widely available auditory analog to graphic portrayals of data. In a study on the effectiveness of using sonification to present the information traditionally conveyed by plots and graphs, Vines et al. (2019) found that participants were able to understand the overall data trend from sonification of the data. Vines et al. go on to state that participants who indicated that they 'enjoyed listening to music' seemed to have an easier time working with the sonifications.

Auditory representations of data might be mostly absent from academia for a few reasons:

1. **Technology:** The creation and recording of an auditory representation of data would require more sophisticated technology than the creation of a visual data element, which can often be easily done using paper and a writing instrument. Visual elements may be preferred due to the simplicity of their creation.

2. **Tradition:** Smeltzer (2010) discusses an example of a bar chart that was published in the year 1770 (Fig. 2), which shows that visual data elements have been used for centuries. Creating auditory data elements would require 20th-century technology to be feasible[2]. Educators may be reluctant to adopt a new method of data representation, especially if learning and using that method requires significantly more work than continuing to use the traditional methods they are well-acquainted with. Visual elements may be preferred due to educators being comfortable and experienced in their use.

3. **Observable Dimensions:** Visual representations of data most often use vertical and horizontal distances to convey the magnitude of their respective datasets. In contrast, auditory representations will most likely need to utilize time in some manner.

   Having to present data over time means that in order to discuss aspects of data, educators would need to easily be able to move to the relevant time within the recording. Visual elements may be preferred due to the convenience of their presentation.

Pfeiffer (2008) found no increased comprehension was associated with visual presentations that incorporated sonification versus visual presentations without any audible elements. However, Pfeiffer identifies the adoption of a musical framework as a potential area of interest for future research. As Sonify was designed to create musical sonification, there is still potential for a beneficial effect.

The Role of Sonify

Sonify appears to have potential as a solution to the considerations on technology, tra-

[2]Feasibility meaning that the sonification audio has minimal recording defects (e.g. clicking or other distortions) and in a format that's easy to duplicate and distribute (stored digitally)

dition, and observable dimensions. Fig. 3 shows the graphical user interface (GUI) of Sonify, which can be seen to contain a main graphing area in the upper left, a list of data points in the upper right, a tagging system in the lower left, and volume controls in the lower right.

Sonify presents data in a musical framework as Pfeiffer suggests. As Vines et al. stated, listeners who enjoyed listening to music had an easier time working with sonfied data, so it is possible that presenting data that is sonified in a musical framework might be a more effective aid in comprehension than a non-musical auditory representation of the same data.

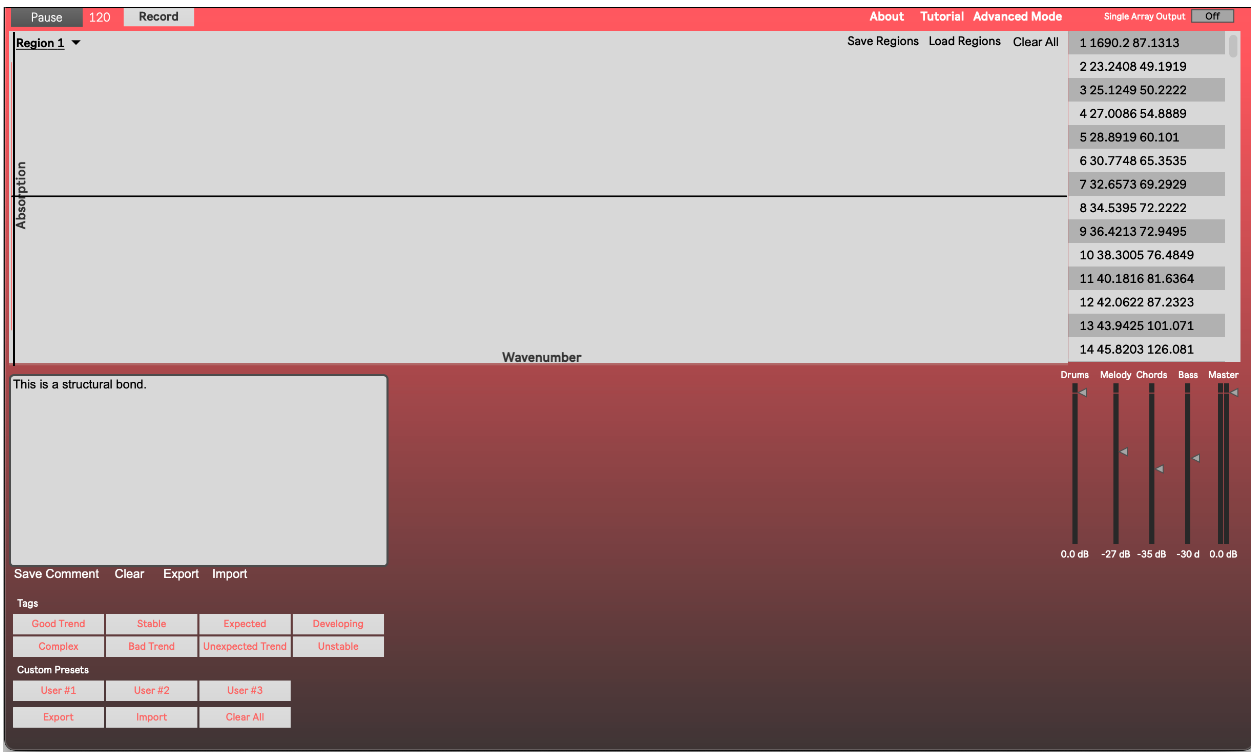


Figure 3: The graphical user interface of Sonify

Methodology

Participant Selection

The purpose of this research was to introduce the Sonify application to educators, then record their opinions and thoughts on its utilization as an educational tool for spectroscopy topics.

As discussed in Bygstad, Ghinea, and Brevik (2008), the sampling pool for a technical subject needs to be carefully and deliberately targeted, as a scope that is too general will yield a low response rate. The technical and specific nature of Ramen spectroscopy necessitated a limitation of the survey pool to educators who exhibited two qualities :

1. Familiarity and understanding of spectroscopy

2. Comfortable and confident with using technical software.

These limitations were put into place to increase the chances that the educator would provide a neutral assessment of Sonify. Specifically, it was important to avoid gathering responses from those who would be unlikely to use such a utility regardless of circumstance. Due to time limitations, sampling was done in what Tracy (2019) defines as *convienence sampling*: choosing a sampling pool that is convenient to the surveyor. In the case of this research, the most likely group to provide a usable response rate were educators associated with Worcester Polytechnic Institute (and by extension Mass Academy).

With these requirements in mind, the following two groups were targeted: professors of chemical engineering and physics at Worcester Polytechnic Institute, and science teachers at Worcester Academy. These two institutions were selected as they particularly focused on scientific and engineering education.

Request for Participation The pool of potential participants was contacted via email. The email estimated that their participation would take between five and ten minutes, and offered a low-value incentive to those who provided their email addresses. The email began by defining sonification and then asked that they watch a short demonstration and complete a survey.

Demonstration

As the interest of this research is placed in the use of Sonify by educators, the usability of the program would ideally be obtained by asking the educators to use the program themselves after a brief explanation and/or demonstration. Other research performed relating to the topic of educational sonification use this hands-on approach. The research by Vines et al. (2019), for example, asked participants to recreate plots of data after listening to associated sonifications.

Unfortunately, several outside circumstances limited how Sonify could be introduced:

1. **Time Constraints:** The study needed to be conceived and conducted within a period of seven weeks.

2. **Academic Period:** The study occurred during the final weeks of the academic year. This period is presumed to be one of the busiest times for an educator due to grading, administration of final exams, and assisting students on projects.

3. **Public Health:** Restrictions on face-to-face interaction were in place

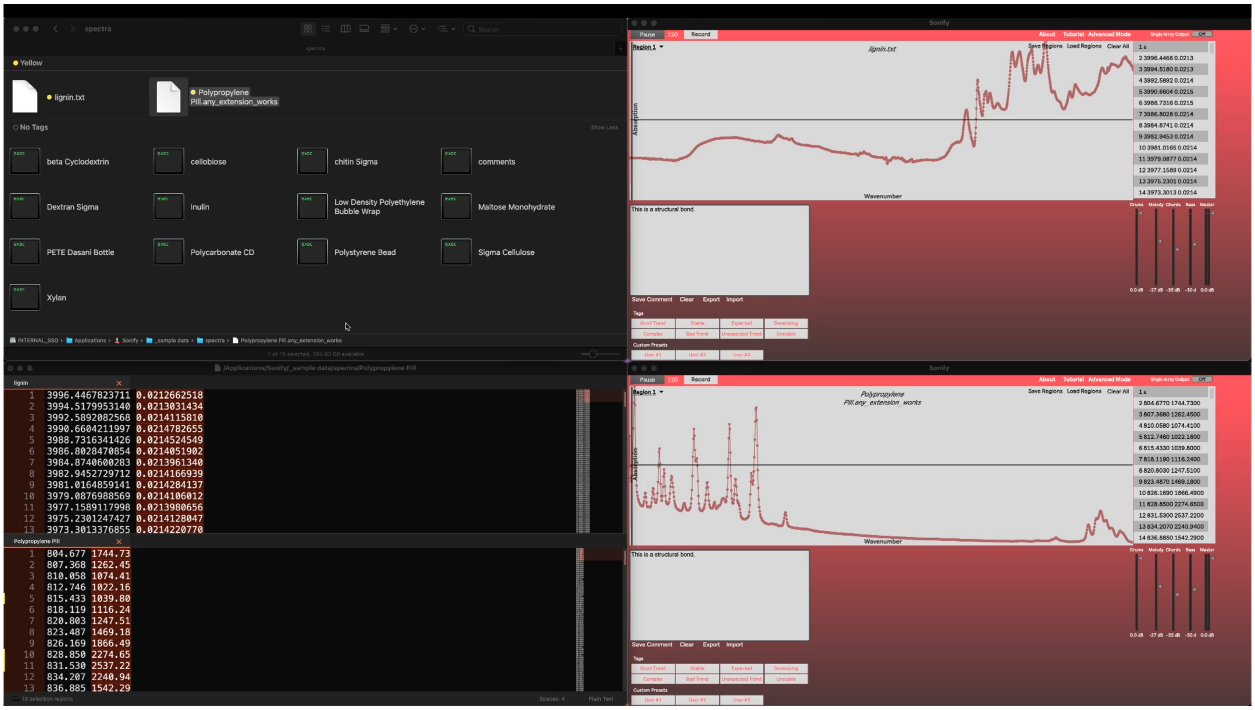


Figure 4: As part of the demonstration, the spectroscopy data for lignin and polypropylene were each loaded into a separate instance of Sonify.

throughout the course of this study due to the COVID-19 pandemic.

Considering these circumstances, it was determined that the most suitable way to introduce Sonify would be to create a video demonstration. Considering that responses were needed quickly and that the likelihood of receiving a response would be relatively low, the demonstration video was made to be about five minutes in duration. The video demonstrated the following:

1. Two sets of data were used to show how the data needs to be formatted, and how it can be loaded into the application. (Fig. 4)

   (a) This was demonstrated by loading the data for lignin and polypropylene into each instance.

   (b) Two instances of Sonify were used to facilitate easy comparison of how the generated music was affected by the data. Lignin and polypropylene were selected because there is significant contrast between the spectroscopy data of each.

2. The process of region selection and tagging was shown by using selection similar areas on each set of data.

   (a) Four selections were made in total, as regions one and two were set for each set of data.

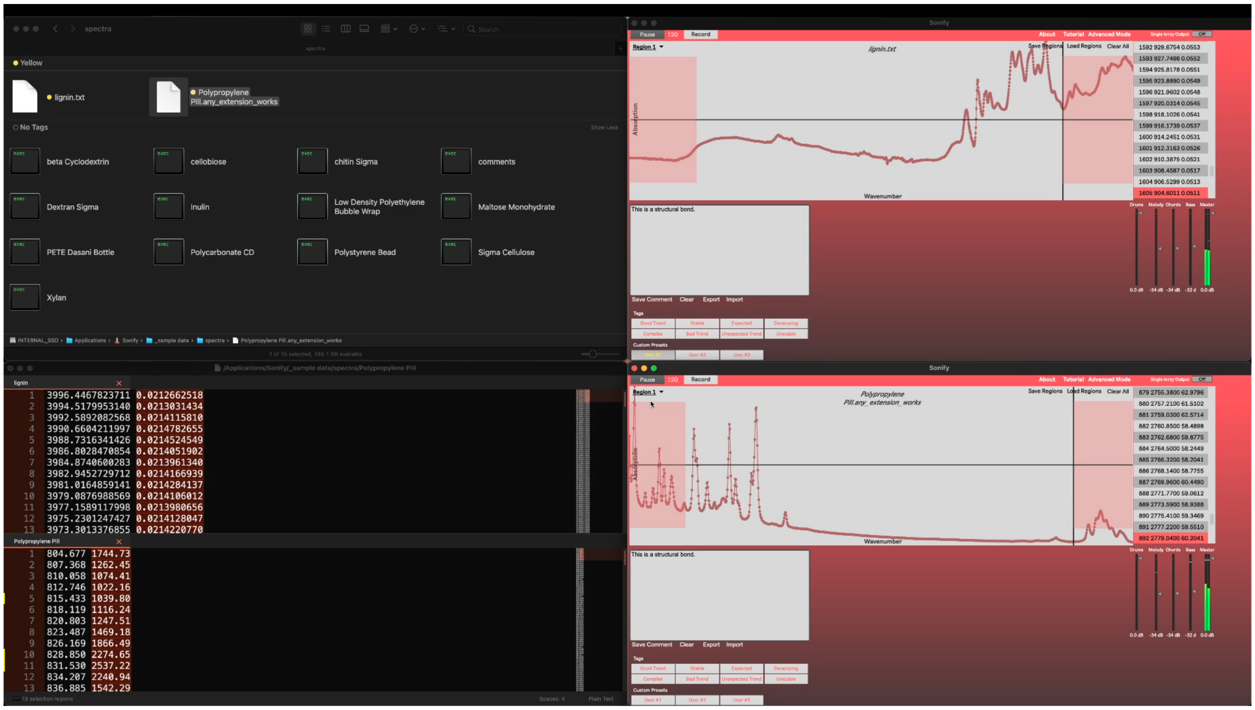


Figure 5: The region selection system was shown picking out two regions for each set of data, after which it was demonstrated how to apply tags.

(b) The same tag was applied to region one for both lignin and polypropylene so that it could be shown how peaks in each set of data affected the generated music

(c) Similarly, a second tag was applied to region two for both sets. By selecting the same tag for both sets and using different tags for each region, it was demonstrated that the tags control the tonality of the generated music.

3. The demonstration was concluded by explaining some of the basic and advanced features which allow for greater musical customization.

Survey

The survey consisted of four sections:

1. Request for consent
2. Quantitative questions
3. Qualitative questions
4. Choice of Anonymity

Quantitative Questions To make the answers quantifiable, the first four questions were converted to first-person statements. The respondents were then asked to rate how much they felt their own opinions matched the statements on a ten-point scale. The questions were posed in this manner to decrease the likelihood of answers being affected by acquiescence bias (Krosnick 1999). Here is an overview of which statements were presented, and what purpose each statement was hoping to achieve:

1. **Statement:** I understand the purpose of Sonify.
   Purpose: *To gauge the clarity of the demonstration to the participant.*

2. **Statement:** It would be easy for me to use Sonify.
   Purpose: *To understand how the user interface was perceived.*

3. **Statement:** Sonify could be used to enhance a student's understanding of spectroscopy concepts.
   Purpose: *To get information on whether or not Sonify could be used in an educational context.*

4. **Statement:** I am interested in using Sonify in its current form.
   Purpose: *To get information on whether or not the respondent would be interested in using Sonify in any context.*

Qualitative Questions Three qualitative questions were included for the purpose of allowing respondents freedom to express their thoughts on how Sonify could be improved and what features were most desired. The questions, which asked for text responses, were as follows:

1. Sonify would benefit most by improving on:
   Short answer

2. The feature I would most like to see is:
   Short answer

3. Additional Comments
   Long answer

Results

A total of eight responses were received from to pool of educators that the demonstration was sent to. Small sample size was expected due to the limitations discussed in the methodology section. While it would be difficult to make broad assumptions based on only eight participants, analyzing the responses will still provide useful information which can be used as a pilot study for future research.

Quantitative Responses

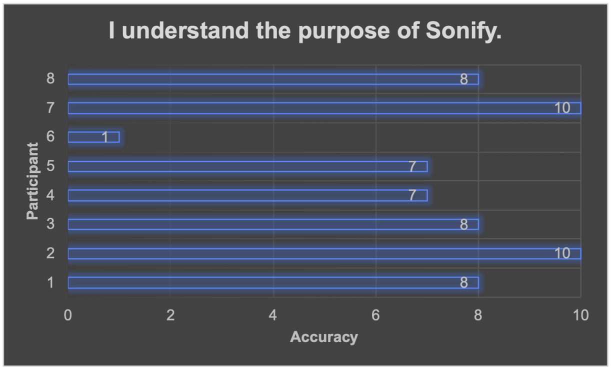
Fig. 6a shows that seven out of eight respondents rated their understanding at a level equal to or greater than 7/10, with the overall mean equaling 7.735/10. These results indicate that the video in the survey was mostly successful in demonstrating and explaining the concept of sonification and the use of Sonify.

Fig. 6b shows a slightly lower mean score of 6.5/10, with six out of eight respondents rating the accuracy of the statement greater than equal to 7/10, and the remaining two assessing ratings of 0/10 and 1/10. These responses indicate that the layout and user interface of Sonify appeared simple enough to use to a majority of participants.

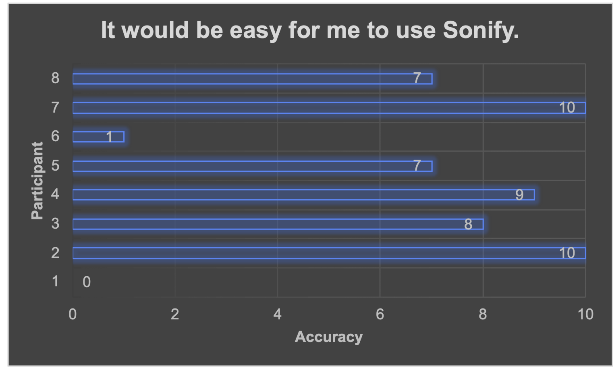
Fig. 6c shows a significant decrease in the assessment of the accuracy of the statement, with a mean result of 4.25/10. Three of eight participants rated the accuracy of the statement as 1/10 or 0/10, and the remaining five responses ranged from 5/10 to 8/10. This indicates that the opinion of the viability of Sonify as an educational tool is generally mixed.

Fig. 6d shows the lowest average score of all quantitative questions with a mean of 3.5/10. Three of the eight respondents again assessed an accuracy rating of 1/10 or 0/10, with the remaining five respondents assessing scores between 4/10 and 8/10 – a slightly diminished score compared to the previous result. The assessments provided for this question indicate that ultimately there is low enthusiasm for the adoption of Sonify by the instructors in their courses.

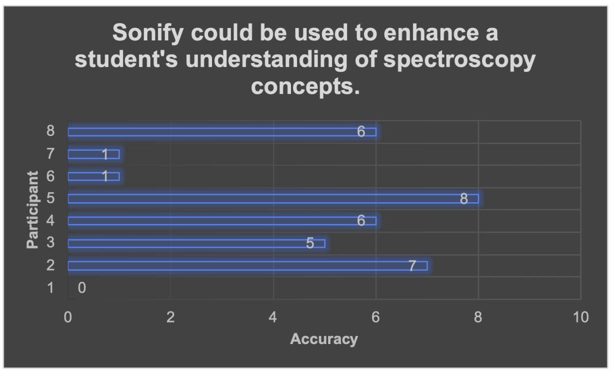
Fig. 6e shows the combination of all four responses grouped together by the participant who provided them. From this data, it can be observed that the responses were highly varied, with some participants providing rankings that were polarized to the extremes of the scale, and others providing answers that were more clustered together.



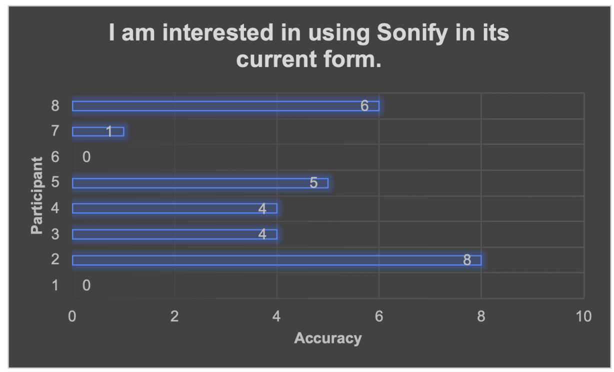
(a)



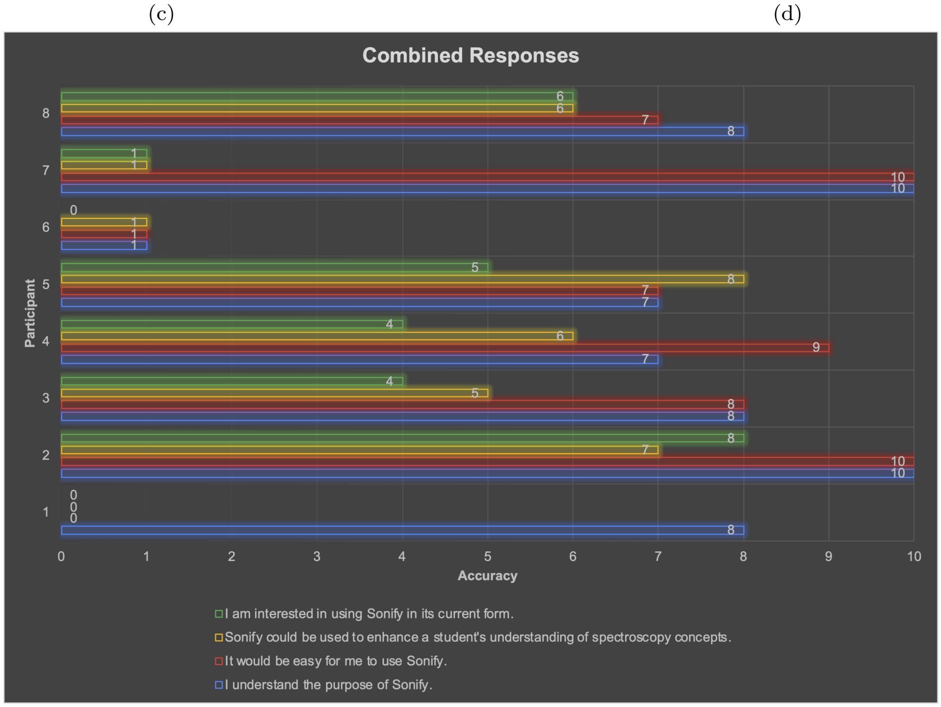
(b)



(c)



(d)



(e) Quantitative responses grouped by participant.

Figure 6

Quantitative Responses

Participant	**Prompt**			
	I understand the purpose of Sonify.	It would be easy for me to use Sonify.	Sonify could be used to enhance a student's understanding of spectroscopy concepts.	I am interested in using Sonify in its current form.
1	8	0	0	0
2	10	10	7	8
3	8	8	5	4
4	7	9	6	4
5	7	7	8	5
6	1	1	1	0
7	10	10	1	1
8	8	7	6	6
Avg	7.375	6.5	4.25	3.5

Table 1: Educator opinions on Sonify after seeing a demonstration. Responses are rated on a scale from zero to ten with zero corresponding to the the respondents assesment of the prompt to be inaccurate to their opionion, and a score of ten representing an assesment of the prompt as accurate to their opinion.

Qualitative Responses

Qualitative Response Categories

Participant	Prompt: Sonify would benefit most by improving on	The feature I would most like to see is	Additional Comments
1	N/A	N/A	Skeptical/Entertained
2	Clarity	N/A	N/A
3	Parameter Mapping	N/A[3]	N/A
4	Defualt Tags	N/A	Entertained
5	N/A[3]	N/A	Skeptical
6	N/A	N/A	N/A
7	Clarity	N/A[3]	N/A
8	Interface	Export Options	N/A

Table 2: Qualitative responses coded into categories. Answers to these prompts were not required to complete the survey. A listing of N/A indicates either the absence of a response, or a response such as "none" or "not sure."

Few qualitative responses were given. This is likely due to the small sample size and the optionality of answering the qualitative prompts in the survey.

The responses were coded into categories based on the prevailing sentiment expressed by them (see Tab. 2). Some responses were reassigned if to a more fitting prompt if they were not fitting for the one that they were answered under. For example, if the respondent indicated that they would like to see a change in how the data was mapped to music as a feature they would like to see, then that answer would be indicated as a suggestion for improvement.

For the case of suggested improvements, two of the eight respondents suggested that it was not clear how Sonify would help students to understand spectroscopy, one indicated that some of the default tags were unclear, and one indicated that the user interface was unintuitive.

Only a single respondent provided a suggestion for a specific feature, which was for the ability of the produced music to be exported as an MP3 audio file.

[3] Response was reassigned to a different prompt.

For additional comments, one respondent indicated skepticism that sonification could be used to help students understand spectroscopy, another indicated that they found Sonify to be entertaining, and a third indicated both skepticism and entertainment.

Discussion

On average, the educators who participated in this survey indicated the following through the ratings they assessed to the quantitative prompts:

1. They understood the purpose that Sonify was designed for.

2. They believed that Sonify would be easy for them to use.

3. They did not believe Sonify could be used in its current form to aid students in their understanding of spectroscopy.

4. They did not have an interest in using Sonify in its current form.

In general terms, the responses provided for the qualitative prompts[4] indicated that the respondents found it difficult to understand either how Sonify could be used to help students understand spectroscopy, or how the music related to the data that was sonified, or what the tags applied to the data were intended to convey.

These results indicate either that the music that Sonify creates from spectroscopy data is not viewed as educationally useful to educators or that the benefit of using Sonify is outweighed by the costs. In this context, the benefit is being used to describe the educational value to students, and costs are being defined as time and effort spent learning how to use Sonify, creating sonifications of data, and then presenting that data in such a way that students will be able to benefit.

Barrass and Kramer (1999) make mention of a primary obstacle in sonification being that the mapping process is done arbitrarily, and is usually unpleasant to listen to. The reason for this obstacle may stem from the fact that the granularity of the data to be sonified is likely to be high when compared to the available pitches in a twelve-tone scale and the limited divisions of time that would need to be adhered to for the purpose of musicality. As a result, It stands to reason that an inverse relationship may exist between the complexity of a given data set and the ability to create a musical sonification of that same set. Mapping the data to follow music theory and keeping the phrasing of the rhythm coherent is likely to require leaving some data out of the mapping.

For example, the data shown in the demonstration, which can be seen graphed

[4]These responses can be read in Appendix A where they are listed verbatim.

the Sonify windows shown in Fig. 4, often has rapid changes. Although Sonify is programmed to recognize and emphasize peaking, it may not convey enough detail regarding the sharpness of the peaks, or the y-values of the data preceding and following the peaks, to be seen as feasible in the eyes of an instructor.

These interpretations should not be made without mention of the methodology limitations, however. As discussed, Sonify was never used first-hand by the participants and the demonstration that was shown was made to be roughly five minutes in length to try and increase the likelihood of participation. It is probable that the results would change if educators were given a more thorough demonstration and were able to experience the process of loading, tagging, and creating music from the data sets themselves. Even if the results did not change, this process would be, by design, a better way of gauging their opinions of Sonify. With first-hand experience, a participant could take more time to understand how the program works, and get a feel for how intuitive it feels to use.

Conclusion

This reasearch was done in an attempt to gain insght into the opinions of educators on the use of Sonify – a software application which sonifies spectroscopy data into music – as a tool that could help studets to understand spectroscopy concepts. The results indicated that the participants of the survey did not see Sonify as educationally valuable, as they found it unclear as to either how the data relates to the music or unclear how the music would be used to further conceptual understanding. These results are likely to be affected by the limitations of the methodology. Those looking for further insight into the value of Sonify as an educational tool would be able to get better information by having participants use the application themselves.

These results may indicate that it is difficult to convey an adequate amount of detail from spectroscopy data through music.

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Appendix A: Qualitative Responses

Each participants full response to the optional qualitative prompts is listed verbatim below.

Prompt: Sonify would benefit most by improving on

Participant 1 None, see "additional comments" below.

Participant 2 More clear explanation of spectroscopy aspect

Participant 3 It seems the frequency in the music is linked to the intensity in the spectrum rather than the frequency - or did I miss something ?

Participant 4 I did not understand some of the options (i.e. developing).

Participant 5 I don't know how I would personally use it so its hard to consider what it would benefit from

Participant 6 *no response*

Participant 7 It is not clear to the user how does sonify allows one to understand spectroscpoy.

Participant 8 User interface. The first impression was that it has a lot things but in an unintuitive order

Prompt: The feature I would most like to see is

Participant 1 None, see "additional comments" below.

Participant 2 not sure

Participant 3 lower spectral frequencies should be matched within an observation window with lower sound frequencies and the music should get loader as the spectral intensity increases

Participant 4 *no response*

Participant 5 n/a

Participant 6 *no response*

Participant 7 Correlation of the music with the spectroscopy of the molecules.

Participant 8 Export music to an MP3 file

Prompt: Additional Comments

Participant 1 This feels like the idea MTT proposed as a part of the outreach in his Career proposal in which students could ““hear”” what a Raman spectrum ““sounds”” like. Has there been research done that suggests that this correlation increases the understanding of how to interpret a specific spectrum? I ask because I am fundamentally skeptical of the premise that listening to what a spectrum ““sounds like”” would increase a student’s understanding of what that spectrum represents. I assume that you’re taking a spectrum, doing some kind of windowing, a baseline correction, and running an inverse Fourier transform with some scaling between the original x-axis and frequency? So higher positions in the spectrum give a different frequency of sound, okay I can take that at face value. Do we need this in order to understand the original spectrum? That’s not exactly how we hear. Two overlapping frequencies near each other are going to give a beat pattern in frequencies that wouldn’t show up in the original spectrum, which would show two distinct lines. How would one deal with a related phenomenon regarding imaginary sounds that we think we hear? Take a barbershop quartet singing a dominant seventh chord of C in perfect temperament that could hit the fourth (C3), fifth (E3), sixth (G3), and seventh (Bb4) overtone of a fundamental C1 frequency. If everyone is really in tune, people would think that they’re also hearing C4, which is the eighth overtone of C1. This is obviously an aural illusion as there is no fifth member in a quartet, and if this was coming from one of these Raman spectra, there would clearly have not been a peak in the original spectrum corresponding to that ““note””. In that sense, the way that someone ““hears”” a spectrum may not necessarily represent that original spectrum at all.

I understand that learning spectroscopy is hard and interpreting spectra can be intimidating. While this might be an enjoyable program to use, my concern is that this would not increase student learning. This isn’t the kind of thing I would write without signing my name at the bottom, so don’t hesitate to contact me if you have further questions or concerns. I’m less concerned about the gift card. :)

Cheers, ***** *****@wpi.edu

Participant 2 *no response*

Participant 3 *no response*

Participant 4 The music was pleasant. I was attempting to see if I could identify an algorithm.

Participant 5 I'm still generally confused on what types of files can be used for it, and what purpose it serves

Participant 6 *no response*

Participant 7 *no response*

Participant 8 *no response*

Appendix B: Demonstration Script

This section contains the script that was used for the video demonstration of Sonify. Black squares in the script indicate pauses in dialogue when something is being demonstrated on screen.

Intro

Hello, Thank you for agreeing to participate in this survey. As mentioned in the invitation, this video is to demonstrate an app named Sonify. Sonify was developed by WPI graduate student Matthew Pietrucha to facilitate theuse of music to present spectroscopy data. I am going to demonstrate how it is used.

Loading Data

I have two instances of Sonify open here, and am going to load a different set of data into each. The data is stored as plain text in a two-column x y format, as you can see here ■ ···

To load the data, I need to drag the data files onto the window. I am going to load the data for lignin into the top, and the data for a polypropylene pill into the bottom. The data is then automatically scaled to fit into the graph display.

Generating Music

Sonify will generate music that emphasizes peaking, and chooses notes of higher or lower pitch proportional to the y-position of the data. It is necessary to begin by selecting a region of data ■ ···

and then tagging that region ■ ···

The mood of the music will be determined by the tag. I am firstly going to select a small region on the right on both sets of data, and apply the *unstable* tag to both of them ■ · · ·

Secondly, I'm going to select a small region on the left, this time applying the *developing* tag to the lignin, and the *complex* tag to the polypropylene pill.

Let's hear what the music sounds like for the region on the right, region one ■ · · ·

Now let's hear region two ■ · · ·

Outro

Sonify includes features which allow users to change the tempo, adjust the volume of each musical element, and create custom tags. Users who have a basic understanding of music theory can use the advanced mode for greater control of the generated music. This concludes the demonstration. Please complete the survey and submit your response. Thank you again for your time and participation.