In our study, we focused on the understanding of students regarding the digitalization process of audio data. In particular, we took notice of users’ understanding regarding (a) the physicality of sound: how sound can be explained as a physical phenomenon of propagation; and the second topic is (b) the process of sampling analog audio data: what it means to sample data and how the sampling rate affects regenerated audio data. Below, we give an overview of each chapter and how they relate to these two topics.

2.1 Chapter 1: Physicality of Sound

The goal of the first chapter is for users to understand topic (a) — that sound is a physical phenomenon. An animated conceptual representation of particle movement is shown in real time as audio is being played by our developed application. Users are able to observe the change of sparseness/density of the particles as they change different variables (e.g. volume, frequency, wave type, number of particles) of the audio being played (see Figure 1).

Users may also choose to see a graph representation of the audio they are listening to. The graph here represents the position of the particles in relation to their original (central) position when there was no audio. Vertical lines may also be added to easily identify where...
the position of each particle in the first window (conceptual animation) is depicted in the second window (graph representation), as we found when users increase the number of particles, it becomes difficult to keep track of where each particle is at each moment.

2.2 Chapter 2: Propagation of Sound

The goal of the second chapter is to further user understanding of topic (a) —the physicality of sound— by learning the concept of sound propagation. Users are able to change the magnification of a linear space and observe how particle movement propagates across that space (see Figure 2). As in chapter 1, users are able to edit variables of the audio being played by our developed application. When a button is pressed, a short segment of sound is produced in the application and it is depicted as taking three seconds to travel across the screen. Users will only hear the audio once the depicted sound has reached the image of an ear at the end of the space.

Similar to chapter 1, users may observe the propagation of sound either through a conceptual representation of particle movement, or through a graph representation plotting the distance each particle has moved. At any moment, users may change the magnification of the space presented in the application and zoom in on the area near the ear.

2.3 Chapter 3: Sampling of Sound

The goal of the third chapter is for users to learn topic (b) - the process of sampling analogue audio data. This includes assisting in the understanding of how sampling rates affect audio when audio data are regenerated and played back. Users are able to sample a sinewave of any given frequency using a sampling rate of their choice. They are then able to both visually see and audibly hear a regenerated sound from their sampled data.

In this chapter, sound is visualized in a graph representation. Once users have chosen a sampling rate, the sampling intervals are indicated by vertical lines that run through the window. A graph of the sampled data is then generated by linearly connecting the data points derived from the intersections of vertical lines and the original graph of audio data (see Figure 3). Users are then able to listen to the audio their sampling process would produce when conducted on the original audio.

While there are many means by which audio data can be regenerated from sampled data, we have chosen the easiest method where we feed the data points from the sampled graph directly into the audio feedback as input. No wave transformations are conducted to try and restore the original (sinewave) data from the sampled data. The visual graph users see corresponds directly to the audio that they will hear.

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**Figure 1.** Chapter 1 of the Developed Application.

**Figure 2.** Chapter 2 of the Developed Application at “Medium Magnification”.

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3. Method of Evaluation

We conducted user tests to evaluate the developed application and its effects on users in aiding their understanding of the digitalization of sound. The tests were conducted as part of a general information education course “Introduction to Informatics II” conducted at Hokkaido University, Japan. All students were from liberal art faculties and were expected to have completed other courses on basic information technology both in their secondary education and in previous semesters at university. The experiments were conducted over two weeks. We explain the experiments below as Experiment 1 and Experiment 2.

In this paper, we focus our explanation of experiments and their results to the two topics described in the previous chapters of this paper; (a) the physicality of sound and (b) the process of sampling analogue audio data. Other questions were given to participants in each experiment (e.g. questions investigating secondary education learning and understanding of concepts), but the discussion of these questions exceeds the scope of this paper.

3.1 Experiment 1

This experiment was conducted during a compulsory lecture of the course using a 40-minute period in the class time. The experiment consisted of three parts; the pre-survey, the class work and the post-survey. A total of 35 students participated and were all registered attendees for this course.

In the pre-survey, we asked participants to answer the following questions.

(1-a) How well do you understand the relationship between pitch and frequency of sound? (Select from: I understand, I pretty much understand, I hardly understand, I don’t understand at all, I don’t know what frequency is.)

(1-b) How do you think the criteria for segmenting along the time-axis (sampling of data: sampling rate) are chosen when digitalizing sound? (Answer freely.)

The class work was conducted right after the pre-survey. The developed application was distributed to all participants as a compressed ZIP file via the Hokkaido University Learning Management System. The experimenter gave a short lecture to the students using presentation slides describing both processes of the digitalization of sound as well as how to use the distributed application. The lecture content followed the three chapters in the application. Participants were given short periods (roughly five minutes each) after the experimenter had described each chapter to operate the application freely on their individual computers. The experimenter and another course staff member walked around the room assisting students with the acquisition and operation of the application.

The post-survey was taken after all portions of the application had been explained and students had had three short periods to operate each chapter of the application. This post-survey included the following questions.

(2-a) Were you able to understand the relationship between pitch and frequency of sound? (Select from: I understand, I pretty much understand, I hardly understand, I don’t understand at all, I don’t know what frequency is.)

(2-b) Were you able to understand how the criteria for segmenting along the time-axis (sampling of data: sampling rate) are chosen when digitalizing sound? (Answer freely.)
3.2 Experiment 2

This experiment was conducted a week after the first experiment in the following lecture of the course. This was the final lecture of this course and students were told in advance that a test would be conducted on the course content. In that test, we included questions regarding topic (b) — the process of sampling analogue audio data — to assess how well students had retained the information they had studied in the previous week. The questions given in the test which were relevant to this study are as follows.

(3-i) In respect to transforming analogue audio waves to digital data, explain the process of sampling.
(3-ii) In the same respect, explain the process of quantization.
(3-iii) The human ear has the capability to hear up to roughly 20kHz. In that respect, when digitalizing sound, how many sampling points should be taken in one second? Also, explain the reason for your answer.

4. Results and Discussion

4.1 Understanding Physicality of Sound

In Table 1, we show the results to questions (1-a) and (2-a). These questions asked participants about their understanding of the relationship of pitch and frequency of sound and pertaining to topic (a) — the physicality of sound. We see that the understanding of this concept was improved throughout all the participants. The fact that none of the students responded with the answers “I don’t understand at all” and “I don’t know what frequency is” in the post-survey after the class work indicates the lecture time revolving around the use of the developed application was effective in deepening the understanding of this concept.

4.2 Understanding Sampling of Sound

In Table 2, we show some results of questions (1-b), (2-b) and (3-iii). These questions ask participants about their understanding of determining the sampling rate of sound. These pertain to topic (b) — the process of sampling analogue audio data. Due to the fact that these questions accepted freely written responses, we give results for the responses which can be categorized into the divisions we have given in the table.

In the pre-survey (Question 1-b), 15 participants (44.1%) either gave a blank response or gave a response indicative that they did not understand how the sampling rate of sound is determined. After the class work, only three submitted blank responses. All three of these participants also submitted a blank response to the remainder of the survey, leaving room for speculation as to whether their responses indicate a lack of understanding, a lack of time to complete the survey, system failure in completing the survey or some other cause.

On the other hand, 11 participants (32.4%) replied correctly to the question in the post-survey (Question 2-b) with comments such as “Double the highest frequency being used” and “Two times that of the audio...
being listened to”. An additional 15 participants (44.1%) did not use the word “double” specifically, but replied with general answers such as “I understand”. This result lies in stark contrast to the fact that not one participant answered the pre-survey before the class work with comments indicating a good understanding of this concept.

Furthermore, it can be noted that the number of participants who answered with comments regarding double the given frequency in the test of experiment 2 (Question 3-iii) had increased even further compared to those who answered in that manner right after the class work. The number of blank responses had also increased, but it was still fewer compared to the combined number of responses indicating they did not understand prior to the class work.

The above results indicate that the lecture time revolving around the use of the developed application was effective in deepening the understanding of participants regarding the sampling of audio data.

4.3 Understanding Processes of Digitalization of Sound

Questions (3-i) and (3-ii) of experiment 2 asked participants to explain the processes of audio digitalization, referring to the sampling of data and the quantization of data respectively. Regarding the sampling of data, 21 of 35 participants (60.0%) described the process correctly as that of “dividing data into equal time intervals” etc. One participant submitted a blank response. Regarding the quantization of data, 15 participants (42.9%) described the process correctly as that of “determining the amplitude of a signal using a discrete measurement” etc. Two participants submitted blank responses.

Both the sampling of data and the quantization of data were referred to during the lecture of the experiment as important aspects of the digitalization of analogue data. However, the application we developed focuses on the process of sampling. Though both concepts were delivered to participants through the lecture slides, they were able to experience only the sampling process using the provided application. The difference in understanding of questions (3-i) and (3-ii) suggests that the interactive learning experience using the designed application in combination with the lecture given in the experiment was effective in furthering and establishing the understanding of some concepts amongst participants. The concept of quantization, given in the lecture but not addressed in the application, gained less of an understanding amongst participants.

4.4 Feedback Regarding the Application

In response to an optional question asking participants their impressions of the developed application in experiment 1, 22 participants (62.9%) responded with positive comments indicating it had assisted them in furthering their understanding of given concepts. Two participants (5.7%) reported system limitations, which were recorded for modification in future versions of the system. Four participants (11.4%) responded with questions indicating that use of the application had drawn out further interests in concepts not discussed in class. Below we give some examples of these comments.

A) I am interested to know how sound would propagate through other materials, such as wood.
B) What materials would be most appropriate when wanting to listen to music in high quality?
C) I want to know how detailed a computer can divide [data].

Comments (A) and (B) indicate some participants had an interest in the propagation of sound in materials other than air. Though not mentioned specifically in the developed application, the experimenter did refer to “air particles” at some points during the lecture as a practical example. Though not intended, this verbal instruction,
along with the content of the application, is thought to have led to some participants to gain an interest in advanced concepts (e.g. propagation of sound through different materials) not mentioned in the lecture. This can be recognized as an extension of topic (a) —the physicality of sound—which we focused on delivering through the application.

Comment (C) indicates some participants took an interest not only in the concepts of digitalization described in class, but also in the technical specifications or capabilities of the computer systems they were using. These comments suggest our developed application was instrumental in generating an interest for further knowledge in some participants. This could be, in part, due to the utilization of computer simulation within the application.

5. Conclusion

In this study, we developed a novel browser-based educational application focused on furthering the understanding of concepts related to the digitalization of sound. In particular, we focused on the enhancement of user understanding regarding two topics; (a) the physicality of sound and (b) the process of sampling analogue audio data. We conducted user experiments in a university lecture setting which included hands-on experience with the application, two surveys and a test.

From the experiment results, we saw that the developed application was effective in both enhancing user understanding of the physicality of sound and also the process of sampling audio data. The application received positive feedback from participants with minimal reports of erroneous functionalities.

We also saw the developed application drew out, in some participants, an interest in further content not addressed directly in the course of the experiments. These interests included advanced concepts of sound propagation in materials other than air and also technical capabilities of a computer system.

Our system was developed to offer an interactive learning experience to users. Kolb\(^3\) discusses an experiential learning model consisting of a recurrent cycle of experience, reflection, formation of abstract concepts and test of concepts in new situations. As an application designed for experiential learning, in the future, we plan to add content that will strengthen each step of the learning cycle and assist users to further their understanding. In particular, we plan to include chapters relating to other aspects of digitalization, such as quantization of data, to assist users in forming abstract concepts. We plan also to include features where the application can be applied to the digitalization process of other analog data, such as digital images and physiological data, as examples of new situations for users to apply their concepts to and deepen their understanding through further learning.

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