

Analysis of the Usefulness of Teaching Materials Including Sound Created by KeTCindy

Koji Nishiura

nishiura@fukushima-nct.ac.jp

Department of General Education

National Institute of Technology, Fukushima College

970-8034

Japan

Abstract

Recently we have come to produce teaching materials that include sound using KeTCindy mathematical software. Verbal learning offers a powerful tool for education. As described in this paper, we analyze how these materials contribute to an understanding of mathematics. We conduct an experimental study to verify the educational effects of teaching materials that include sound. Data collected by a cognitive detection clicker can be visualized with KeTCindy, which also provides a platform for statistical analysis of the results. Results suggest that teaching materials that include sound are useful for students to understand mathematical concepts.

1 Introduction

For upper secondary and higher education, we study how students comprehend mathematical concepts. Our research was designed to aid in the development of better teaching materials and to contribute to classroom improvements. For these purposes, we conduct an experimental study, as described herein.

We have created many mathematics teaching materials that include high-quality mathematical expressions and formulas, in addition to scientific artwork using mathematical software: KeTCindy. Recently, we have become able to use KeTCindy to produce teaching materials that include sound. Presentations of materials using both words and pictures are expected to improve understanding by students [1]. Verbal learning offers a powerful tool supporting education. Therefore, we add explanations by voice to the teaching materials, including high-quality mathematical expressions, formulas, and scientific artwork so that students can study independently. As described herein, we conduct an experimental study to verify the educational effects of teaching materials that include sound. As the results of the experiment demonstrate, we analyze how the accurate use of teaching materials that include sound can contribute to a better grasp of mathematical concepts.

We first created teaching materials of two kinds using KeTCindy. One consists only of problems. The other includes sound for explaining some mathematical concepts and examples. These materials were then used in a trial with students at a technical college. Participants were given several problems derived from the teaching materials and were asked to provide answers to the problems. Answers were recorded using a Cognitive Detection Clicker (CDC), a device of our making, which facilitates recording of participants' responses along with response times. Using the CDC, one can measure the teaching materials effects on understanding. Next, participants were instructed to learn using the teaching materials that include sound. Finally, participants were asked to solve the problems, again. Data collected by the CDC can then be visualized with KeTCindy, which also provides a platform for statistical analysis of the results.

In section 2, we explain how KeTCindy is used. Section 3 presents a description of how the experiment was conducted and section 4 analyzes results of the experiment. Finally, in section 5, the concluding remarks and the future work are described.

2 KeTCindy

To create mathematics teaching materials, teachers often must generate graphics. Although TeX is a popular tool to generate high-quality mathematical expressions or formulas in printed teaching materials, the process of producing high-quality graphics in TeX documents can be challenging for most teachers. Nevertheless, in recent years, KeTCindy mathematical software was developed [2, 3]. It is a plug-in to Cinderella dynamic geometry software.

We first put a dynamic figure on the Cinderella screen. Then KeTCindy converts the drawing procedure into R commands to generate the corresponding graphical data, which are subsequently formatted into TeX graphical codes. The TeX source file compilation generates the final PDF output including the corresponding figure. Using this procedure, even TeX beginners can readily produce mathematical graphics as required [4]. Furthermore, KeTCindy is implemented with the function of calling other computing tools such as R and Maxima [5]. Using this function, it is possible to import data with comma-delimited values into Cinderella and to analyze them statistically.

We can also use KeTCindy to produce PDF documents that include sound. It is possible to embed sound files in the MP3 format into PDF documents using the style file media9 of TeX. The package KeTCindy includes the style file ketmedia, by which the macro of media9 can be used easily. We first record sound and save it as an mp3 file for each page. It is convenient that audio data can be modified for each page. Next, we write the following in a TeX source file.

```
\includesound[horizontal position]{directory}{mp3 file}
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Using the style file ketmedia of KeTCindy, the compilation of the TeX source file engenders sound generation in the final PDF output. Therefore, anyone can easily create PDF documents that include sound.

For this research, we need mathematics teaching materials, which include high-quality mathematical expressions or formulas, scientific artwork, and sound. Because we can create the teaching materials required and further analyze data obtained by experiments by KeTCindy, using KeTCindy is very useful.

3 Experimental Study

3.1 Cognitive Detection Clicker System

In this experiment, a clicker system is used. This device can aggregate students' answers to questions in real time. Especially, we use the CDC system created by Usui et al., some of whom work in our study group. The CDC records the question number, the answer, and the timing of the button press [6]. The CDC system needs only these functions for this experiment. Although some clicker systems have these functions, the cost of such devices was prohibitive given the number required to run the experiment [7]. Therefore a decision was made to build a less-expensive alternative for use in this research.

Figure 1 shows the CDC slave device, which has four question buttons and four answer buttons. A record of the button choice and response timing is saved as a CSV file on the linked personal computer. Data communication between the master device and the slave device is conducted through a ZigBee module, which uses a wireless communication standard.

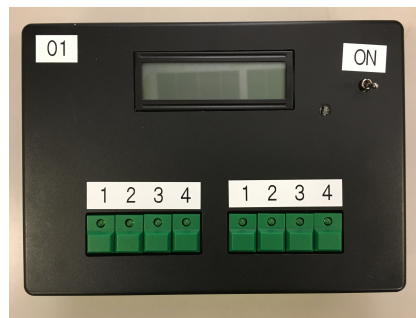


Figure 1: CDC slave device.

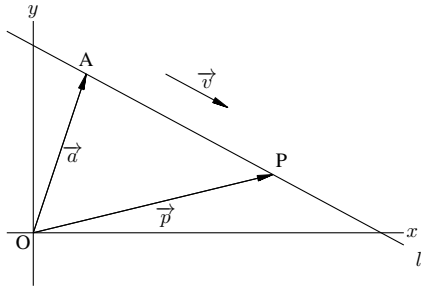
3.2 Teaching Materials

Many students are unable to work with vector equations well. Therefore, for this study, we created teaching materials for vector equations. Using KETCindy , we produced teaching materials including sound. They consist of an explanation of the concept of vector equations and some examples. This sound is a spoken explanation of the material. These teaching materials include flip type animations in which graphics changes one by one.

We also produced the teaching material shown in Figure 2, which consists of three problems: P1–P3. Furthermore, we produced five problems: Q1–Q5. The key point to note is that the problems P1 and Q1 are the same and that the problem used for Q2 is a replication of P2, while that for Q3 replicates P3. These problems test the understanding of a vector equation of a straight line passing through a point and parallel to a vector. The problems Q4 and Q5 are applications of problems Q1–Q3. These problems test whether students fully have understood the concept of vector equations. Each problem consists of several multiple-choice questions, each with four possible choices. For example, when participants select (1 - 3), they push button 1 on the left side and button 3 on the right side of the CDC in order. Then, the answer and the time are recorded.

We created these teaching materials of three kinds using KETCindy and conducted the experiment using them.

P1



A vector equation of a straight line passing through point A and parallel to vector \vec{v} is expressed as shown below.

$$\boxed{(1)} = \boxed{(2)} + \boxed{(3)} \boxed{(4)}$$

1. Choose $\boxed{(1)}$ from (1-1) – (1-4).

- (1-1) \vec{a} (1-2) \vec{v} (1-3) \vec{p} (1-4) t

2. Choose $\boxed{(2)}$ from (2-1) – (2-4).

- (2-1) \vec{a} (2-2) \vec{v} (2-3) \vec{p} (2-4) t

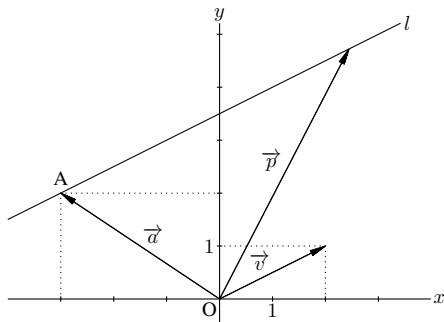
3. Choose $\boxed{(3)}$ from (3-1) – (3-4).

- (3-1) \vec{a} (3-2) \vec{v} (3-3) \vec{p} (3-4) t

4. Choose $\boxed{(4)}$ from (4-1) – (4-4).

- (4-1) \vec{a} (4-2) \vec{v} (4-3) \vec{p} (4-4) t

P2



1. For position vector \vec{a} at point A in the figure, $\vec{a} = \boxed{(1)}$ holds.

- (1-1) $(-3, 0)$ (1-2) $(-3, 2)$ (1-3) $(0, 2)$ (1-4) $(2, -3)$

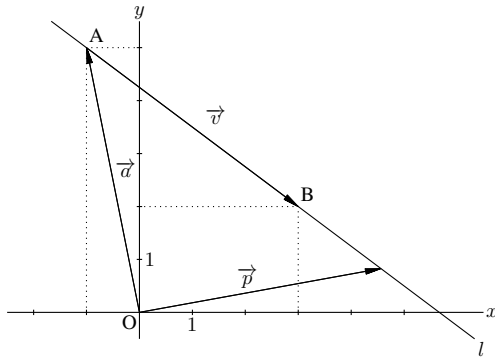
2. For direction vector \vec{v} of straight line l in the figure, $\vec{v} = \boxed{(2)}$ holds.

- (2-1) $(0, 1)$ (2-2) $(1, 2)$ (2-3) $(2, 0)$ (2-4) $(2, 1)$

3. Let \vec{p} be the position vector of any point on line l . Then, the vector equation of the straight line l is expressed as $\boxed{(3)}$.

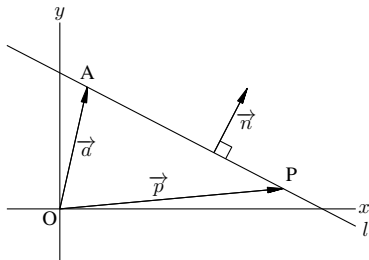
- (3-1) $\vec{v} = \vec{a} + t\vec{p}$ (3-2) $\vec{v} = \vec{p} + t\vec{a}$
 (3-3) $\vec{p} = \vec{a} + t\vec{v}$ (3-4) $\vec{p} = \vec{v} + t\vec{a}$

P3



- For position vector \vec{a} at point A in the figure, $\vec{a} = \boxed{(1)}$ holds.
 (1-1) $(-1, 0)$ (1-2) $(5, -1)$ (1-3) $(0, 5)$ (1-4) $(-1, 5)$
- For direction vector $\vec{v} = \overrightarrow{AB}$ of straight line l in the figure, $\vec{v} = \boxed{(2)}$ holds.
 (2-1) $(4, -3)$ (2-2) $(4, 3)$ (2-3) $(3, 2)$ (2-4) $(-1, 5)$
- Let \vec{p} be the position vector of any point on line l . Then the vector equation of the straight line l is expressed as $\boxed{(3)}$.
 (3-1) $\vec{v} = \vec{a} + t\vec{p}$ (3-2) $\vec{v} = \vec{p} + t\vec{a}$
 (3-3) $\vec{p} = \vec{a} + t\vec{v}$ (3-4) $\vec{p} = \vec{v} + t\vec{a}$

Q4

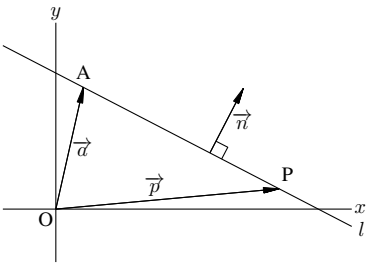


For position vector \vec{a} at point A, normal vector \vec{n} of straight line l and position vector \vec{p} at any point P on straight line l in the figure,

vector $\boxed{(1)}$ and vector $\boxed{(2)}$ are $\boxed{(3)}$.

- Choose $\boxed{(1)}$ from (1-1) – (1-4).
 (1-1) $\vec{p} + \vec{a}$ (1-2) $\vec{p} - \vec{a}$ (1-3) $\vec{p} + \vec{n}$ (1-4) $\vec{p} - \vec{n}$
- Choose $\boxed{(2)}$ from (2-1) – (2-4).
 (2-1) $\vec{n} + \vec{a}$ (2-2) $\vec{n} - \vec{a}$ (2-3) \vec{a} (2-4) \vec{n}
- Choose $\boxed{(3)}$ from (3-1) – (3-4).
 (3-1) parallel (3-2) perpendicular
 (3-3) equal (3-4) equal in magnitude

Q5



A vector equation of a straight line passing through point A and perpendicular to vector \vec{n} is expressed as (1) .

1. Choose (1) from (1-1) – (1-4).

(1-1) $\vec{p} = \vec{a} + t\vec{n}$	(1-2) $\vec{p} = \vec{n} + t\vec{a}$
(1-3) $\vec{p} \cdot (\vec{a} + \vec{n}) = 0$	(1-4) $(\vec{p} - \vec{a}) \cdot \vec{n} = 0$

Figure 2: Teaching materials.

3.3 Implementation

The experiment was conducted in December, 2017 at the National Institute of Technology, Numazu College, Japan. Participants in this study were 38 fourth-year students from the Department of Mechanical Engineering. Most were around 19 years old. They had already learned vector equations in the second grade. The experimental session took forty minutes. At the beginning of the experimental session, CDCs and teaching materials were distributed to all participants. After they were shown how to use the CDC, they were given time to familiarize themselves with its operation. Participants were next instructed to solve the three problems P1–P3, recording their answers on the CDC. They were given two minutes per question to record their answers. Multiple answers were allowed during this timeframe in case participants wished to change their responses. The last responses were counted. At the end of the two minutes, they were required to turn to the next problem. After solving the problems, all participants learned the vector equations with the teaching materials that include sound projected on the screen for six minutes. Finally, participants were instructed to solve the five problems of Q1–Q5.

4 Results and Statistical Analysis

The CSV data from the CDC included the CDC number, the time at which the button was pressed, and the selected answer. Scripts for processing the data were written in KETCindy, which charted the responses of the participants showing the patterns of answers over time. This result is shown in Figure 3. The horizontal axis represents time. The vertical axis represents the participants. Numbers in Figure 3 are the questions' numbers of the respective problems. We devote attention to the correct answers (blue), incorrect answers (red), and their solution time in Figure 3. In comparison to problems P1–P3, clear indication exists of an increase in the correct answer rate for problems Q1–Q3, with a corresponding decrease in the time to answer.

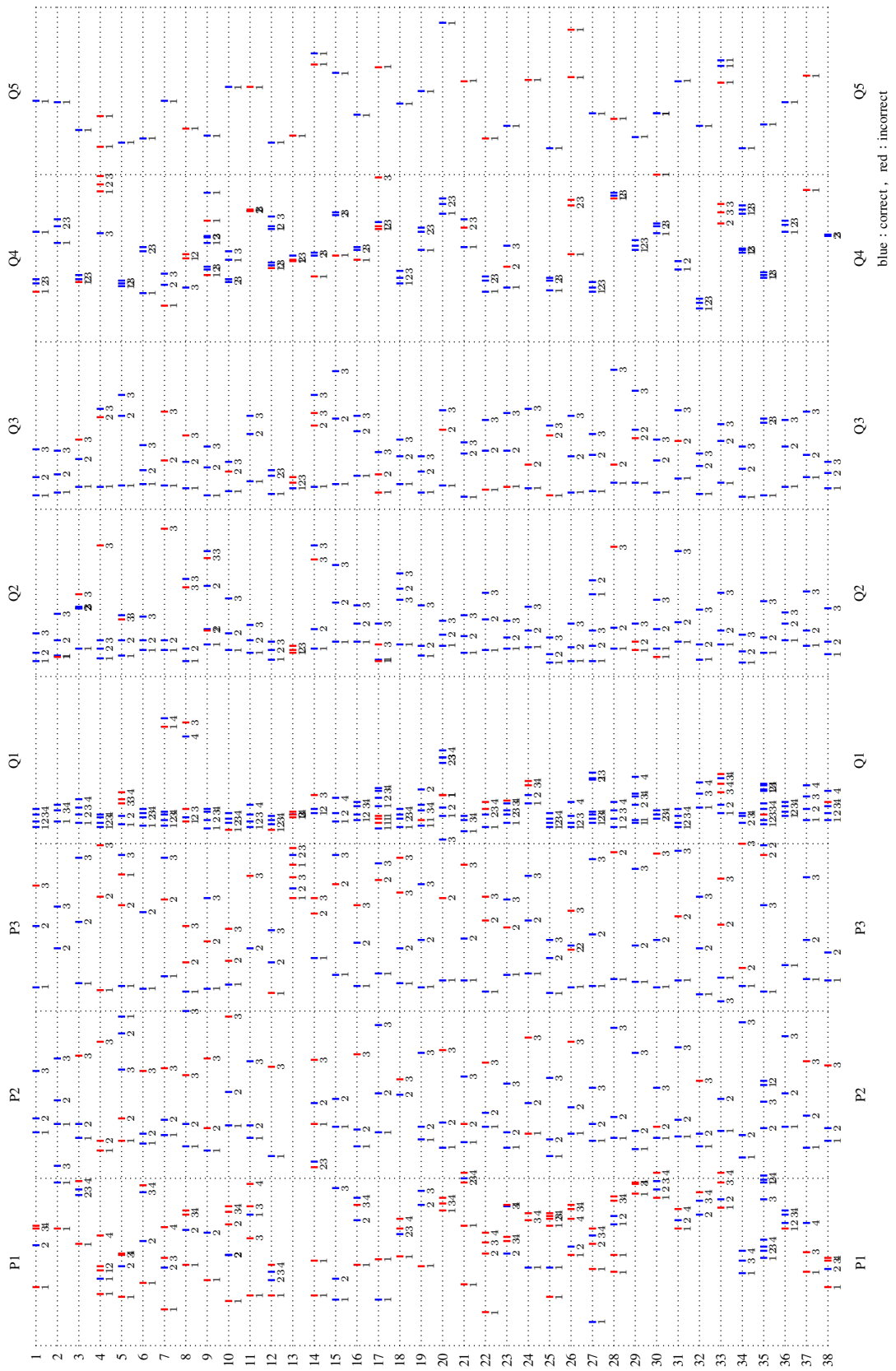


Figure 3: Patterns of participants' responses.

We next analyze participants' responses considering the proportions of correct answers, and the changes in responses over time.

As explained in section 3.2, P1 and Q1 are the same; P2 and P3 are replications of Q2 and Q3, respectively. An examination of changes in the participants' answers provides one measure of the effects arising from learning by the teaching materials that include sound. Table 1 presents the overall proportions of correct answers for P1 and Q1, P2 and Q2, and P3 and Q3. As might be apparent from the results, the proportions increased for all questions.

Table 1: Proportions of correct answers for each question

P1	Q1	P2	Q2	P3	Q3
2.6	50.0	42.1	81.6	23.7	60.5

The paired responses are presented in Table 2 through Table 4. The numbers in the “correct × incorrect” cell (i.e. those who changed their original incorrect response to a correct response after working with teaching material including sound) warrant special attention because overall improvement was apparent in the participants' answers.

Table 2: Cross table of paired responses, P1 & Q1

		P1		Totals
		Correct	Incorrect	
Q1	Correct	1	18	19
	Incorrect	0	19	19
Totals		1	37	38

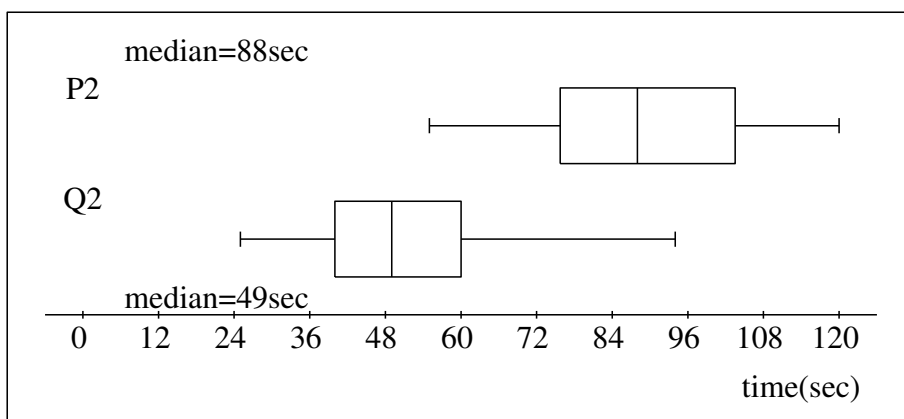
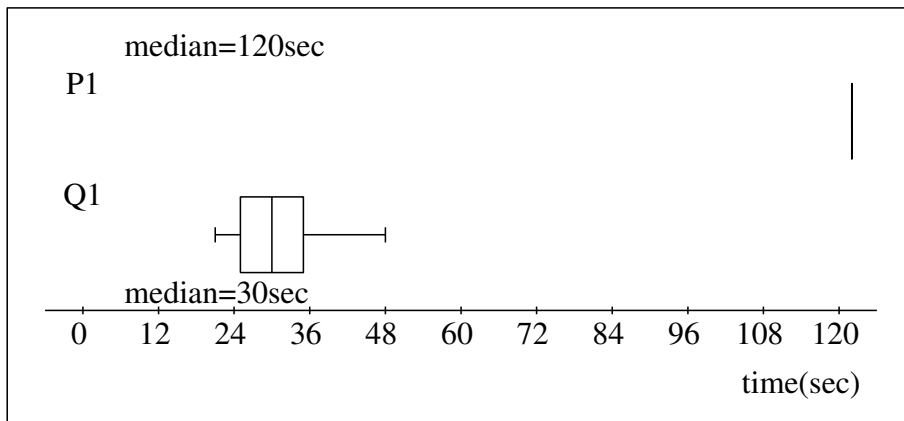
Table 3: Cross table of paired responses, P2 & Q2

		P2		Totals
		Correct	Incorrect	
Q2	Correct	13	18	31
	Incorrect	3	4	7
Totals		16	22	38

Table 4: Cross table of paired responses, P3 & Q3

		P3		Totals
		Correct	Incorrect	
Q3	Correct	6	17	23
	Incorrect	3	12	15
Totals		9	29	38

Figure 4 shows boxplots of the times required for giving correct answers in P1 and Q1, P2 and Q2, and P3 and Q3. Only one participant answered P1 correctly. These results show statistically significant difference in the time taken for all questions.



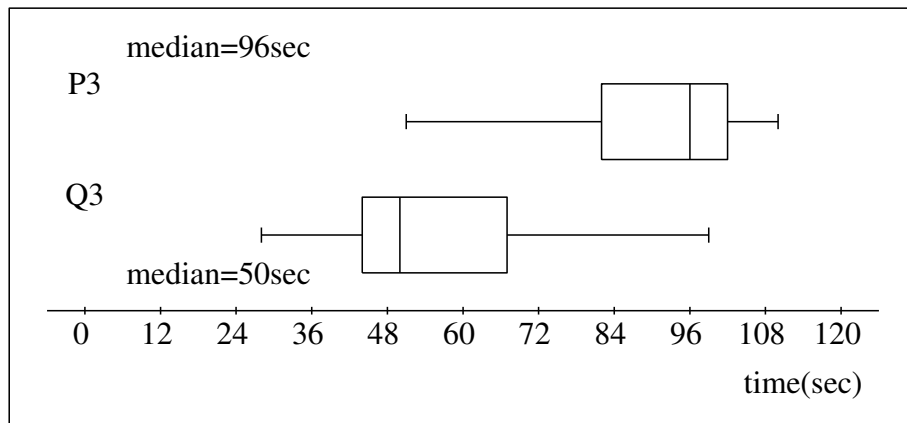


Figure 4: Boxplot of changes in response times for correct answers.

As described in section 3.2, Q1–Q3 are problems with a vector equation of a straight line passing through some point and parallel to some vector. However, Q4 and Q5 are the problems with a vector equation of a straight line passing through some point and vertical to some vector. Table 5 presents overall proportions of correct answers for Q4 and Q5. Although a vector equation of a straight line passing through some point and vertical to some vector is not explained in the teaching materials including sound, the proportions of correct answers for Q4 and Q5 are not low.

Table 5: Proportions of correct answers for respective questions

Q4	Q5
50.0	68.4

5 Concluding Remarks

From statistical analysis of CDC data, we obtained that there were significant improvements in the proportions of correct answers and the response times for correct answers after working with teaching materials that include sound. It might be true that a practice effect from answering problems P1–P3 contributed to the decrease in response times and to higher success rates. Therefore, considerations for future research are related to the type of questions used in the pre-experimental and post-experimental conditions.

Editing voice data of teaching materials is easy because we are able to create it for each page. We will create teaching materials including sound with other software, and compare them to ascertain which is easier to create. It is also necessary to verify differences in effect between audio-attached teaching materials and audio-less teaching materials. It is fundamentally important to create a comparative control group and experiment.

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