Development and evaluation of a learning support robot for vector learning

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Abstract

Vectors studied in high school are a new concept that differs from those studied in previous scalars. Therefore, it has been pointed out that difficulties arise in the conceptual formation of vectors. This study aims to develop a learning support robot that can visualize vector information by robot movements, and to acquire vector concepts for students through classroom practice using the robot. The robot operates on a piece of imitation paper, marking the start and end points and connecting them with arrows to visualize the vectors. In a class using the robot, the student predicts the sum of the vectors, and the robot confirms it. A questionnaire was administered before and after the class. The results revealed significantly higher mean values when comparing the pre- and post-assessments.

Keywords: Educational Support, Robot, Omni-wheel, Omnidirectional movement, High school mathematics

1. Introduction

Recent large-scale surveys such as OECD-PISA and TIMMS have shown that "while there has been some improvement in the percentage of students who responded positively to the enjoyment of learning mathematics and its relationship to the real world, there are still issues in terms of motivation to learn, such as the fact that the percentage is still low compared to other countries" and in upper secondary schools, "the motivation to learn mathematics is not high. [1] Therefore, in the Guidelines for the Course of Study for Senior High Schools announced in 2018, it is stated that in senior high school mathematics "problems that reflect the real world are handled, students who are not highly motivated to study mathematics are made aware of the significance of studying mathematics, and this will lead to increased motivation and the development of mathematical ability. This will lead to the development of mathematical skills.

"Vectors" are "quantities that have magnitude and direction," a new concept that is different from the "quantities that express only magnitude" that students have learned in the past. Therefore, various difficulties have been pointed out in the concept formation of vectors. One reason for this is that vector learning is conducted only at the level of abstraction on the blackboard, making it difficult to formulate concepts. In addition, lack of understanding of the phases of vectors has also been pointed out [2], which may be caused by a lack of understanding of the concept of vectors themselves.

It has been noted that the use of robots in schools can have a positive impact on students. The use of robots, as part of STEM education, has been noted to have a positive impact on students' understanding of science, technology, engineering, and mathematics; students acquire a broader range of knowledge because robots are associated with technological applications that span multiple disciplines; and the use of robots can increase students' motivation and engagement in the classroom. The use of robots can have a positive impact on students by increasing their motivation and engagement in the classroom. [3], [4], [5], [6]

Therefore, the purpose of this study is to develop a learning support robot for learning vectors and to propose a class in which students can acquire the concept of vectors in addition to numerical calculations. By using the robot, students can learn vectors not only on the blackboard but also through concrete objects, which is expected to enhance their conceptual understanding. Through the proposed class, we expect to achieve the learning effects of understanding the concept of vectors and improving the motivation to learn.

2. Robots to be developed.

2.1. Definition of robot requirements

The robot is used to consider the problem of two vectors with respect to the sum of the vectors, and to develop a robot that represents the motion of the vectors in terms of the robot's motion. The angle between the two vectors shall be limited to 0-180°. The robot should be easy to operate for high school students to acquire the concept of vectors. To visualize the vectors (trajectory of the robot), the robot is placed on a piece of imitation paper.

2.2. Robot Functions

The speed of the robot's motor is defined as the vector magnitude, the direction of the tires is defined as the vector direction, and the trajectory of the robot's progress is defined as the vector motion. When studying vector sums, the robot's trajectory can be defined as the sum of vectors by simultaneously performing the motions of the two vectors before combining the vectors.

2.3. Robot Design

This Robot will be developed using Artec Robo from Artec, Inc. The robot to be developed uses Artec blocks, DC motors, servo motors, and a battery box Studuino: bit. The omni wheel is an omni-directional moving mechanism. [7] The omni wheel is an omni-directional moving mechanism, and the wheels using the omni wheel can move in any direction. [8] Studuino: bit is used as the microcontroller. Artec blocks are used to assemble the robot. The servo motors are used to change the direction of the tires. DC motors are used to rotate the wheels, which allow the robot to move on a flat surface. Servo motors are used to change the direction of the tires. Electric power is supplied from a battery box. The size of the robot is about the same as the size of the classroom. The size of the robot should be large enough for students to hold in their hands and manipulate on a desk.

2.4. Correspondence between robot motion and vectors

Fig. 1 shows the appearance of this teaching material. Hereafter, the two wheels at the bottom of the robot will be referred to as Wheel A and the two wheels at the top of the robot in Fig. 1 as Wheel B. In Fig. 1, the direction of rotation and speed of the tires are specified for Wheel A and Wheel B, respectively, and the trajectory of the robot's motion is referred to as vector motion. The motion of the omni wheels is shown in Fig. 2. As shown in Fig. 2, the velocity in the x-direction is V_x and the velocity in the y-direction is V_y. Let the rotational velocities of the omniwheel be V_1 and V_2, respectively. considering the x-axis as the axis horizontal to V_1, the x-axis as 0 rad, counterclockwise as positive, and the angle between the two wheels as θ, the calculation of the velocity components can be expressed by the Eq. (1). With V_x and V_y known, the direction of movement is determined, and the direction of rotation and rotation speed of V_1 and V_2 are controlled.

$$V = \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \cos(\theta) & sin(\theta) \end{bmatrix} \begin{bmatrix} V_x \\ V_y \end{bmatrix} \qquad (1)$$

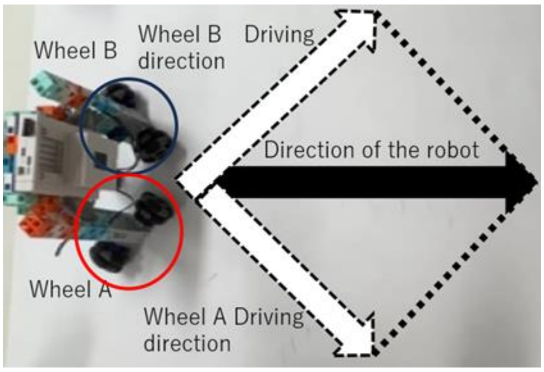

Fig.1 Robots to be developed.

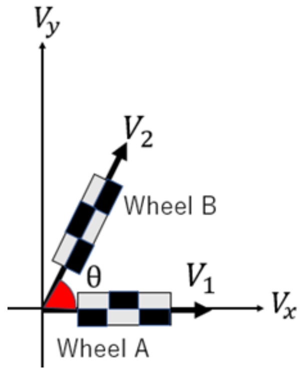

Fig.2 Omni wheel movement

However, V_1 is assumed to move in the direction V_x. If $V_1 = V_2$, the body moves straight ahead. The use of an omniwheel allows the robot to move without turning, so the sum of vectors can be moved in a direction different from the direction in which the wheels rotate. The wheels can be changed to any position by using servo motors in the upper positions where the wheels are mounted. This allows the direction of the wheel to be changed.

2.5. Image Analysis

Image analysis is performed to check whether the sum of vectors can be represented by the robot's motion. For the image analysis, we use a camera stand and a video shot from the top of the robot with an iPhone13. The frame rate of the video is 30 fps. PV Studio 2D PRO is used as the image analysis software [9]. Place a marker at the center of the robot and record the axis of the robot's movement. The x-axis and y-axis are set so that the center becomes the origin. The frame when the robot starts moving is used as the reference frame. Because of the blurring of the axis, the frame when the axis increases or decrease in a certain direction without any increase or decrease in the axis is the frame of the start of the movement. Similarly, the last frame in which the axis increases or decrease in a constant direction without increasing or decreasing back and forth is the frame at the end of the motion. Image analysis is performed by combining the two motions when the sum of vectors is decomposed. The analyzed data is quantified, theoretical values are derived, and a comparison of the motion and the theoretical values is made to confirm that the sum of vectors can be expressed.

2.5.1. Image Analysis Theoretical Value

Define the first values of x-axis and y-axis (axis of the initial position) x_1 and y_1. Thus, the x-axis and y-axis values in frame n can be defined as x_n and y_n. The general forms of the x - and y-axis are x_n and y_n, respectively, where x_1 and y_1 are first term values.

The robot is assumed to move in the minus direction of the x -axis. Therefore, if the robot stops moving at frame m, the total number of frames can be represented by m. If the range of frames in the x -axis and y-axis directions is defined as a and b, respectively, then a and b can be expressed by Eq. (2) and Eq. (3), respectively.

$$a = |x_m - x_1| \quad (2)$$

$$b = |y_m - y_1| \quad (3)$$

If the values advancing in the x-axis and y-axis directions per frame are defined as g and h, respectively, then g and h can be represented by Eq. (4) and Eq. (5), respectively.

$$g = \frac{a}{m} \quad (4)$$

$$h = \frac{b}{\frac{m}{2}} \quad (5)$$

In the case of h, the vector shows two directions, so the number of frames is $m/2$, since the direction changes after half the time. Therefore, the values x_n and y_n of the x and y-axis in the nth frame can be expressed by Eq. (6), Eq. (7) and Eq. (8). However, when $n = 1$, $x_1 = g$ and $y_1 = h$.

$$x_n = x_{n-1} - g \ (n \geqq 2) \quad (6)$$

$$y_n = y_{n-1} - h \quad (1 < n \leq m/2) \quad (7)$$

$$y_n = y_{n-1} + h \quad (m/2 < n \leq m) \quad (8)$$

When the number of frames is half, y_n can be expressed in two equations for $n/2$, since the sum of the vector's changes direction after half the number of frames has elapsed, since the vectors indicate two directions.

2.5.2. Results and Discussion of Image Analysis

In PV Studio 2D PRO, each displacement of one axis results in a movement of one meter. Based on this, comparing the results of image analysis with the theoretical values, the motion when the left and right wheels are moved simultaneously is shown in Fig. 3.

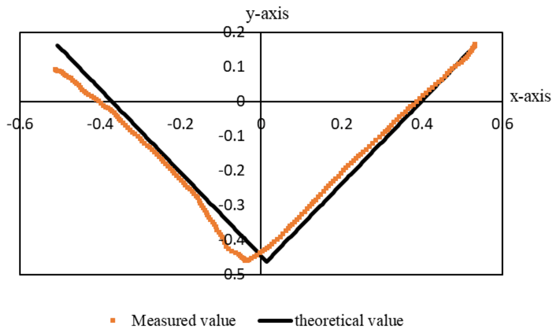

Fig.3 Results of Image Analysis.

When the number of frames is half, that is, when the direction of the vector sum changes, there is a difference of several frames between the measured and theoretical values. This may be due to the motor. We believe that the individual differences in the motors caused the slight discrepancies.

In addition, there was a discrepancy in the y-axis between the initial value and the final value of the measured value. This can be attributed to friction. Friction is considered to have shifted the y-axis by approximately 0.05 meter compared to the initial position.

The results show that the approximate shape of the sum of the vectors can be represented, although there is an error of a few centimeters from the theoretical value. In order to improve these deviations, we believe that the problem can be solved by making the arrows connecting the trajectories thicker. We also believe that the learning about the robot mechanism can be expanded by having the students consider the reasons for the deviations from the theoretical values.

3. Classroom Practice

3.1. Class Structure

In the class, the sum of vectors is represented by moving a robot on paper, attaching points to the starting and ending points of the robot, and connecting these points with arrows. The goal of the class is "to be able to consider the sum of vectors by transforming the decomposed vectors. The structure of the class is shown in Table 1. A questionnaire will be administered before and after the class.

Table 1. Class Flow.

Intro.	Explanation of how to use the robot. About vectors and sums in one direction.
Dev.	Sum of vectors in two directions Same magnitudes on the left and right Different magnitudes of left and right
Con.	Confirmation of the sum of vectors

Table 2. Results of pre-post comparison of questionnaires (t-test (with correspondence))

questionnaire	Pre		Post		*t*-value	*p*-value		effect *d*
	M	*SD*	*M*	*SD*				
1. Do you think you enjoy learning?	3.25	1.24	3.50	1.16	1.17	.261		0.21
2. Do you think you are able to participate willingly in class?	3.50	1.21	3.75	1.00	0.70	.497		0.23
3. Would you like to find out more about what you have learned?	2.31	1.08	3.00	1.10	2.71	.016	*	0.64
4. Can relate what they have learned to what they have studied and to what is happening in their daily lives and soc	2.38	1.20	2.80	1.13	1.00	.333		0.32
5. Can base one's opinions and thoughts on reasons and in a well-sequenced manner.	2.31	1.01	2.81	1.28	1.52	.150		0.44
6. Can imagine and look ahead and think about what could happen in relation to what they are learning.	2.31	0.95	3.63	1.09	3.88	.001	**	1.30
7. Organize materials and information gathered for a purpose into diagrams and tables.	2.56	1.21	3.06	1.34	1.94	.072		0.39
8. Can express facts and results based on the regularity and lawfulness of things.	2.50	1.03	3.25	1.29	2.54	.023	*	0.65

※In the post-survey, add "Through the use of the robot in the class" at the beginning of the survey item. $^{*}p < .05$; $^{**}p < .01$

3.2. Survey Summary

On October 11, 2023, 17 high school sophomores (16 pre-survey, 17 post-survey) will be surveyed. The subjects are students who have not studied vector sums. The questionnaire will be administered using a five-item method with reference to the literature [10]. In order to measure knowledge, survey questions were administered before and after the survey. The pre-survey was conducted before the class, and the post-survey was conducted after the class. A *t*-test (with correspondence) was used to analyze the differences in attitudes toward independent.

3.3. Result

The results of the survey are shown in Table 2; significant differences were found in three items. For the knowledge question, the response rate for Question 1 was 62.4% before and 93.8% after the response. For question 2, the pre-response rate was 18.8% and the post-response rate was 50.0%.

4. Conclusion

In this study, we developed a learning support robot that represents vector sums. The robot was also used in a class. A questionnaire survey was conducted, and significant differences were found. In addition, the percentage of correct answers in the test was higher than before and after the class. In the future, we plan to further analyze the questionnaires and modify the robot and the classes.

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