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STEM-based Education Learning Flow Using Robots for Systematical Understanding

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ABSTRACT

Disenchantment with science and mathematics has recently become a major problem around the world and it is said that the period in which children tend to become dissatisfied with science and mathematics commonly occurs in the late elementary to early junior high school period. As a way to stimulate interest and motivation in the science, technology, engineering, and mathematics (STEM) education fields, we have developed a method that uses a robot system as instructional equipment in order to motivate students toward understanding and applying science and mathematics fundamentals. We contend that using robots in classes provides incentives for students to pursue their studies, make experimental discoveries, and acquire solid knowledge foundations. For our study, we chose the LEGO MINDSTORMS Education EV3 robot system because this robot's structure can be modified and applied to a wide variety of study fields. Conventionally, students tend to expect arithmetic, mathematics, and sciences to become increasingly difficult as their grade levels advance. A primary reason for this is that the systematized learning contents of each field are taught in isolation from the curriculums of other fields. Contrastingly, our STEM-related curriculum learning flow systematically integrates the learning content of each curriculum using the same robot. As a result, students systematically assimilate an understanding of all presented learning contents because they can associate them with the iterative learning they received in each previous grade. The learning flow consists of five steps: 1) course unit introduction, 2) robot assembly, 3) robot interaction, 4) contemplation and problem solving, and 5) summarization. This paper also describes a learning flow for the proportional relationship curriculum in the arithmetic and mathematics classes of elementary and junior high schools, and provides a practical example of a curriculum-based class conducted at a Japanese elementary school.

KEYWORDS

STEM education system; Systematic Understanding; Robot; LEGO MINDSTORMS Education EV3; Proportional relationship curriculum

1 INTRODUCTION

Disenchantment with science and mathematics has recently become a major problem around the world, and it has been said that the period when children tend to become most disillusioned with sciences and mathematics occurs during the late elementary and early junior high school years. Their reasons for moving away from sciences and mathematics generally involve the perceptions that the subjects are difficult and incomprehensible, and that studying them is not fun.

One reason for this is that many elementary school teachers are not good at teaching sciences and mathematics, partially because elementary school teachers in Japan are humanities course graduates. Furthermore, students are exposed to the learning contents of each curriculum separately because they learn them in different grades. In recent years, as a result of support being extended to science and mathematics classes, significant advances have been made in providing educational equipment. However, since the use of such equipment is generally restricted to a particular course unit and cannot be used by other units, or at different grade levels, in practice, it is often left unused.

The science, technology, engineering, and mathematics (STEM) education system has been attracting interest as a method for enabling students to efficiently acquire the basics of sciences and mathematics. It facilitates integrated student learning of science, technology, engineering, and mathematics related topics. From among the various STEM-based approaches that have been adopted in many countries, we have focused on an education method that utilizes LEGO bricks and LEGO robot system as an instructional device [1].

LEGO bricks and the LEGO MINDSTORMS Education EV3 robot system [2] are extremely useful because they can be applied to a wide variety of study fields. In fact, LEGO-based robot systems have long been used to teach mechanical and software engineering at high schools and science and technology universities [3].

Robot related studies have been ongoing for numerous years and a variety of robots now present in our daily lives. Because many children, especially elementary school students, have developed a deep fascination with robots, it is believed that a learning method that incorporates robots can motivate students to increase interest in their learning. With this point in mind, we have been developing robot-centered science and mathematics curriculums for elementary and junior high schools and have found that robots can be effectively integrated into every unit of the curriculum. However, students continue to believe that the arithmetic, mathematic, and science courses will become increasingly difficult as their grades advance, primarily because their exposure to such learning contents has been systematized and presented to them separately.

In this paper, we propose an integrated STEM-based education learning flow that will help students systematically understand the contents of each curriculum by building each lesson around the use of the same robot. In our proposed learning flow, because students obtain their normal curriculum objectives via integrated experiments that all use the same robot, they gain a systematic understanding of all learning contents because they can associate them with the iterative learning they received in each previous grade.

Each course unit of the proposed learning flow consists of five steps: 1) course unit introduction, 2) robot assembly, 3) robot interactions, 4) contemplation and problem solving, and 5, summarization. Each stage of the flow will be explained in detail in Section 3. Section 4 describes a learning flow for proportional relationships in the arithmetic and mathematics classes of an elementary and junior high school curriculum, and then shows a practical example of a curriculum-based class at a Japanese elementary school.

2 LEGO MINDSTORMS EDUCATION EV3

The LEGO MINDSTORMS Education Core Set includes a programmable EV3 brick with a 64-bit ARM9TM microcomputer based on the LINUX Operating System. The set also includes two large interactive servomotors, one medium interactive servomotor, two touch sensors, one color sensor, one ultrasonic sensor, one gyro sensor, and a variety of LEGO components such as beams, axles, and connectors, all for use when building and programing robots. LEGO MINDSTORMS NXT, which is the predecessor of EV3, is still used in practical programming and robotics courses in various universities and companies [4, 5].

The electronic bricks in the LEGO MINDSTORMS Education Core Set are shown in Fig. 1. Note that specialized instructional equipment created for a particular course unit may extremely useful for that unit, but may be worthless in other course units. In contrast, the LEGO MINDSTORMS Education EV3 is designed for maximum flexibility so it can be applied to numerous course units simply by modifying the robot structure.

The LEGO MINDSTORMS Education EV3 software is based on the Laboratory Virtual Instrument Engineering Workbench (LabVIEW) system-design platform and development environment, with which users can create programs using its graphical programming language. This same programming environment can be used by both elementary school students to create basic programs and by scientists to design advanced programs. Figure 2 shows an example of LEGO MINDSTORMS EV3 program designed to move the robot. The program instructs the robot advance forward at motor power 50 for three seconds.

Figure 1. Electronic bricks of the LEGO MINDSTORMS Education Core Set.

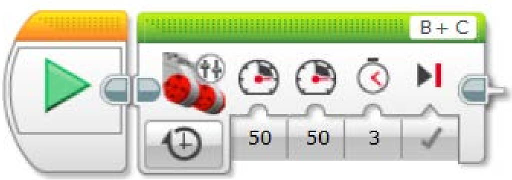

Figure 2. Example of a LEGO MINDSTORMS EV3 program to move the robot. The program instructs the robot to advance forward at motor power 50 for three seconds.

3 LEARNING FLOW OF COURSE UNIT IN STEM EDUCATION CURRICULUM USING ROBOT

The contents of each subject are provided by the government curriculum guidelines written by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and were systematized for the periods from elementary to high school. However, the students may not notice this systematization because the ways in which they learn each unit are entirely dependent on teacher explanations of each systemized subject. Teachers also control whether the students learn beyond the systemization boundaries. As a result, students may come to view the systemized learning contents as totally separate contents and thereby fail to gain an integrated understanding of the practical utility of studying arithmetic, mathematics, and sciences.

In this paper, we propose an integrated STEM education learning flow that will help students systematically understand the contents of each curriculum by building each lesson around the use of the same robot. In our proposed learning flow, because students obtain their normal curriculum objectives via integrated experiments that all use the same robot, they gain a systematic understanding of all learning contents because they can associate them with the iterative learning they received in each previous grade.

Since the abovementioned LEGO MINDSTORMS Education EV3 robot equipment used in our learning flow is expensive, it would be difficult for public elementary and/or junior high schools to justify the purchase of a large number of robot sets, and therefore the available sets must be shared by multiple classes. Accordingly, when a robot set is used in a class, any experiments or lessons involving its use must be concluded within the class period, which is normally between 45 and 50 minutes. With this point in mind, our course unit learning flow proposal is designed to allow teachers to conclude classes within the class period, providing the teacher encourages the students to concentrate.

As mentioned above, our proposed flow for each course unit consists of five steps. In Step 1, the teacher introduces the course unit to the students. In Steps 2 and 3, the students assemble an experimental robot for use as an instructional device and interact with it. Note that the robot structure is the same regardless of the student grade level. In Step 4, students contemplate the experimental results and solve problems and challenges. In Step 5, the teacher summarizes the target points of the course unit and connects those contents with information the students learned in previous grades. The following subsections explain each step in detail.

3.1 Course Unit Introduction

In this step, the teacher introduces the course unit and works to motivate students towards an understanding of the unit’s themes and objectives. The teacher may explain the course unit goals directly, or he or she may explain them indirectly by making a reference to a familiar topic. At this stage, it is also recommended that the teacher present students with challenges related to the course themes and objectives. Naturally, the teacher should adopt a method that matches the students and the course unit themes.

3.2 Robot Assembly

Here, the teacher allows the students to assemble a robot that is related to the course unit themes and objectives. The students will interact with this robot later. When the themes are flexible, allowing the student groups to assemble the robot with a free structure can have positive benefits. In this step, it is also important that the students view the robot assembly as creating an instructional device, because the process stimulates their curiosity, questions, and appreciation.

3.3 Robot Interaction

In this stage, the teacher encourages the students to interact with the robot they have assembled by explaining how to create a program with which to operate it. The ease of the programming procedure allows students to immediately and intuitively acquire an understanding of the programming process. Depending on the course units, there may be cases where the students will only instruct the robot to move, or others where they use the robot to measure a physical quantity. Students at the higher grade levels will obtain the same results that they experienced with the same robot previously, but do not get bored, because they do not even remember the experimental results.

3.4 Contemplation and Solving Problems

In this stage, the teacher will encourage students to contemplate the results obtained by interacting with the robot and use that information to solve the presented problems. Such problems should naturally reflect the students' grade level and provide challenges that stimulate their motivation, interest, and curiosity so that they discover the things the teacher wants them to learn via their own efforts. Accordingly, teachers are encouraged to introduce game elements into the challenges, and must work to ensure that the students never become inactive. This can be done by providing additional challenges to students who have completed the first set of challenges, or by providing hints to students who are losing interest because they cannot solve the challenge.

3.5 Summarization

Here, the teacher works to link the awareness and findings the students have achieved with the principle, theory, and properties of the lesson itself. For students who were able to solve the problem intuitively, the teacher should explain how their solution accurately coincided with the principle lesson. In the higher grade level classes, the teacher should also connect the contents learned with any related contents that the students may have learned in previous grades, thus allowing them to systematically build and integrate concrete knowledge. In this stage, it is also important that the teacher answer any questions the students may have encountered to the greatest extent possible, even if the answer is not included in the content of the course unit, because it may stimulate their desire for knowledge and lead to increased interest in other things.

4 PRACTICAL EXAMPLE OF PROPORTIONAL RELATIONSHIP CURRICULUM USING ROBOT

4.1 Proportional Relationship Curriculum in Japan

In Japan, the compulsory education curriculum is provided by government guidelines written by MEXT. These guidelines divide elementary school arithmetic and junior high school mathematics into four categories in order to make their entire contents readily understandable, and to simplify system and content development.

The elementary school arithmetic categories consist of "Numbers and Calculations", "Quantities and Measurements", "Geometrical Figures", and "Mathematical Relations", while the junior high school mathematics categories consist of "Numbers and Algebraic Expressions", "Geometrical Figures", "Functions", and "Making Use of Data". In the curriculum relationship between elementary and junior high school, elementary school "Quantities and Measurements" and "Geometrical Figures" develop into "Geometrical Figures" during junior high school, and elementary school "Numbers and Calculations" and "Mathematical Relations" develop into "Numbers and Algebraic Expressions", "Functions", and "Making Use of Data" during junior high school.

Additionally, a proportional relationship develops from elementary school "Mathematical Relations" into the proportion and the linear function in the "Functions" and "Numbers and Algebraic Expressions" categories junior high school. Table 1 shows a list of the systematized proportional relationship curriculum in each grade based on Japan's government curriculum guidelines [6, 7].

Table 1. Systematized curriculum of the proportional relationship in Japan.

Grade	Unit	Objective
6	Ratio and Proportion	· To understand proportional relationships, and to explore their features via algebraic expressions, tables, and graphs. · To solve problems by using proportional relationships.
7	Algebraic Expressions using Letters	· To understand the necessity and meaning behind the use of letters and equations. · To cultivate student ability to represent and process the relationships and rules for numbers and quantities in a general and simple manner. · To make use of linear equations with one unknown.
	Ratio and Proportion	Through exploring concrete phenomena, · To deepen student understanding of direct and inverse proportion. · To cultivate their ability to investigate, represent and think in terms of functional relationships.
8	Linear Function	Through exploring concrete phenomena, To understand linear functions, To foster students' ability to find out, represent, and think in terms of functional relationships.

As shown in the Table 1, the proportional relationship curriculum is systematized in the government curriculum guidelines. However, some students may not fully integrate the systematized proportional relationships that exist between the various contents, because they study related subjects with different teachers at different grade levels. To address this issue, our approach handles the learning flow of each grade based on the systematized proportional relationship curriculum shown in Table 1. In addition, we develop a robot for use in the learning flow. The robot used is the same regardless of grade level, as mentioned previously.

4.2 Robot Model

This subsection describes model robot fabrication using the LEGO MINDSTORMS EV3 for use in proportional relationship curriculum course units. Such robot models should be simple and have short assembly times because robot assembly is not the core work of the curriculum. However, it is also important to avoid omitting robot assembly by simply presenting the finished robot to the students because such behavior tends to discourage student interest and participation.

Our robot model consists of 19 parts including an intelligent block, two motors, and two cables to connect the intelligent block and the motors. Figure 3 shows the robot model. Students can assemble the robot in about five minutes.

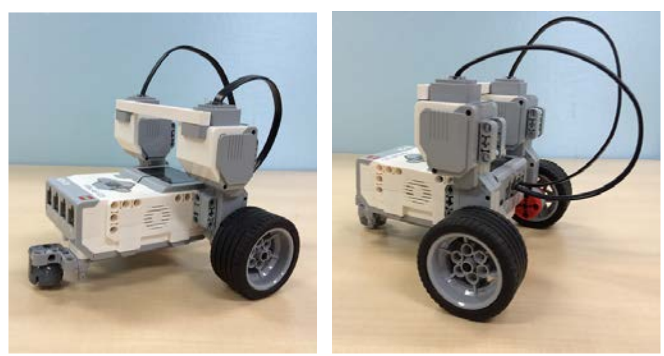

Figure 3. Our robot model.

As stated previously, even though learning objectives vary depending on the school year, the same robot is used as education equipment for all school years. This is because it is hoped that students will notice that even though the objective and approach to the experimental results is different in each school year, they are all obtained using the same robot. We think that such experiences stimulate and integrate student knowledge by showing them how easily they can assimilate new results that expand on what they learned in previous school years.

4.3 A Practical Example in Elementary School

This subsection describes a practical example of a proportional relationship class conducted in a small elementary school in Japan. The subjects are a sixth grade class consisting of 10 students. In this class, the teacher forms five groups of two students each and gives each group a computer and a LEGO MINDSTORMS EV3 Education Core Set. The class period is 45 minutes.

When introducing the course unit (Step 1), the teacher presents the problem to the students. In this case, saying, “If a car travels a certain distance in one hour, how far will it travel in two hours?” Naturally, the students respond that the distance will be doubled, but the teacher then proposes conducting an experiment to verify this conclusion.

In Step 2, the students fabricate the abovementioned robot as an educational device by following the teacher’s instructions and viewing appropriate slides. Working together, each pair of students can assemble the robot in about five minutes.

During Step 3, robot interaction, the teacher explains how to program the robot and instructs the students to measure the distance the robot traveled by changing movement times. After that, they are instructed to create a table and draft a graph showing their results. The measurement is performed while changing the robot speed in each group in order to remind them that the relationship between time and movement distance does not depend on the robot’s speed. This is because the speed of the robot can only be adjusted by changing the power value of the program. Figure 4 shows an example of a graph describing the relationship between the time and the robot travel distance. The functions in the graph represent the approximate linear function.

In Step 4, contemplation and solving problems, the teacher presents the students with a challenge. In this case, the challenge is named "Robot Dart", and the rules are as follows:

1) Each group can only try it once.
2) Each group starts their robot from an arbitrary position selected by the teacher and can get points according to the position that the robot stops.
3) The challenge field and point are shown in Fig. 5.

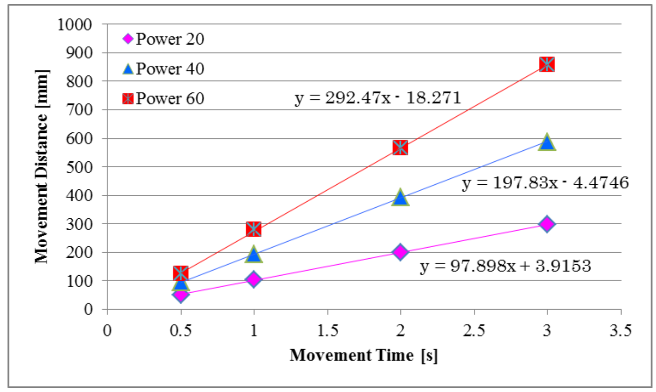

Figure 4. Relationship between the time and the distance the robot moved. Functions in the graph represent the approximate linear function.

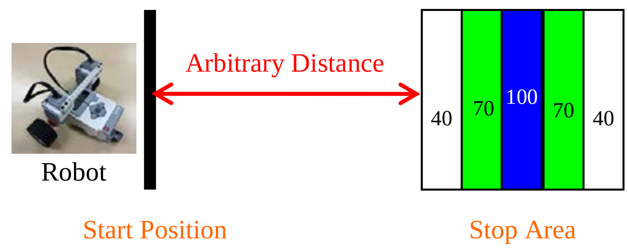

Figure 5. Challenge field and end points.

After they try the challenge, the teacher instructs the students to draw a straight line via the measured points. Next, the teacher instructs them to plot the results as a graph. If they can use a personal computer, they may create the graph using a spreadsheet or a graph tool.

The students then use a tape measure to calculate the distance between the assigned starting position and end points, read the time value from their graph using the measured distance, and then program the robot. Most groups were able to obtain the maximum points in the challenge.

In Step 5, summarization, the teacher displays the each group’s graphs on the blackboard and explains to them how the relationships between such graphs create a "proportion relationship", thus instructing them on the properties of proportion relationships as applied to an actual situation.

The students then recognize that their graphs helped them not only to visualize two relationships, but also to find the other value from one value. The students also realized that the graph gradients were different by the robot movement speed differences by comparing the graph of each group. The teacher explained that the graph's gradient degree represented the movement speed of the robot. The students will learn the theory. After that, the students disassembled their robot, stored everything carefully, and finished their class.

4.4 Discussion

The enjoyable format captured the students' interest and helped them to concentrate, thereby improving awareness during class. In the above example regarding proportion relationships, the use of graphs, class speed, and other factors all combined to dynamically connect the students to knowledge, as opposed to passively listening as the teacher one-sidedly dispensed information.

In Steps 4 and 5, rather than simply reading the time value from their own graph, teachers in higher level classes would be able to instruct students on how to determine linear functions and compute time values by assigning distance values. Those teachers could also explain the relationship between the velocity and the differentiation, and then lead students through the processes that explains why the graph shown in Fig. 5 does not pass through zero, even though the robot does not move at time zero. This, in turn, would explain an electrical transient in the science field. For all of these questions, our proposed learning flow can be of equal use to classes of every grade level.

5 CONCLUSION

In this paper, we propose an integrated STEM education learning flow that will help students systematically understand the contents of each curriculum by building each lesson around the use of the same robot. The proposed learning flow of each course unit consists of five steps that facilitate student concentration, stimulate knowledge awareness, and promote the systematic acquisition and integration of knowledge by incorporating repetitive learning activities with different lesson points that use the same robot. Since students gain new discoveries and interests as their grade levels increase, they become further motivated to challenge forthcoming lessons and other subjects.

In our future work, we will investigate the depth of understanding that students obtain by our robot-centered curriculum in order to evaluate its utility via the results and to develop suitable curriculums for other units.

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