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Analysis of the learning effects of knowledge acquisition in science class using a user-created robot

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Despite the growing popularity of research on the application of robots in education, few studies have investigated the acquisition of knowledge in classes that use robots. Therefore, the purpose of this research is to identify the changes in students' acquisition of scientific knowledge in a science class that uses a robot as a teaching aid. The participants were 50 students who were 6th graders at an elementary school. They were divided into two classes: In the comparison class, students were taught using traditional mathematics instruction with a textbook and other teaching materials such as photos and videos. In the experimental class, students used a robot as a teaching aid as well as a textbook and other conventional teaching materials. We selected the topic 'energy change' and asked the teacher to teach the class using the robot. We administered a pre- and post-test. The pre-test measured the level of the students' declarative knowledge, and the post-test measured both declarative and procedural knowledge about energy change. The results are as follows: (1) Students in the experimental class acquired more declarative knowledge about energy change compared to students in the comparison group, (2) Students in the experimental class were active in writing about their procedural knowledge, and (3) Slow learners in the experimental class acquired knowledge better than those in the comparison class. (4) Students in the experimental class were enthusiastic in their writing about energy conversion but needed help in developing their thoughts.

Keywords: Teaching aid robot, R-learning, Knowledge acquisition, Elementary school, Instruction

Introduction

Research on the use of robots in education is increasing. Figure 1 shows the number of papers on this topic published in each year from 2001 to 2013 in 140 journals in Korea. The papers were retrieved from the Research Information Sharing Service (RISS) using two keywords ('education' and 'robot').

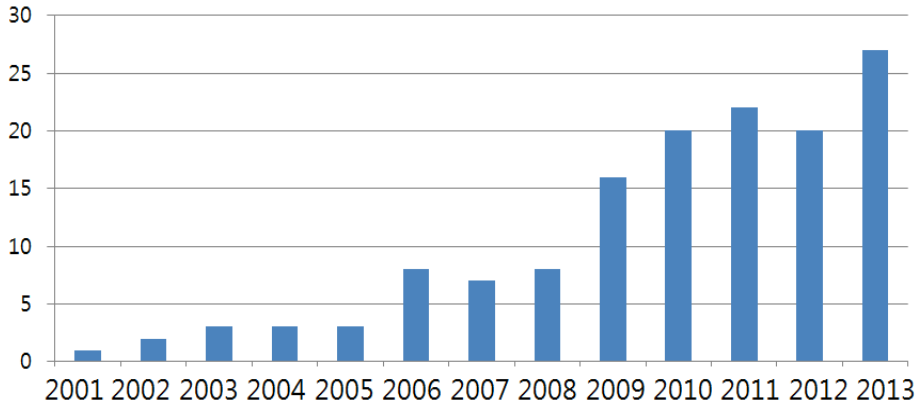

Figure 1. Number of articles about robots in education published in Korean journals

Robot education is implemented in after-school courses in most of South Korea's elementary schools (Lee & Han, 2009) and is slated to be included as a part of a regular practical course beginning in 2015. Viewpoints about robot learning (r-learning) are diverse. Shin and Kim (2007) presented three points of view based on Jonassen (1995): 'learning about robots', 'learning by robot', and 'learning with the robot'. In addition, Baker et al. (2012) proposed two aspects of r-learning, robot as a learning purpose and learning tool/aid. Han and Jo (2009) divided r-learning into learning using a user-created robot and learning supported by an intelligent robot. The effects of r-learning can be divided into attitude (interest, self-confidence, etc.), ability (creativity, problem-solving skills, critical thinking, etc.), and knowledge (concept, etc.). Taken together, these points of view suggest the purpose of r-learning can be summarized as improving students' attitude, ability, and knowledge by learning about ICT or various subjects using robots. The classification of the 50 journals about r-learning that Kim (2013) reviewed showed that only two journals (Kim & Seol, 2010; Lee et al., 2010) belong to the knowledge category.

Scholars have pointed out that little attention has been paid to the research on knowledge acquisition in r-learning. Williams et al. (2007) commented that there is limited empirical evidence to prove the impact of robotics activities on achieving curricular goals, and most of the literature on robotics use in education is anecdotal and descriptive in nature. He further pointed out measurable evidence is needed to convince educators of the positive impact of robotics activities on curricular goals. After reviewing two studies (Kim & Seol, 2010; Lee et al., 2010) focusing on knowledge acquisition, we found an improvement in student's grades in mathematics and language. There was no improvement in social studies or science. Given that acquiring knowledge and concepts is more important in social studies and science than in language and mathematics, an analysis of the knowledge acquisition in classes using robots is needed. Against this background, we designed an experimental study on the learning effects of 'acquiring knowledge'.

Acquiring knowledge and concepts is the basis of learning, and it plays a pivotal role in thought processes such as reasoning, judgment, problem-solving, decision-making, and creativity. It can be said that 'concepts' are established by 'knowledge' through classification and connection. Knowledge can be divided into procedural knowledge that corresponds to 'knowing how' and declarative knowledge, which explains what it is. South Korea's national curriculum specifies that improving students' searching ability through exploratory activities is the first criterion to achieve. For example, the criteria of science subjects in 5th and 6th grade include understanding the basic concepts in the field of 'Earth and life' and developing the ability to search. This could be said to be connected to the theory of situated learning (Brown et al., 1989) and Learning by Doing (Dewey 1916). In connection therewith, Schank (1995) described one reason that the application of 'learning by doing' was denied in school is that educators and psychologists have not fully understood how learning by doing works. Also Sawyer (2014) stated "factual and procedural knowledge is only useful when a person knows which situations to apply it in and exactly how to modify it for each new situation".

In order to overcome these problems, research on the acquisition of scientific concepts through authentic practices using robots is needed. To combat these problems, we attempted to identify the changes in students' acquisition of scientific knowledge in a science class that uses a robot as a teaching aid. For a deeper analysis we focused on 'procedural knowledge' and 'declarative knowledge'. Therefore we attempt to address the following questions.

(1) Does a science class using a user-created robot improve students' acquisition of declarative knowledge about energy conversion?
(2) Does a science class using a user-created robot improve students' acquisition of procedural knowledge about energy conversion?
(3) Does a prior knowledge of energy conversion impact students' acquisition of declarative/ procedural knowledge about energy conversion?

Research Design and Method

In this study, we took a comparison and an experimental class and administered a pre-post questionnaire. The participants were 50 students, divided into the two classes, who were 6th graders at an elementary school in Seoul. The comparison class was taught using traditional energy change instruction with textbooks and other teaching materials, such as photos and videos. The experimental class used a robot as a teaching aid as well as a textbook and other conventional teaching materials. Figure 2 shows the research design.

G1	O1	X1	O2
G2	O1	X2	O2

G1: Experimental class
G2: Comparison class
O1: Pre-test (to evaluate the students' understanding of energy and energy conversion)
X1: Lesson with the teaching aid robot (learning about energy conversion)
X2: Lesson without the teaching aid robot (learning about energy conversion)
O2: Post-test (to evaluate the students' understanding of energy conversion)

Figure 2. Research design

We selected the topic 'energy change' and asked the teacher to use a robot as a teaching aid. According to the teacher guidelines, the learning objective of the course is 'to explain the concept and the process of energy conversion through examples from daily life'. The teacher who taught the experimental class created the teaching plan (Table 1). He had a seven-year career in r-learning. The teaching plan for the comparison class was created by other teachers at the same school. The robot used in the experimental class was a manufacturing-type teaching aid robot that could assemble blocks and communicate with laptops wirelessly. When the generator motor was turned by hand, the robot's LED lamp lit up, and the amount of power generation was displayed on the students' laptops. In pairs, students of the experimental class shared one robot kit for collaboration and communication. Through this activity, the students witnessed energy conversion firsthand. The experimental class met one time (40 minutes) on November 19, 2013.

Table 1.
Teaching Plans for Energy Conversion in the Experimental and Comparison Classes

Step (Time)	Comparison class (n = 25)	Experimental class (n = 25)
Introduction (5 min)	Shake the sand in a plastic bottle - Measure and compare the temperature before/after shaking the plastic bottle containing sand. - Explain why the temperature changed using the concept of energy.	Look at photos and videos related to kinetic energy - Photos: bumper cars, Gyro Drop, Dublin tram, Ferris wheel, volcanoes -Videos: Placing beads on a tabor, rubbing the palms of both hands together - Q&A about energy type and concept
Development (30 min)	Explain the process of energy conversion after seeing photos and videos related to kinetic energy. - Rub the palms of both hands together. - Look at photos: Placing beads on a tabor, incandescent bulbs, fans, trains, escalators, hydroelectric plants, solar cells, self-development flashlight - Watch videos: a roller coaster, Japanese subway stairs, stepping on stairs to generate electricity	In pairs, assemble a teaching aid robot for energy conversion. - See energy conversion by connecting to a laptop after assembling the teaching aid robot. (Teacher helps students who have trouble with assembling the robot kit) Explain the energy conversion process using the teaching aid robot.
Conclusion (5 min)	Explain the energy conversion process.	Explain the energy conversion process.

The pre- and post-tests were intended to evaluate students' knowledge of energy and energy conversion. Both tests were developed and checked in cooperation with the teacher and three education professionals who each held a Ph.D. (one Ph.D. was in science education). The pre-test consisted of five items (two multiple-choice, three short-answer), and the post-test consisted of 11 items (eight short-answer, three open-ended) such as in Table 2.

The multiple-choice and short-answer items were intended to measure the students' declarative knowledge of energy conversion. The open-ended items on the post-test were to measure their procedural knowledge of energy conversion. The pre-and post-test, respectively, were administered one week before the lesson using the robot, and the same day after the lesson. The multiple-choice and short-answer items were evaluated as either right or wrong. The open-ended items were assessed according to the criteria such as in Table 3. To assess the 3 open-ended questions, we scored the answers by comparing the score lists to each other.

Table 2.
Number of Items on the Pre- and Post-Test by Type

Knowledge	Item Type	Knowledge Type	Number of Items (score per 1 item)	
			Pre-test	Post-test
Energy	Multiple-choice	Declarative	2 (4)	
	Short-answer	Declarative	1 (4)	
Energy conversion	Short-answer	Declarative	2 (4)	8 (1)
	Open-ended	Procedural		3 (4)

Table 3.
Standard and Score to Assess Students' Responses to the Descriptive Questions

Standard	Score		
	Item 1	Item 2	Item 3
No answer	0	0	0
Inappropriate example or explanation	0	*	0
Listing words	2	2	2
Short/insufficient explanation	3	3	3
No mistake	4	4	4

* Item 2 was to explain energy conversion based on the example given.

Results

We checked the process of instruction given to the experimental class based on the video and teaching plan. The lesson was conducted by checking the students' prior knowledge of energy, which they had learned in the previous lesson. After the teacher presented on the type of energy and energy conversion, students worked in pairs to assemble the generator and teaching aid robot using the robot controller, DC motor, LED modules, and plate prepared by teacher (see Figure3). They witnessed energy conversion through this activity. Finally, the teacher explained the process and checked the students' understanding of energy conversion.

Moreover, we analyzed the change in students' declarative/procedural knowledge and compared it between the two groups; comparison and experimental, - based on the pre-post-test scores. For this purpose, we compared the two group's prior and posterior knowledge of energy conversion. In addition, we analyzed and compared the two groups' open-ended answers.

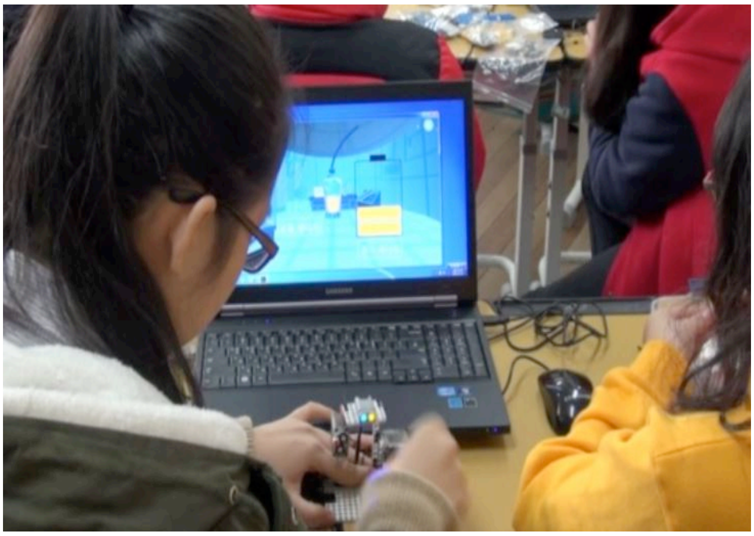

Figure 3. Two students assemble a teaching aid robot to learn about energy conversion

Comparison of prior knowledge of energy conversion between the experimental and comparison class

As seen in Table 4, the analysis showed the comparison class had more declarative knowledge than the experimental class (t = -3.18, p < .01).

Table 4.
Comparison of Prior Knowledge of Energy Conversion between the Two Classes

	N	Mean	SD	t	p
Experimental class	25	8.96	4.937	-3.18	.003
Comparison class	25	12.80	3.464		

Comparison of posterior knowledge of energy conversion between the experimental and comparison class

The items on the pre and post-test were different, and prior knowledge also differed between the two groups. Considering these two differences, we divided the students in both classes into three groups (upper 16 students, middle 13 students, lower 21 students) based on their pre-test score and analyzed the change in each group's knowledge of energy conversion. The experimental class was divided into groups of 5, 4, and 16 students, and the comparison class into groups of 11, 9, and 5 students. The experimental class showed a high ratio of lower level students compared to the comparison class. By comparing the students' posterior knowledge of energy conversion in the experimental and comparison class, we found the following results. As Figure 4 shows, (1) the mean scores of the three groups in the experimental class were higher than those of the three groups in the comparison class, (2) the difference between the upper (also lower) group's mean score is particularly large between the two classes, and (3) the lower group in the experimental class had a higher mean score on the open-ended question than the middle group in the comparison class.

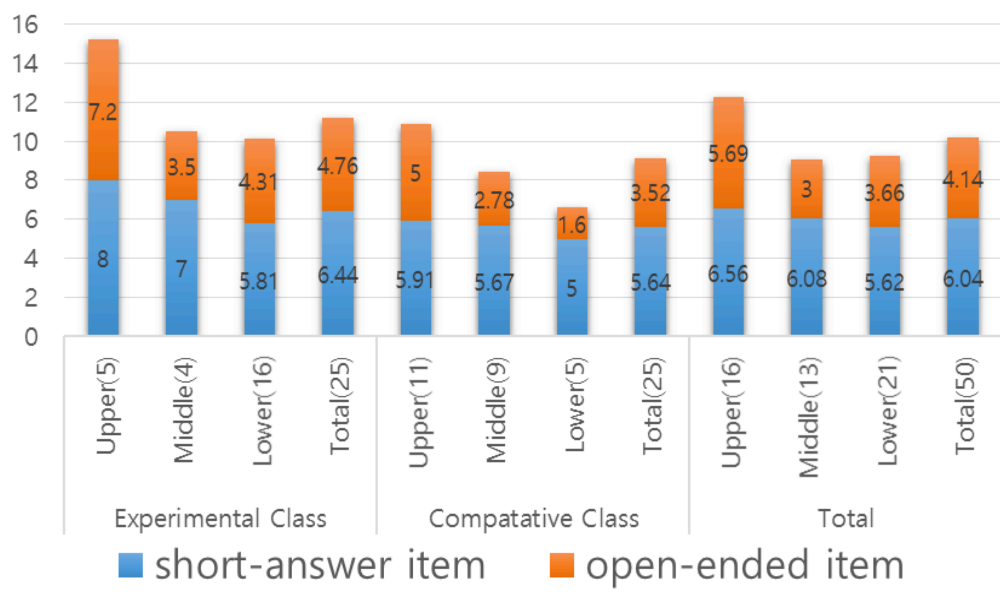

Figure 4. Post-test mean scores of the three groups * two classes

Table 5.
Descriptive Statistics of the Post-Test Scores of the Two Classes

Answer type	Class		Mean	SD	N
Post-test Short-answer (8)	Experimental	Upper	8.00	0.000	5
		Middle	7.00	1.414	4
		Lower	5.81	2.007	16
		Total	**6.44**	1.895	25
	Comparison	Upper	5.91	1.514	11
		Middle	5.67	1.414	9
		Lower	5.00	.707	5
		Total	**5.64**	1.350	25
Post-test Open-ended (12)	Experimental	Upper	7.20	2.168	5
		Middle	3.50	4.509	4
		Lower	**4.31**	**3.737**	16
		Total	4.76	3.700	25
	Comparison	Upper	5.00	2.898	11
		Middle	2.78	1.856	9
		Lower	**1.60**	**2.510**	5
		Total	3.52	2.771	25

Table 6.
Comparison of post-test scores between the two classes

Source		Type 3 III S S	df	Mean square	F	*p*
Model	Short-answer	30.573	5	6.115	2.506	.044
	Open-ended	106.027	5	21.205	2.190	.072
Intercept	Short-answer	1528.541	1	1528.541	626.530	.000
	Open-ended	650.489	1	650.489	67.188	.000
Class	Short-answer	19.628	1	19.628	8.045	.007
	Open-ended	34.718	1	34.718	3.586	.065
Group (pre-test score)	Short-answer	17.624	2	8.812	3.612	.035
	Open-ended	85.158	2	42.579	4.398	.018
Class×group	Short-answer	2.968	2	1.484	.608	.549
	Open-ended	6.591	2	3.295	.340	.713

Analysis of the difference in post scores of the three groups (upper/middle/lower) and two classes (comparison/experimental) showed the mean score on the short-answer items was higher for the experimental class than for the comparison class ($F = 8.045$, $p < .01$). Also, the post-test scores (for both short-answer and open-ended items) differed from the pre-test scores for all three groups (short-answer: $F = 3.612$, $p < .05$; open-ended: $F = 4.398$, $p < .05$)(Table 6). Moreover, given that the two classes were divided into three groups (upper, middle, lower) according to the pre-test scores, we analyzed the difference in the scores of these two items types in each of the three groups. The upper group's open-ended score ($m = 5.69$) on the post-test was higher than the middle group's open-ended score ($m = 3.00$) at a statistically significant level ($p < .05$). However, no significant difference was found between the three groups' short-answer scores.

These results suggest that (1) the teaching aid robot is effective at helping students acquire declarative knowledge (short-answer items) and procedural knowledge (open-ended items) and (2) acquiring declarative knowledge could play an important role in achieving procedural knowledge.

Comparison of patterns of post-test answers between the two classes (comparison/experimental)
We carried out non-parametric verification of the pattern of responses to the open-ended questions for the two classes to investigate the characteristics of students' acquisition of gradual knowledge in the class using robots. The results showed a significant difference in the type of answers given to the open-ended questions between the two classes only for Item 3 (not in Item 1 or 2). Given this result, it could be said that specifying the energy name or situation influenced the students' writing about energy conversion. Item 1 was to explain energy conversion from potential energy to sound energy. Item 2 was based on the example of an aerogenerator. However, Item 3 was to explain energy conversion in daily life.

Table 7.
Non-parametric verification of the number (%) of students by answer type for post-test item 3 and class

	No answer	Inappropriate example or explanation	Listing words	Short/insufficient explanation	No mistakes	χ^2 (p)
Experimental Class	4 (16%)	5 (**20%)**	5 (20%)	1 (4%)	10 (**40**%)	
Comparison Class	9 (**36%)**	0 (0%)	9 (36%)	3 (**12%)**	4 (16%)	11.64 (0.02)
Total	13 (26%)	5 (10%)	14 (28%)	4 (8%)	14 (28%)	

Through non-parametric verification, we found that the students in the comparison class gave no answers, provided only a short explanation, or listed words more often than the students in the experimental class. However, the students in the experimental class wrote more inappropriate examples or explanations in addition to giving more appropriate examples or explanations (no mistakes) than their counterparts in the comparison class (Table 7). They were not able to organize their declarative knowledge sufficiently or explain it well, even though they had more declarative knowledge of energy conversion than the students in the comparison class (Table 5). Regarding this contradiction, it could be said that the students in the experimental class were enthusiastic in their writing about energy conversion but needed help in guiding their thoughts. In addition, the use of more than half of the lesson time for assembling the robot was an important reason for the contradiction.

Assembling and operating the robot kit with classmates for knowledge acquisition is an opportunity to learn through authentic practice. However, using more than half of the lesson time could be seen as an overambitious task for teachers. It is difficult for teachers to explain the knowledge about energy conversion as well as maintain classroom management throughout the process. There is already a lot of existing content to cover in the national curriculum. These research results show that the students who engaged in authentic practice wrote more inappropriate examples or explanations than others without practice. Therefore applying authentic practice in one class over 20 minutes must be considered but may be more appropriate for lessons that require a long time period than a single 40 minute class. Considering we concentrate our study on knowledge acquisition in one 40 minute class, a limitation to the study was not being able to investigate the students' knowledge acquisition over a longer time period.

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