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메타 분석을 이용한 로봇교육과 프로그래밍교육의 효과 비교

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요 약

로봇교육과 프로그래밍교육이 학습자들에게 미치는 긍정적인 효과는 거의 동일하지만, 로봇교육은 프로그래밍교육에 비하여 로봇구입이라는 경제적 비용과 학습자의 인지적 부담을 증가시키는 로봇 제작 과정이 포함되기도 하는 차이점이 있다. 이러한 차이점으로 인하여 모든 학교급 또는 모든 학습 목표에 대하여 프로그래밍교육이 동일한 효과를 갖지 않을 수도 있을 것이다. 이러한 가정을 확인하기 위하여 본 연구에서는 국내에서 발표된 로봇교육의 효과에 대한 논문을 메타분석하여 효과크기를 산출하고 프로그래밍교육의 효과크기와 비교한다. 비교 결과를 바탕으로 로봇교육의 방향을 제시하고자 한다. 로봇교육과 프로그래밍교육의 평균 효과크기는 각각 0.6664과 0.4060로 유의미한 차이를 보였다. 초등학생의 경우 평균 효과크기가 로봇교육은 0.373, 프로그래밍교육은 0.667로 유의미한 차이를 보였다. 중학생이 로봇교육과 프로그래밍교육 모두에서 가장 큰 효과를 보였으며, 학교급이 높아질수록 프로그래밍교육에 비하여 로봇교육의 효과가 커짐을 알 수 있었다. 목적별 분석 결과 프로그래밍교육은 모든 영역에 고르게 중간의 효과를 보인 반면 로봇교육은 인지적 영역보다 정의적 영역에 더 큰 효과가 있었다. 교육방법별로 분석한 결과 로봇제작의 효과크기는 1.3294로 높은 효과를 보이며, 로봇제작과 프로그래밍, 로봇프로그래밍, 로봇활용의 순으로 중간의 효과를 보였다. 본 연구의 결과에 따라, 프로그래밍교육이 로봇교육에 비하여 전반적으로 효과가 크고, 로봇교육은 중학생 이상의 대상에 대하여 프로그래밍 교육보다 효과가 크며, 로봇교육은 정의적 영역의 향상에 효과가 있다. 또한 로봇교육은 단순 로봇활용보다는 로봇제작, 로봇프로그래밍을 포함하여, 다양한 주제에 적용할 때 더 큰 효과가 있음을 알 수 있다.

키워드 : 메타분석, 효과크기, 로봇교육, 프로그래밍교육, 교육용 프로그래밍언어

Comparison of the Effects of Robotics Education to Programming Education Using Meta-Analysis

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ABSTRACT

The positive impacts of robotics education and programming education on learners are similar. However, robotics education differs from programming education because it includes purchasing and building robots that cause financial and cognitive load of learners. Due to these differences, two kinds of education may not possess equal efficacies for all schools or all learning objectives. To verify this hypothesis, we conducted meta-analysis of

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studies on robotics education published in South Korea to estimate the effect sizes and compare it to that of programming education. The difference between the average effect sizes of robotics education and of programming education was significant, as the former was 0.4060 and the latter 0.6664. The average effect size of programming education was significantly larger than that of robotics education for primary school students. Middle school students achieved the highest results in both robotics education and programming education. Also, robotics education became more effective than programming education as students were older. Analysis on objectives showed that programming education uniformly affected all areas, whereas robotics education had more impact on affective domain than cognitive domain. Robot construction had the largest effect size, followed by robot construction and programming, robot programming, and robot utilization. Programming education has larger positive impacts on students overall compared to robotics education. Robotics education is more effective to upperclassmen than programming education, and improves affective domain of students. Also, robotics education shows higher efficacy when combined with various subjects.

Keywords : Meta-analysis, Effect Size, Robotics Education, Programming Education, Educational Programming Languages

1. Introduction

Wing redefined “computational thinking”, a word she defined in 2006, as “the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can effectively be carried out by an information-processing agent” in 2011[18]. Computational thinking is closely related to essential skills in knowledge-based society of 21st century such as critical thinking, problem solving, communication, and collaboration[1]. Robotics education and programming education are suitable tools in improving computational thinking[6][7][12]. Robotics education is effective for all ages in subjects such as mathematics, science and arts, and it is a suitable education for improving a higher-level thinking ability[2][4][14][15]. Many researchers have reported positive effects of robotics education in betterments of affective domains including achievements in particular subjects, creativity, problem solving and thinking ability. Furthermore, it is reported that robotics education is also effective in improving students’ cognitive domains like attitudes, flow, and self-efficacy. However, some critics point out that robotics education may stay only as a vogue if researchers fail to provide evidence and theories that robots have direct influences on students’ academic achievements[3][17].

There are some researches about the effects of robotics education including C. Kim’s study on the effects of robotics education in regular courses for primary and middle schools and what should be considered for robotics education[10]. As for meta-analytic researches on robotics education, there are Benitti’s research on the educational potentials of robots in schools[3], and study of Kim et al. on robotics learning targeting pre-K[11]. However, these studies are restricted to understanding current standings of robotics education or evaluating the effects of robotics education in limited areas.

The positive impacts of robotics education and programming education on learners are quite similar. However, robotics education differs from programming education because it includes actual building of robots. Some knowledge in engineering is either required beforehand or is acquired while building robots. Such knowledge can present cognitive burdens for learners. When all these factors are considered, it is possible that robotics education and programming education may not have identical effects for all schools or all learning objectives. To confirm the hypothesis, this paper estimates the effect size of robotics education by conducting meta-analysis on the studies that argue positive impacts of robotics education in South Korea. The average effect size of robotics programming is compared with that of programming education that uses educational programming languages. The aim of this paper is to provide directions for robotics education through the comparison.

We have limitations that the only two variables such as school levels and learning objectives were considered. Therefore additional studies are required to analyze the effects of robotics education and programming education based on the various factors such as learning methods.

2. Research Method

2.1 Meta-Analysis

Meta-analysis is an analysis the statistical analysis of a collection of results from multiple independent studies for the purpose of integrating the findings and providing a general conclusion[5].

Meta-analysis is conducted through following steps:

1) Formulating problem
2) Search and selection of data
3) Coding the variables of data
4) Conducting meta-analysis
5) Providing results of meta-analysis

2.2 Data Collection and Selection

To collect papers related to programming education published in South Korea, we searched online database provided by RISS. Keywords used to collect papers regarding robotics education are ‘robot learning’ and ‘robot education’ in both Korean and English. For programming education-related papers, we used ‘dolittle programming’, ‘logo programming’, ‘squeak programming’, ‘scratch programming’ and ‘alice programming’ in both Korean and English as keywords.

After excluding identical papers, papers published in journals that overlap with theses, and papers not published in KCI journals, we have selected 66 papers and 129 study results on robotics education and 64 papers and 100 study results on programming education. They offer pre-test score and post-test score of a group or post-test scores of two independent groups.

2.3 Data Analysis

To conduct meta-analysis, we set variables as in <Table 1>, <Table 2> shows the number of papers by published years, and <Table 3> is the number of papers by objectives.

<Table 1> Variables for Meta-Analysis

Dependent Variables	The Effect of Robotics Education and Programming Education
Moderator Variables	-School Level(Primary School, Middle School, High School, College) -Learning Method of Robotics Education (Construction, Constr.+Programming, Programming, Utilization)
Dependent Variables	-Cognitive Effects (Creativity, Academic Achievement, Problem Solving Ability, Thinking Ability) -Affective Domains (Flow, Interest, Self-Efficacy, Motivation, Attitude)

<Table 2> No. of Studies by Pub. Years

	PE	*RE*	Total
1994	1	0	1
1997	2	0	2
2004	0	5	5
2006	2	2	4

2007	1	2	3
2008	19	15	34
2009	13	23	36
2010	27	24	51
2011	10	20	30
2012	13	22	35
2013	7	14	21
2014	5	2	7
Total	100	129	229

<Table 3> No. of Studies by Objectives

		PE	*RE*	Total
Cognitive Effects	Problem Solving Ability	20	11	31
	Thinking Ability	31	5	36
	Academic Achievement	14	29	43
	Creativity	5	34	39
Affective Effects	Attitude	12	24	36
	Self-Efficacy	9	5	14
	Flow	4	6	10
	Motivation	5	7	12
	Sociality	0	8	8
Total		100	129	229

Meta-analysis was done in following order using statistical software R's meta package.

1) Calculate the effect size of each study based on Cohen's index d[13].

2) Detect publication bias[16] using funnel plot, and adjust bias by adding missing studies with Trim and Fill method.

3) Measure heterogeneity using Higgins's index I^2[9].

4) Depending on I^2, calculate the average effect size through either using a fixed effect model[8], or using a random effect model[9].

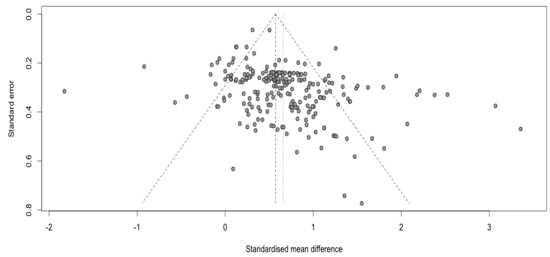
3. Results

3.1 Average Effect Sizes of Robotics Education and Programming Education

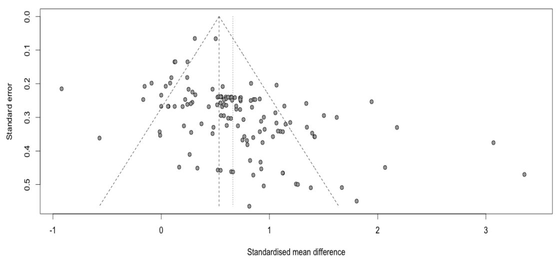
<Table 4> shows the average effect size $\overline{ES}$ and the I^2 of robotics education(RE) and programming education(PE). $\overline{ES}$ is calculated through random effect model since I^2 is larger than 50 in both cases.

<Table 4> Average Effect Sizes of Robotics Education and Programming Education

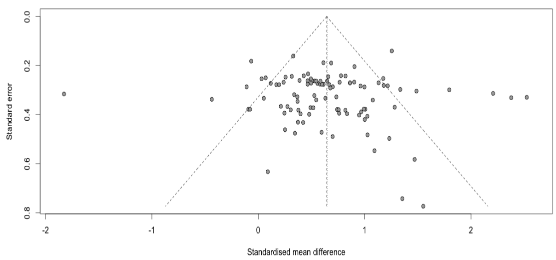
	N	$\overline{ES}$	I^2
RE	129	.6621	72.7
PE	100	.6510	69.3
Overall	229	.6585	71.5



(Fig. 1) Funnel Plot of Robotics Education and Programming Education



(Fig. 2) Funnel Plot of Robotics Education



(Fig. 3) Funnel Plot of Programming Education

(Fig.1), (Fig.2) and (Fig.3) are funnel plots used to detect publication bias in studies analyzed. Because the funnel plots of overall results of studies and those of robotics education are asymmetrical, there are publication biases.

<Table 5> shows the $\overline{ES}$ and I^2 after adding missing studies through Trim and Fill method. Since I^2 is calculated to be 80.7 after adding 69 studies, $\overline{ES}$ computed through random effect model becomes 0.4112, and the range of value in the confidence level of 95% is [0.3374; 0.485]. I^2 of robotics education becomes 80.9 as 41 studies have been added. New $\overline{ES}$ of robotics education using random effect model is 0.4031, and the range of value in the confidence level of 95% is [0.3095; 0.4968].

<Table 5> Summary of Average Effect Sizes after Trim and Fill is Applied(Added Studies)

	N	$\overline{ES}$	CI(95%)	I^2
RE	171 (42)	.4031	[0.3095; 0.4968]	80.9
PE	100 (0)	.6510	[0.5431; 0.7589]	69.3
Overall	298 (69)	.4112	[0.3374; 0.485]	80.7

<Table 6> The Result of t-test for Robotics and Programming Education(**<.005)

	N	M	SD	t	p
RE	129	.4060	.7884	3.156	.001786**
PE	100	.6664	.5629		

From the result of t-test, it is evident that $\overline{ES}$ of programming education is significantly larger than $\overline{ES}$ of robotics education($t=3.1564$, $p=0.001786$).

3.2 Average Effect Size of School Levels

<Table 7>, <Table 8> and (Fig. 4) show results of comparing $\overline{ES}$ of robotics education and programming education of school level.

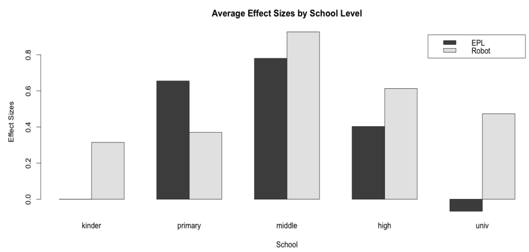
$\overline{ES}$ of robotics education targeting kindergarteners is 0.3149, it means a small effect according to Cohen's standard. This result is different from average effect size of 0.639 calculated with 39 studies reported in the research of Kim et al.[11]. We conjecture this difference comes from the publication bias we considered beforehand that [11] did not consider.

$\overline{ES}$ of robotics education targeting primary school students is 0.3707 and $\overline{ES}$ of programming education is 0.6553. The difference between two $\overline{ES}$ through t-test is that $p=0.0074$, a significant difference in the range of confidence level of 95%. Such result shows that programming education is more effective than robotics education for primary school students. For middle school students, $\overline{ES}$ of robotics education and programming education are 0.970 and 0.778, respectively. It means the effects of robotics education and programming education targeting middle school students are large. For high school students, robotics education and programming education both have medium effect with 0.623 and 0.415 respectively.

<Table 7> Average Effect Sizes of School Level

		N	$\overline{ES}$	CI(95%)	I^2
Kinder garden	RE	34 (9)	.3149	[0.0395; 0.5903]	80.7
	PE	0	-	-	-
Primary School	RE	95 (22)	.3707	[0.2564; 0.485]	80.7
	PE	73	.6553	[0.5232; 0.7874]	72.5
Middle School	RE	11	.9270	[0.5746; 1.2793]	72.7
	PE	20	.7804	[0.5914; 0.9693]	31.1
High School	RE	17 (3)	.6134	[0.3538; 0.873]	66.0
	PE	6	.4027	[0.1664; 0.6391]	28.9
College	RE	8 (2)	.7458	[0.4738; 1.0179]	46.4
	PE	1	-.066	[-0.4234; 0.2907]	-

Programming education is significantly more effective than robotics education for primary school students. For middle school and high school students, although $\overline{ES}$ of robotics education is larger than $\overline{ES}$ of programming education, there is no significant difference between the two. Therefore, it can be conjectured that robotics education gets more effective than programming education as school level gets higher.



(Fig. 4) Average Effect Size of School Level

<Table 8> Average Effect Sizes of School Level

		N	*M*	*SD*	*t*	*p*
Primary School	*RE*	95	.373	.797	-2.71	0.0074*
	PE	73	.667	.604	-	-
Middle School	*RE*	11	.970	.613	0.926	0.3686
	PE	20	.778	.427	[0.5232; 0.7874]	72.5
High School	*RE*	17	.623	.713	0.975	0.3412
	PE	6	.415	.310	[0.5914; 0.9693]	31.1

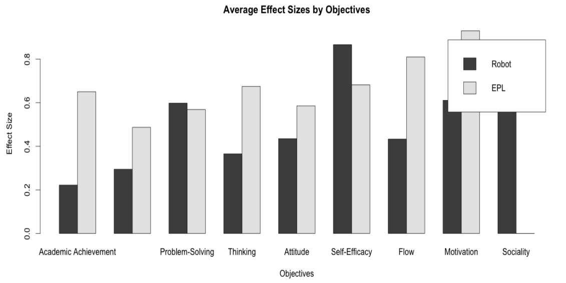
3.3 Average Effect Size of Objectives

<Table 9> and (Fig. 5) shows the difference between the effects of both robotics education and programming education for each learning objective. Robotics education has small effect on academic achievements and creativity, has medium effect on problem solving ability, thinking ability, attitude, flow, motivation and sociality, and has large effect on improving self-efficacy. Programming education has large effect on motivation and flow, and medium effect on the rest of areas. Programming education has better overall impact on all areas, whereas robotics education is more effective in improving affective domains including self-efficacy rather than cognitive domains such as creativity and academic achievements.

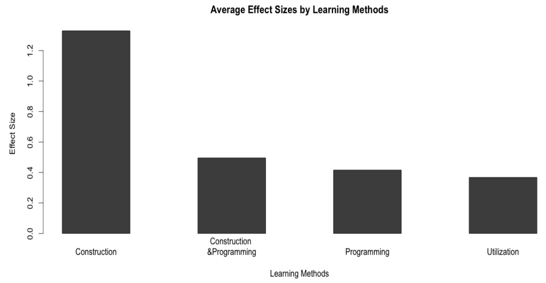
As it can be seen in <Table 10>, although there is no meaningful statistical difference in positive impacts of both educations, $\overline{ES}$ of robotics education for all categories except for self-efficacy are smaller than $\overline{ES}$ of programming education.

<Table 9> Average Effect Sizes of Objectives

		N	$\overline{ES}$	*CI*(95%)	I^2
Academic Achievement	*RE*	27 (8)	.2218	[-0.1205; 0.5642]	89.5
	PE	14	.6505	[0.4101; 0.8909]	69.6
Creativity	*RE*	45 (11)	.2947	[0.1321; 0.4573]	73.0
	PE	5	.4871	[-0.2627; 1.2369]	85.6
Problem Solving Ability	*RE*	15 (4)	.5979	[0.4396; 0.7562]	2.2
	PE	20	.5689	[0.2724; 0.8654]	75.7
Thinking Ability	*RE*	7 (2)	.3652	[0.1094; 0.621]	34.4
	PE	31	.6750	[0.4909; 0.8590]	62.8
Attitude	*RE*	36 (12)	.4350	[0.1963; 0.6737]	89.3
	PE	12	.5856	[0.2172; 0.9540]	75.0
Self-Efficacy	*RE*	5 (0)	.8664	[0.5936; 1.1391]	0.0
	PE	9	.6820	[0.4285; 0.9355]	35.2
Flow	*RE*	9 (3)	.4332	[0.1502; 0.7162]	75.8
	PE	4	.8099	[0.5344; 1.0853]	0
Motivation	*RE*	7 (0)	.6112	[0.2328; 0.9895]	6
	PE	5	.9300	[0.3129; 1.5472]	83.8
Sociality	*RE*	8(0)	.7824	[0.3436; 1.2212]	70.0
	PE	0	-	-	-



(Fig. 5) Average Effect Sizes of Objectives



<Fig. 6> Average Effect Size of Learning Methods

<Table 10> The results of t-test of Average Effect Sizes of Objectives

		N	M	SD	t	p
Academic Achievement	RE	27	0.226	1.035	-1.6845	.1004
	PE	14	0.611	0.418		
Creativity	RE	45	0.294	0.683	-0.4905	.646
	PE	5	0.480	0.814		
Problem Solving Ability	RE	15	0.603	0.491	-0.0429	.3412
	PE	20	0.611	0.694		
Thinking Ability	RE	7	0.372	0.404	-1.8637	.0904
	PE	31	0.702	0.498		
Attitude	RE	36	0.436	1.028	-0.5824	.5648
	PE	12	0.586	0.669		
Self-Efficacy	RE	5	0.894	0.284	0.7936	.4434
	PE	9	0.741	0.440		
Flow	RE	9	0.443	0.635	-1.4931	.1635
	PE	4	0.816	0.265		
Motivation	RE	7	0.655	0.702	-0.6716	.52
	PE	5	0.943	0.753		

3.4 Average Effect Sizes of Learning Methods

<Table 11> Average Effect Sizes of Learning Methods

	N	$\overline{ES}$	CI(95%)	I^2
Construction	4 (0)	1.3294	[0.6539; 2.0049]	79.7
Construction & Programming	43 (8)	.4954	[0.3169; 0.674]	69.1
Programming	57 (14)	.4158	[0.284; 0.5475]	72.2
Utilization	61 (14)	.3675	[0.2017; 0.5332]	86.2

<Table 11> and (Fig.6) show $\overline{ES}$ of robotics education for each learning method. Robot construction has very large effect of 1.3294, and the effectiveness of robotics education dwindles in the order of robot construction and programming, robot programming, and robot utilization respectively. From this result, it can be seen that robotics education becomes more effective when it combines various subjects with robot construction and programming.

4. Conclusion

This research analyzed the differences in effect sizes for both programming education and robotics education in terms of school levels, ways of robotics education, and purposes through meta-analysis of 66 papers and 129 studies on robotics education and 64 papers and 100 studies on programming education. Publication bias have been corrected through Trim and Fill methods, and the average effect size has been calculated using random effect model.

The average effect size of programming education is 0.6664 and the average effect size of robotics education is 0.4060. The two average effect sizes show a statistically significant difference($t=3.156$, $p=0.001786$ in the confidence level of 99%).

For primary school students, the average effect size of robotics education is 0.373 and the average effect size of programming education is 0.667. The result of t-test shows that robotics education and programming education have a significant difference with $t=-2.71$, $p=0.0074$ in the confidence level of 95%. Middle school students have the largest effect with both robotics education and programming education. The effectiveness of robotics education gets higher than that of programming education, as school level gets higher.

In analyzing the average effect size of each education in terms of objectives, robotics education has small effect on academic achievements and creativity, has medium effect on problem solving ability, thinking ability, attitude, flow, motivation and sociality, and has large effect on improving self-efficacy. Programming education has large effect on motivation and flow, and medium effect on the rest of areas. Programming education has better overall impact on all areas, whereas robotics education is more effective in improving affective domains including self-efficacy rather than cognitive domains such as creativity and academic achievements.

The average effect size of robot construction is 1.3294, and the effectiveness of robotics education gets higher in the order of robot utilization, robot programming, robot construction and programming, and robot construction.

These results show that programming education is generally more effective than robotics education. Robotics education is effective for students including and older than middle school students and effective in improving affective domain such as self-efficacy and motivation in learning. Furthermore, robotics education becomes more effective when it combines various subjects with robot construction and programming.

We have limitations that the only two variables such as school levels and learning objectives were considered. Therefore additional studies are required to analyze the effects of robotics education and programming education based on the various factors such as learning methods.

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