A Meta-Analysis Study on The Effect of Software Education on Computational Thinking

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Abstract

The main purpose of this study is to determine the effect of software education on elementary students' computational thinking. In this study, the meta-analysis method was employed which examined 24 studies conducted by year 2020 and have met the inclusion criteria. The types of software, group age, group size, and number of treatments were determined as moderating variables. An analysis based on a random effect model showed that the mean effect size value was calculated as 0.606 with an error of 0.08. It was also determined that there was no publication bias in the meta-analysis. According to the results of the moderator analysis, it was found that the effect of software on computational thinking of the students did not change according to the types of software education and group age, but it changed according to the group size and the number of software educational treatments. The effect size on computational thinking was high in small group (less than 6 students) and large group (more than 31 students who encouraged peer study). In addition, the number of treatments was 21 or more, the effect size was the highest.

Keywords: Computational Thinking(CT), Software(SW), Meta-Analysis, Elementary Students

1. Introduction

Humanity has entered the era of the Fourth Industrial Revolution, where convergence of SW education technology is emphasized along with high-speed networks. The era of the fourth industrial revolution is a SW-centered society, and it has become very important to nurture talented people with SW capabilities who can lead the nation's growth more innovative in order to enhance the nation's competitiveness[1].

The Korean government announced 'Software-Centered Society Realization Strategy' in 2014, and the Ministry of Education proposed 'Plan to Revitalize Elementary and Secondary Software Education'[1]. Accordingly, SW education began for middle school students in 2018, and SW

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education is being implemented for fifth and sixth graders in elementary school from 2019.

The purpose of SW education in schools is to improve students' CT ability to solve problems. CT is an important capacity that everyone living in the 21st century should have, and is the cognitive ability required to solve complex and diverse problems in real life in an efficient and systematic way[2]. In other words, CT is the ability to think like the way a computer system processes information, and it can be applied to various fields such as humanities and society, not only to computer-related fields[3-8].

In Korea, studies on effective CT improvement for elementary school students are being carried out very actively through SW education activities. Several studies have shown that SW education has a positive influence on improving CT in elementary school students[9-12]. However, the generalized conclusion of SW educational activities on CT improvement cannot be reached. Therefore, in order to more objectively measure the CT improvement effect of SW education, meta-analysis research is needed to analyze the results of each study in an integrated manner.

Meta-analysis is an analysis method that collects quantitative studies in areas of interest and converts them into the same measurement through statistical methods[13]. In addition, meta-analysis can generalize the effect of moderators, including various research conditions conducted in each study[14]. Thus, the generalized analysis results derived through meta-analysis can propose more practical applications to the educational site.

This study aimed to provide information on the direction and operation methods for SW education activities for effective CT improvement. For this purpose, the following research questions were established

Research question 1. What is the effect of SW education on CT?

Research question 2. What is the effect of SW education on CT in terms of the following: types of SW, group age, group size, and the number of treatments.

2. Theoretical Background

2.1 Educational Programming Language(EPL)

Educational Programming Languages(EPL) are classified as block-based programming language(Scratch, Entry, App inventor, etc.), physical computing(Arduino, BitBrick, FunBoard, etc.), and text-based programming language(Python, Dolittle, etc.). This chapter focuses on the

block-based and physical computing-based suitable for elementary school students' learning of improving CT, and the unplugged learning method[15].

2.1.1 Block-based Programming Language

Block-based programming language refers to a language in which individual functions are represented by icons in the form of blocks, and programmed, such as building towers by dragging and dropping blocks. Block-based language is a suitable programming language for programmers, and elementary and middle school students because it is easier to visually simplify, structure, and utilize the structure or contents of a program when written in text-based language. Scratch can be programmed by dragging and dropping blocks, and provides 10 types of block categories of 'action, form, sound, pen, data, event, control, observation, computation, additional block'. Each block category has several blocks, and because each category has a different color, the color of the block alone can tell which category it belongs to[16]. Entry is an educational programming language developed so that anyone can receive free software education. Instead of using difficult command symbols or grammatical forms to program, it is an educational platform that can easily create works such as games, animations, and media art by imaging commands in blocks that are easy to manipulate, connecting and assembling them in order[17]. Entry was created by Korean companies, so Korean is fully supported and can be easily used in schools. App Inventor (for Android) was developed by Google in the U.S. in 2010, making it easy for anyone to create smart phone applications by making it easier to express and implement ideas without knowing the program development language. App Inventors have all the advantages of block editors, such as scratches, which are commonly used as educational programming languages, and have the advantage of being able to use devices such as Bluetooth, GPS, camera, memory, and audio systems on a single smart-phone[18].

2.1.2 Physical Computing-based

Physical computing began with Professor Dan O'Sullivan and Professor Tom Igoe teaching interactive physical systems at NYU. They describe physical computing as "making the physical real world and the virtual world of computers connect with each other." In other words, the real world's phenomena are detected through sensors or devices, and physical devices are controlled through computers using detected values. Physical computing tools can be divided into robot, modular, and board types depending on their shape[15].

Through physical computing, students understand that information in the real world can be

connected to a computer system through various sensors, and thus experience a series of processes to create a system in which monitors, LEDs, and other operable devices respond. In addition, existing standardized interfaces such as a mouse, keyboard, monitor, and speaker will be expanded so that computers can be understood and used in material ways using the five senses of the real world.

2.2 Unplugged

The Unplugged learning method was introduced as a new educational method for Bell and Fellows (2006) in New Zealand to learn the principles of computer science by learning the principles of computer operation and creative ideas through specific manipulation activities. Unplugged, meaning that it is not connected to a computer, is intended to guide computer science without using a computer. Unplugged learning has features that enable learners to fully understand logical thinking and practical activities without the functional aspects of conventional computer use and complex programming learning[19]. Therefore, unplugged learning uses various forms of activities such as board games and worksheets to educate users.

3. Methods

3.1 Search Strategy

In this study, among the degree papers and articles published in Korea by 2020, a paper that examines the effects of SW education on improving CT was selected as the subject of analysis. Using the Korean Research Information Sharing Service(RISS), National Assembly Library, and DB-PIA, 'Elementary School & SW' and 'Elementary School & CT' were used as key words to search and collect the papers to be analyzed. As a result, a total of 225 studies (150 degree papers, 75 articles) were searched.

3.2 Study Selection

The criteria used in the selection of the studies included in the research are as follows: (1) Appropriate research method in the studies - In order to obtain the effect size in the meta-analysis studies, the included studies had experimental-control group, the dependent variable was able to measure the computational thinking, and the independent variable was the use of software in education. (2) Contain numerical data - In order to calculate the effect size

required in the meta-analysis, the descriptive statistics (sample size, average, standard deviation, student age, number of treatments) in the experimental and control groups were included.

The studies excluded from the meta-analysis study were those whose subjects are elementary school teachers or disabled students and not the elementary school students. In addition, the studies of the same authors and data comprised both an article and a thesis were excluded in this meta-analysis. As a result, a total of 201 studies were excluded, and a total of 24 studies(14 degree papers, 10 articles) were finally selected and used for analysis.

3.3 Data Coding

Studies were reviewed and cross checked independently by two authors. Percentage agreement between and authors on the quality review ranged between 95% to 100%. Any disagreements were resolved by consensus of all authors. Data on the following characteristics were independently extracted : year of publication, author name, types of SW, sample size, sample age, the number of treatments, pre-test Mean, pre-test standard deviation, post-test Mean, post-test standard deviation and so on. The aforementioned data were collected and analyzed for quality and cross-checked.

3.4 Variables

The moderators of the research are the independent variable which have effect on the observed effect size. The moderators of this research are determined as follows : (1) Types of SW(EPL, Physical, Unplugged, EPL+Physical, Unplugged+EPL/Physical, (2) Group Age(3rd, 4th, 5th, 6th Grade, Mixed Age), (3) Group Size(0~6, 7~11, 12~20, 21~30, over 31 students), (4) The Number of Treatments(0~10, 11~20, over 21 times).

3.5 Procedure and Data Analysis

The data obtained during the data collection stage were coded and processed into a Microsoft Excel document. And Comprehensive Meta-Analysis 2.0(CMA) software was used for data analysis and the effect sizes, heterogeneity test and publication bias calculations were performed through these programs.

Details are as follows. First, if all studies of the same subject do not use the same scale, then a standardization process is required to aggregate the results of the study, which is

referred to as effect size in meta-analysis. Common types of effect sizes used include the standardized mean difference (Cohen's d Hedges' g), the ratio of two groups (Risk ratio, Odds ratio, Risk difference), and the correlation between two variables (Fisher's z). This study was analyzed using the standardized mean difference of Hedges' g and Cohen's d used to correct the small sample because it tends to overestimate its effect size[20].

Second, meta-analysis shows different effect sizes derived from each individual study, and this difference between effect sizes is referred to as heterogeneity of effect size[20]. This study calculated the ratio of the actual variance I^2 to the total variance, indicating the degree of heterogeneity of the effect size, and also the Q value used for the test of homogeneity of the effect size. If I^2 is 50% or more and the significant probability of homogeneity verification is less than .10, the effect size is judged to be significant[21]. In this study, meta-ANOVA was performed using adjustment variables for further explanation due to the considerable heterogeneity of effect size. In meta-analysis, an adjustment variable means a variable in the level of study[22].

Third, the Funnel Plot method was used to solve publishing errors and correct them when they occurred. Publication bias occurs when the results of published studies do not represent the results of all studies performed, but only positive findings are reported by researchers without reporting negative findings.

4. Results

The results of calculating the overall effect size of 24 studies (44 effect sizes) selected in this study are shown in Table 1. Prior to the analysis of the overall mean effect size, one model was selected between the fixed effect model and the random effect model. Since the I^2 value is 76.014%, and the significance probability is less than .10, the heterogeneity of the population effect size is very high. In addition, the homogeneity verification at the significant level of .05 indicates that the $Q=179.269$ ($df=43$, $p=.000$), the $Q-df > 0$, so the Random effect model can be selected. In this study, the researchers selected a random effect model and looked at the effect size. An analysis based on a random effect model showed that the mean effect size (Hedges' g) value was calculated as $g=0.606$ with 0.08 standard error. The lower limit of the 95% confidence interval was 0.45 and the upper limit was 0.76.

[Table 1] Studies' Overall Effect Sizes, Heterogeneity Distribution Value According to Effects Model, and Confidence Intervals

Model	N	ES(g)	$U^3(\%)$	95% CI		Q	df	p	I ²
				Lower	Upper				
Fixed	44	0.530	70.19	0.458	0.603	179.269	43	0.000	76.014
Random	44	0.606	72.77	0.454	0.758

[Fig. 1] Funnel Plot

The cumulative distribution analysis of the effect size corresponds to 72.77% in the non-redundant percentile(U^3) index. Cohen (1988) can define the effect size as medium when the effect size is between .50 and .80, so the overall effect size for elementary school students' computational thinking ability using SW is medium.

The results of the publication error analysis of 24 studies(44 effect sizes) included in the analysis target were symmetrical as shown in [Fig. 1] and no additional methods were taken to correct the publication error. The funnel plot was first checked to determine whether the overall effect size calculated is due to publication bias. As a result, the funnel plot showed that there is no publication bias in the study with a symmetrical distribution around the overall effect size.

According to Table 2, in terms of types of SW, the homogeneity test value was found as $Q=6.319$. In the table, χ^2 was found as 9.49 and its significance level was found as 95% at 4 degrees of freedom ($\chi^2_{(0.95)}= 9.49$). Since the Q statistical value is found less than the critical value of χ^2 distribution with 4 degrees of freedom, it can be stated that the distribution is homogeneous. When the studies were reviewed according to the types of SW, it was found

that there is no significant difference between the types of SW and computational thinking on students($Q=6.319$, $p>.05$). On the other hand, it can be stated that the overall effect size ($g=0.593$) of the types of SW corresponds to the medium effect size according to Cohen(1988) classification.

[Table 2] The Effect Sizes of Studies on including Moderators in Relation to CT

Moderator	N(%)	ES(g)	U^3 (%)	95% CI		Q	df	p
				Lower	Upper			
Types of SW	Block-based (BB)	15	0.763	77.73	0.499	6.319	4	0.177
	Physical computing(PC)	8	0.397	65.43	0.035			
	Unplugged(UP)	12	0.507	69.39	0.222			
	BB & PC	5	0.929	82.36	0.482			
	UP & BB/PC	4	0.299	61.75	-0.245			
	Overall	44	0.593	72.34	0.347			
Group Age	3rd Grade	1	0.719	76.39	-0.322	3.791	4	0.435
	4th Grade	1	0.534	70.33	-0.521			
	5th Grade	7	0.487	68.69	0.095			
	6th Grade	27	0.584	72.04	0.372			
	Mixed Age	8	0.982	83.70	0.587			
	Overall	44	0.662	74.60	0.398			
Group Size	~6 students	2	1.045	85.20	0.175	9.985	4	0.041
	8~11 students	8	0.204	58.08	-0.158			
	12~20 students	12	0.813	79.19	0.530			
	21~30students	21	0.564	71.36	0.363			
	more than 31 students	1	1.294	90.22	0.356			
	Overall	44	0.657	74.44	0.335			
Number of Treatments	~10 times	18	0.480	68.44	0.253	6.023	2	0.049
	11~20 times	21	0.605	72.74	0.384			
	more than 21 times	5	1.132	87.12	0.664			
	Overall	44	0.678	75.11	0.371			
					0.984			

In terms of group age, the homogeneity test value was found as $Q=3.791$. In the table, χ^2 was found as 9.49 and its significance level was found as 95% at 4 degrees of freedom($\chi^2_{(0.95)}=9.49$). Thus, since the Q statistical value is less than χ^2 , there is homogeneity between the effect sizes. In this case, it can be stated that the effect of computational thinking on students does not change according to group age ($p>.05$). On the other hand, it can be revealed that the overall effect size value is $g=0.662$, and according to Cohen (1988), it is a medium effect size. When it comes to interpreting this finding, it is possible to say that computational thinking has a

positive effect on the learning performance.

In terms of group size, the homogeneity test value was found as $Q=9.985$. In the table, χ^2 was found as 9.49 and its significance level was found as 95% at 4 degrees of freedom ($\chi^2_{(0.95)}=9.49$). Since the Q statistic value is greater than the critical value of χ^2 distribution with 4 degrees of freedom, the distribution is heterogeneous. According to these results, it can be argued that computational thinking ability on students changes in terms of group size because the group size of students positively affects learners' computational thinking and contains significant differences ($p<.05$). In the same table, it is determined that the greatest value of the effect size is in 'more than 31 students(1.294)' and the lowest effect size value is in the '7~11 students(0.204)'. 'Less than 6 students' also showed a large effect size of 1.045.

In terms of the number of treatments, the homogeneity test value was found as $Q=6.023$. In the table, χ^2 was found as 5.99 and its significance level was found as 95% at 2 degrees of freedom ($\chi^2_{(0.95)}=5.99$). Since the Q statistic value is greater than the critical value of χ^2 distribution with 2 degrees of freedom, the distribution is heterogeneous. According to these results, it can be argued that learners' computational thinking changes in terms of the number of treatments because the number of treatments positively affects learners' computational thinking and contains significant differences ($p<.05$). In the same table, it is determined that the greatest value of the effect size is in 'more than 21 treatments(1.132)' while the lowest effect size value is in the 'less than 10 times(0.480)'.

5. Conclusions

The main purpose of this study is to identify the impact of software(SW) education on computational thinking(CT) in elementary school students, and to provide information for SW education activities for effective CT improvement of student. The present meta-analysis, involving 24 studies, found that SW education had a positive effect on Computational thinking ability for Elementary students. The results showed large heterogeneity among the different studies with respect to types of SW, group age, group size, and the number of treatments. The publication bias was not observed among studies. The conclusions obtained from this study are as follows.

First, the overall effect size for elementary school students' computational thinking ability using SW is medium, which means that it is not large but effective. Second, when analyzing the difference in effect size on CT by the types of SW, both EPL and Physical computing were used as SW teaching methods, the influence on the CT of students was the highest($g=.929$).

However, there was no statistically significant effect size differences in students' CT depending on the types of SW($Q=6.319$, $p>.05$). Third, when the difference in effect size on CT by group age was analyzed, the effect was higher when it consisted of mixed age than when it consisted of a single age($g=.982$). However, there was also no statistically significant effect size differences in students' CT depending on the group age($Q=3.791$, $p>.05$). Fourth, there was a statistically significant effect size differences in students' CT depending on the group size($Q=9.985$, $p<.05$). The effect size was the higher in small group(less than 6 students)($g=1.045$) and large group(more than 31 students)($g=1.294$). The high effect results of small groups are similar to those of this study in that other studies[23][24] had a high effect on students when the group size was small. The large group size also had a large effect, and the results would need to be interpreted with a more in-depth analysis based on information such as which teaching methods and teaching environment were provided to students in the relevant study.

Fifth, there was a statistically significant effect size differences in students' CT depending on the number of treatments($Q=6.023$, $p<.05$). The higher the number of treatments, the higher effect on CT than when the number of treatments was less. Similar to the results of this study, prior meta studies[25][26] have also shown that the higher the number of activities provided to students, the higher the effectiveness of the activities. However, in the study[27], the effect increased as the number of activities increased, and the effect decreased when it exceeded a certain level. Therefore, further studies must be conducted on the existence of effective numbers of activities depending on the purpose of the activity.

Based on the results of this study, the effect of current elementary school students' SW education on CT was not very significant in this meta-analysis study. In order to improve the effect of SW education on CT, classes will have to be taught in small groups, and in addition, classes will have to be provided continuously over a long period of time, not in a short period. In the follow-up study, it should be analyzed the impact on CT more accurately by analyzing whether elementary school students have experience in past SW education as a moderating variable. In this study, researchers performed an analysis of CT improvement according to the number of SW education treatments, some of which were conducted in high numbers over a short period of time during the vacation. Therefore, it is necessary to examine whether there is a difference in the impact of the overall education period and number of times per week on CT.

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