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A Study of Development of Algorithm Thinking Evaluation Standards

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Abstract **- As technological advances which has a wide impact on society accelerate digital transformation, computational thinking, utilizing digital technology and solving problems, has become more important. computational thinking is being strengthened worldwide in school as a 21st-century core skill set required for upcoming generations. Algorithmic thinking is a key element in computational thinking and being emphasized in education. In addition, algorithmic thinking that devises logical solutions is the key to problem solving and is the first step and essential element in software implementation that forms a digital society. This study developed evaluation standards for algorithmic thinking skills to provide useful information for education and it was intended to establish an evaluation system to help teaching and learning. Based on literature analysis for the development of evaluation standards, they were composed of three areas and 13 sub-areas of algorithm design, analysis, and expression. A Delphi survey of 10 computer education experts was conducted on evaluation standards, and the final three areas and six sub-areas were confirmed through content validity analysis.**

Index Terms **– Algorithm education, Algorithmic thinking evaluation, Algorithmic thinking skills, Computer science education**

INTRODUCTION

The development of modern digital technology has a wide range of effects on our lives, such as changes in mindset, decision-making, and occupational forms. As digital transformation accelerates, awareness of the importance of improving computational thinking (CT) that understands, utilizes, and solves problems with digital technologies has grown. Computational thinking skills are becoming an essential competency for future generations worldwide in that they are beneficial to daily life, and the importance of computational thinking skills has grown rapidly over the past decade in education [1][2].

The computational thinking first mentioned by Papert were discussed modernly by Wing as a basic tool for understanding and actively participating in the digital society [3]. In this regard, several studies have tried to reveal the elements and scope that make up computational thinking, but one integrated definition has not been achieved.

Instead, a consensus has been reached that computational thinking includes basic computational concepts such as abstraction and algorithms, and performance factors such as problem decomposition and debugging [2].

Among them, algorithmic thinking is a core competency of computational thinking. Wing included algorithmic thinking as a fundamental component of computational thinking [4]. Denning stated that computational thinking already has a long history in computer science and was known as "algorithmic thinking" in the 1950s and 1960s [5]. Selby and Werner et al. also included algorithmic thinking in the components of computational thinking [6][7]. In a digital society, algorithmic thinking is a key competency that can be applied not only in computer science but also in terms of daily life [4].

In addition, algorithms are the first step in implementing software to form a digital society and are an essential element. Algorithms are a set of procedures that abstract and logically describe accurate methods for problem solving. This abstract problem-solving procedure is embodied through an implementation tool called a computer program. Therefore, algorithmic thinking that devises logical solutions is the core of problem solving and is an essential element in software production as it precedes the programming stage [8].

Major countries around the world are strengthening computer science education based on computational thinking for future education. In particular, the algorithm is specified as the content area of the British school curriculum and is included as a content element in the Korean curriculum [9][10]. For education to be well conducted, an evaluation that helps teaching and learning is essential. This is because appropriate evaluation monitors learning progress and provides information for making educational decisions. Good evaluation also helps students become more effective self-directed learners [11].

Despite the need for effective and reliable evaluation tools in practical training operations, sufficient research has not yet been conducted on algorithmic thinking [4].

This study aims to develop algorithmic thinking evaluation standards to provide information related to cultivating algorithmic thinking skills and to prepare an evaluation system that helps teaching and learning.

RELATED WORKS

I. Definition of Algorithmic Thinking

Algorithms are well-defined, ordered, logical problem-solving procedures that can be executed in finite time. Computer algorithms should be available by computers as an accurate way to solve problems. Algorithms allow you to understand and approach the nature of various problems in real life. Through this, problem-solving skills, logic skills, and thinking skills are improved. Therefore, algorithm education is essential to foster creative talent required in the future intelligent information society through the process of solving problems applying the basic principles of computer science [12].

Algorithmic thinking is a key element of CT, the ability to construct algorithms through logical and procedural thinking processes to solve a given problem. Algorithmic thinking is an essential ability applicable to everyday life, not limited to computers, and several scholars stress the importance of practicing algorithmic thinking and developing problem-solving skills from childhood [1].

Algorithmic thinking includes the ability to understand the core of a problem, the ability to solve problems, the ability to explore solutions in terms of accuracy and efficiency, and the ability to clearly present a step-by-step problem-solving process [4]. Regarding algorithm optimization, the problem-solving process may have one or more appropriate approaches. Thus, algorithmic thinking entails the ability to differentiate optimal solutions toward predefined goals among several approaches [1].

II. Previous Works

Since Wing, the importance of CT has been emphasized, and discussions on what CT is and studies on how to measure it have been actively conducted globally. Despite its importance, algorithmic thinking is treated as some areas and elements of CT evaluation, and there is a lack of research covered as an independent evaluation.

Existing studies on evaluating CT and algorithmic thinking in Korea and abroad are as follows.

In the study of Jun, the CT area was extracted based on the ICT literacy test tool of KERIS (Korea Education & Research Information Service) in 2007, and a three-stage test tool was developed to verify validity and reliability. Algorithmic thinking is included as part of the CT evaluation element, which includes the problem-solving process in phase 1, algorithmic thinking in phase 2, and algorithmic understanding and execution in phase 3 [13].

Kim’s study emphasized that algorithm design to understand problems and devise solutions is the core of CT. The study proposed strategies for teaching and evaluating algorithm for elementary school students.

The learning elements of algorithm education were divided into seven stages, and they were shown as 1: algorithm representation, 2: algorithm understanding, 3: algorithm and flow chart, 4: algorithm structure, 5: algorithm result, 6: algorithm modification, and 7: algorithm improvement. The evaluation of the algorithm was divided into four types: selecting algorithms, filling algorithms, modifying algorithms, and predicting algorithms by analyzing 800 missions of "Hour of Code". It is revealed that this process includes evaluations such as understanding algorithms, using functions, understanding the meaning of conditional statements, decomposition, logic, and debugging [14].

In the study of Ahn, he presented 10 evaluation factors classified into three stages of problem-solving based on the detailed components of CT (CSTA & ISTE, Selby & Wallard, CB & NSF). The evaluation of algorithmic thinking is included as an 'algebra and procedure' element in program design, the last of the three stages of problem solving, and consists of evaluation standards for sub-factors: logic, performance efficiency, interaction, and regression [15].

In the study of Park, evaluation elements were defined as three areas for CT measurement and the areas are ‘Computational Materials & Outputs (CMO)’ defined as area underlying CT, ‘Computational Concepts(CC)’ that must be learned to learn or improve CT, and ‘Computational Practices(CT)’, the area of performance and execution processes to learn or improve CT. Each of the three areas represents a core element of CT, a content element for learning, and a performance process. It has a dynamic that is interlocked with each other. Thus, the evaluation of algorithmic thinking takes place across all three areas [16].

In the study of Lee et al., problem decomposition, abstraction, algorithmic procedures, and automation were organized into evaluation areas to evaluate CT from the perspective of problem-solving programming education. Among them, the algorithmic procedure corresponding to algorithmic thinking evaluation was subdivided into algorithm design, algorithm representation, and algorithm analysis [17].

In a study by Kanaki et al., a CT evaluation tool for children aged 4 to 8 who are not yet familiar with programming is implemented on a digital platform called PyGramming, and this test focuses on algorithms. This is based on previous studies that stated that it is important to practice algorithmic thinking and develop problem-solving skills from an early age for efficient CT cultivation and emphasized algorithmic thinking as an alternative key element for CT evaluation. The study did not present sub-areas of CT or algorithmic thinking by emphasizing CT and algorithmic thinking that extends away from computer science to the implementation of everyday activities [1].

Lafuente Martínez et al. noted the urgent need to develop valid and standardized tests to evaluate adults’ CT and developed and validated CT evaluation suitable for adults regardless of background knowledge of STEM.

Based on literature research, CT's components adopted five components: algorithmic thinking, decomposition, abstraction, pattern recognition, evaluation and debugging, and finally expressed two scientific areas [Algorithms, Data][18].

III. Implications of previous works

In the algorithmic thinking evaluation case discussed above, the detailed components of algorithmic thinking included in each evaluation are summarized in <Table 1>.

Table I
COMPONENTS OF ALGORITHMIC THINKING INCLUDED IN PREVIOUS STUDIES

Jun	Kim	Ahn
•Problem solving processes •Alorithmic thinking •Understanding and execution of Algorithms	•Selecting Algorithms •Completing Algorithms •Modifying Algorithms •Predicting Algorithms	•Algorithms and process - Logic - Efficiency - Interaction - Regression
Park et al.	**Lee et al**	**Mart´ınez et al.**
•Algorithms - Analyzing - Representing - Designing - Implementing - Debugging	•Algorithm design •Algorithm representations •Algorithm analysis	•Algorithms •Data and representations

Jun's research includes algorithmic thinking as some elements for evaluating CT, and the evaluation content is limited to creating algorithms and expressing algorithms, so it has limitations.

Kim's research is significant in that he focused on algorithm education and dealt with teaching and learning methods and evaluation methods, and in particular, divided algorithm learning into seven stages and presented two content elements for each stage in detail. However, algorithm evaluation has limitations in that evaluation tools linked to learning content were not presented and only analyzed the mission of 'Hour of Code'.

Ahn's study is significant in that it presented SW evaluation standards in addition to the educational value aspect deeply related to CT, as well as the SW quality aspect. The evaluation standard in terms of SW quality reflects the unique characteristics of the algorithm, so it can also be used as an algorithmic thinking evaluation standard. However, as this standard is defined as the SW program evaluation standard, correction and supplementation are necessary to be used as an algorithmic thinking evaluation standard.

Lee et al. organized an evaluation of algorithm design, algorithm expression, and algorithm analysis with 6 out of 24 questions for CT evaluation.

It can be said that it is relatively suitable for algorithmic thinking evaluation in terms of evaluation content and composition. However, there is a limitation in that it takes the form of self-evaluation. It is pointed out that self-evaluation questionnaires, even if standardized, may lack accuracy, especially for students who do not have expertise in the subject [18].

Kanaki et al. emphasized algorithmic thinking as an alternative key element for CT evaluation but did not present specific evaluation elements. Research by Park et al. and Lafuente Mart´nenez et al. include algorithms as part of CT evaluation, requiring detailed elements for algorithmic thinking evaluation.

RESEARCH METHODS AND PROCEDURES

In this study, to develop algorithmic thinking evaluation standards, the research procedure is as follows (Fig. 1).

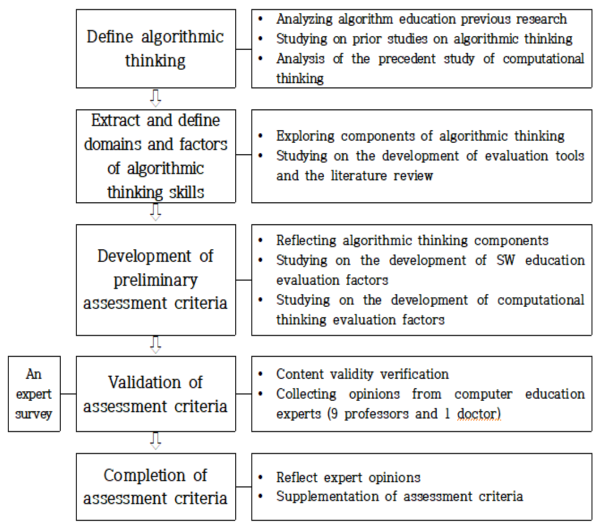

Figure 1 RESEARCH PROCEDURE OF DEVELOPING ALGORITHMIC THINKING EVALUATION

Evaluation standards for algorithmic thinking were developed based on previous studies and literature reviews, and a Delphi survey was conducted to verify the validity of the set evaluation area and standards. The Delphi survey is a research method that systematically collects expert opinions on the research topic to derive collective consensus. In general, the size of the Delphi survey expert group consists of 10 to 15 or more people to minimize errors and maximize reliability [19]. Ten computer education experts participated in the Delphi survey of this study as a panel.

DEVELOPING EVALUATION TOOL

I. Analyzing the Evaluation Factors of Algorithmic Thinking

The evaluation standards for algorithmic thinking are unique concepts that are not mixed with the concept of CT, as suggested in the evaluation case analysis discussed earlier. Detailed factors should be specified to evaluate algorithmic thinking. Detailed elements of algorithmic thinking are summarized and shown as shown in <Table 2> [1][4].

TABLE 2
ALGORITHMIC THINKING SKILLS [1][4]

Skills	Meaning
Problem analysis	Analyzing to understand problems
Problem specification	Deciding what problem addressed
Algorithm design	Creating algorithms and solving problems
Algorithm optimization	Finding the best way to solve the problem

The evaluation standards for algorithmic thinking should also include a reference diagram based on the characteristics of an algorithm to evaluate whether the algorithm development product meets the characteristics of the algorithm. The characteristics of the algorithm are shown in <Table 3>.

TABLE 3
CHARACTERISTICS OF ALGORITHM

Characteristics	Meaning
Effectiveness (Generality)	It should be generally applicable to defined inputs
Accuracy (Validity)	Always ensure the correct answer for all inputs
Efficiency	It aims for the best way to solve the problem
Clarity	It should have a clear working step that does not change
Finiteness	It should be stopped after a specific number of steps
Transition	One algorithm can often be transformed or transferred to another algorithm

II. Developing Draft Evaluation Standards for Algorithmic Thinking

In this study, the evaluation standards were constructed by synthesizing the detailed elements of algorithmic thinking, the characteristics of algorithmic thinking, and the elements of algorithmic thinking dealt with in previous studies. Based on this, the areas of algorithm evaluation standards were set to 'Algorithm Design', ' Algorithm Analysis', and ' Algorithm Expression', and detailed elements for each area were selected and defined as shown in <Table 4>.

Table 4
DEVELOPMENT OF ALGORITHMIC THINKING SKILLS EVALUATION STANDARDS

Domains	Factors	No.	Evaluation Standards
Ability to Design Algorithms	Logic	1	Will the correct result be obtained for a given input?
		2	Are the operations necessary for solving the problem step by step?
		3	Are the operations necessary for problem solving designed using conditions, repetition, and control structures?
		4	Is there an ambiguous procedure that can be interpreted in many ways?
		5	Can algorithms be accurately expressed in natural language, flow chart, or pseudocode?
	Finiteness	6	Does the algorithm terminate in a finite amount of time?
		7	Can the program be properly initialized?
Ability to Analyze Algorithms	Efficiency	8	Can you calculate the time complexity of the algorithm?
		9	Is the algorithm's time complexity exponential time?
		10	Is the time complexity improved over conventional algorithms?
Ability to Represent Algorithms	Input & Output	11	Are the required inputs and outputs accurately specified after performing the algorithm?
		12	Is the whole algorithm concisely represented?
	Automation	13	Are all procedures in the algorithm converted into computer-executable procedures?

VALIDATION OF EVALUATION STANDARDS

In this Delphi study, computer education experts (1 doctor's degree and 9 university professors) were asked to respond to the validity with a 5-point Likert scale (1 point very unsuitable ↔ 5 points very suitable) to verify the validity of the evaluation standards for algorithmic thinking. During November 2022, a total of 8 days of survey were conducted, and margins were provided together to write down other opinions. And after statistically analyzing the collected response data, the CVR value was calculated again to verify the content validity. The formula for calculating the content validity ratio (CVR) is as follows.

$$CVR = \frac{n_e - \frac{N}{2}}{\frac{N}{2}}$$

(n_e:Number of cases answered at least 4 points, N: Total number of cases)

Lawshe set the minimum value of CVR, which can be judged to be consistent with experts, according to the number of members of the expert group, and the minimum value of CVR applied to this study consisting of 10 experts is 0.62.

I. Statistical analysis of content validity

As a result of reviewing the content validity of the evaluation standards for algorithmic thinking, it was shown in <Table 5>.

Table 5
CONTENT VALIDITY OF EVALUATION STANDARDS

Domains	Factors	No.	Mean	SD
Ability to Design Algorithms	Logic	1	4.5	0.67
		2	4.7	0.46
		3	4.3	1
		4	4.0	1.26
		5	4.6	0.66
	Finiteness	6	4.1	0.83
		7	4.1	0.83
Ability to Analyze Algorithms	Efficiency	8	4.4	0.66
		9	3.8	0.6
		10	4.1	1.04
Ability to Represent Algorithms	Input & Output	11	4.6	0.66
		12	4.3	0.78
	Automation	13	4.6	0.49

The content validity average of 13 evaluation standards in three areas was at least 3.8 points to 4.7 points, except for No. 8 being more than 4.0 points. The standard deviation was also from a minimum of 0.49 points to a maximum of 1.26 points, indicating that all 13 evaluation standards did not differ significantly on content validity. According to the content validity mean and standard deviation, the content validity of all evaluation standards except No. 8 was determined to be appropriate.

II. Content Validity Ratio Analysis

Table 6 shows the results of analyzing the content validity ratio of the evaluation standards for algorithmic thinking.

TABLE 6
CONTENT VALIDITY RATIO OF EVALUATION STANDARDS

Domains	Factors	No.	CVR
Ability to Design Algorithms	Logic	**1**	0.80
		2	1.00
		3	0.60
		4	0.40
		5	0.80
	Finiteness	**6**	0.40
		7	0.40
Ability to Analyze Algorithms	Efficiency	**8**	0.80
		9	0.40
		10	0.20
Ability to Represent Algorithms	Input & Output	**11**	0.80
		12	0.60
	Automation	**13**	1.00

Some items were judged to be suitable by the mean and standard deviation of content validity, but the CVR value was found to fall short of the minimum value of 0.62, for validity determination. Regarding the items judged as above, experts commonly suggested that 'it is inappropriate as an evaluation standard for elementary school students'. Based on this, the evaluation standards were revised and supplemented by reflecting the opinions of experts on items with low CVR values.

III. Results of Evaluation Standards for Algorithmic Thinking

Based on the results of content validity ratio analysis and expert opinions, the evaluation standards for algorithmic thinking were finally selected as six items. In the selection process, the following correction and supplementation standards were applied. First, in principle, items with a content validity ratio smaller than the minimum value for determining suitability were rejected. Second, if other opinions were presented by experts, they were modified to reflect this and integrated or deleted in the adopted items. As a result, the evaluation standards for the finally selected algorithmic thinking are shown in <Table 7>.

TABLE 7
RESULTS OF EVALUATION STANDARDS FOR ALGORITHMIC THINKING

Domains	Factors	Evaluation Standards
Ability to Design Algorithms	Logic	Will the correct result be obtained for a given input? Are the operations necessary for problem solving expressed using the control structure of sequential, selection, and repetition? Can algorithms be expressed in natural language, flow chart, or pseudocode?
Ability to Analyze Algorithms	Efficiency	Can you calculate the time complexity of the algorithm?
Ability to Represent Algorithms	Input & Output	Are the required inputs and outputs accurately specified after performing the algorithm?
	Automation	Are all procedures in the algorithm converted into computer-executable procedures?

CONCLUSIONS AND FURTHER RESEARCH WORKS

This study developed algorithmic thinking evaluation standards to provide information related to algorithmic thinking improvement and to prepare an evaluation system that helps teaching and learning. To this end, evaluation tools related to existing algorithmic thinking were first analysed. As a result, algorithmic thinking is treated as some areas and elements of CT evaluation, and even specific evaluation elements have not been presented, and some have equated CT evaluation with evaluation of algorithmic thinking. Despite its importance, algorithmic thinking has been found to lack research treated as an independent evaluation.

Therefore, in this study, the evaluation standards for algorithmic thinking necessary for effective algorithm education were developed. To this end, detailed elements of algorithmic thinking were extracted based on literature research and analysis of previous studies, and evaluation standards were developed by reflecting algorithm's unique characteristics. To secure the validity of the developed evaluation standards, a Delphi survey was conducted on 10 computer education experts. As a result, 12 of the 13 items were validated by the average and standard deviation of the content per capita, but some items revised and supplemented the evaluation standards because the CVR value did not reach the minimum value for validity determination.

When synthesizing the contents so far, this study has the following significance. First, it independently defined the evaluation of algorithmic thinking that is mixed with computing thinking ability or even evaluation elements have not been presented, and prepared evaluation standards. Second, the results of this study set the standard for developing practical evaluation tools suitable for various students, various methods, and algorithm education at various levels.

The future research tasks of this study are as follows. First, in addition to the evaluation standards presented in this study, continuous research is needed to find factors that can evaluate algorithmic thinking. This is because it is necessary to prepare more detailed evaluation standards to develop reliable evaluation tools that can be used in education. Second, an actual test tool should be developed based on the evaluation standards of algorithmic thinking developed in this study. Based on the evaluation standards presented in this study, evaluation can be conducted in various forms and methods. It is hoped that the results of this study will be used as a reference framework for measuring the effectiveness of algorithm education and used as a basis for developing effective algorithm education contents and methods.

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