Development of Thinking Tools to Foster Creative Problem Solving Skills: A Trial in Programming Education

Kazuya Takase, Taichi Yasunaga, and Shingo Shiota

***Abstract*—Learning creative problem solving (CPS) and programming helps children develop problem solving skills. Although previous research has focused on how to teach problem solving, methods for teaching children how to analyze the gap between ideals and reality remain underexplored. Accordingly, there is a need for current CPS and programming education to improve the ways of teaching skills for analyzing a situation and defining ideals.**

In this research, 10 cards were developed as a thinking tool for CPS and programming learning. An experiment was conducted in elementary school programming classes, where students used the cards to analyze problems and discuss the gap between ideals and reality. The results of a questionnaire survey revealed an improvement in the students' attitudes toward focusing on ideals. Therefore, from the viewpoint of clarifying ideals, the thinking material supports the development of CPS abilities. As a future research subject, in order to make it easier for students to analyze the gap between ideals and reality in CPS learning, it will be necessary to develop a thinking tool for the clarification of reality.

***Index Terms*—Define ideals, creative problem solving, thinking tools, teaching materials, programming education.**

I. Introduction

Beginning in 2020, programming education will be compulsory in Japanese elementary schools. Toyoda (2018) categorizes recent programming materials into three types: software, combined use with electronic kits, and unplugged [1]. In programming education that uses these teaching materials, students engage in problem solving learning with various themes.

In the teaching guidelines for elementary and junior high schools, the Ministry of Education, Culture, Sports, Science, and Technology (2017) lists "problem finding and solving ability" as one of the qualities and abilities that form the foundation of learning [2], [3]. These qualities and abilities are related to various subjects, with the aim of cross-subject learning organization.

As Yumino (2012) points out, "Unlike regular problem solving in schools, real-world problem solving often does not know what the problem is and how to solve it [4]." This suggests the need to learn creative problem solving (CPS) (p. 42).

However, in the problem solving learning process, there is room for debate on how to clarify problems, goals, and ideals. Sasaki (2015) explains that "Even if an 'agreement' is formed only on the form without sufficiently useful discussions, it does not leave the domain of 'deformed consensuses' [5]." (p. 1). Viewed from this perspective, current problem solving learning involves the "planning" and "practice" of ideas for solving problems but lacks sufficient activities corresponding to the "definition of problems." If the problem definition is inadequate, the quality of deliverables such as children's ideas and portfolios may not be high. In other words, if a group attempts to think of ideas without first clarifying the problems and goals, it can be difficult to arrive at a creative and novel solution. In the context of problem solving learning, especially CPS, creativity is emphasized, so teaching materials that support the novelty and originality of ideas are needed.

Therefore, this study aims to develop and evaluate a thinking tool that can support the process of clarifying ideals and goals in CPS learning.

Manuscript received December 20, 2019; revised April 3, 2020. This work was supported in part by the U.S. Department of Commerce under Grant BS123456.

The authors are Shizuoka University, Shizuoka, Japan (e-mail: kazuya.takase.0221@gmail.com, yasunaga.taichi@gmail.com, shiota.shingo@shizuoka.ac.jp).

II. Theoretical Framework

For the development of teaching materials, we will first review the theory of CPS. CPS, one of the methods of problem solving learning, consists of three-phase, six-step activities, shown in Table I.

In light of the points made by Sasaki (2015), in order to devise more creative and novel ideas in the generation of Phase 2 ideas, it is necessary to enrich discussions in Phase 1. Regarding this, Kaneda (2019) described that "the child himself/herself sets the task" in problem solving learning [6].

Especially in Phase 1, as Murata *et al*. (2015) suggested, the issue is how to carry out the "target setting" process [7]. In other words, before thinking of an idea to solve a problem, it is important to identify what the problem is by discussing and defining the goals and ideals. This process corresponds to the second stage of Phase 1 in Table I.

TABLE I: Three Phases and Six Steps of Creating Problem Solving

3 Phases	6 Steps
1. Search for challenges	1-1. Confirm the purpose
	1-2. Check the goal list
	1-3. Clarify the problem
2. Generation of ideas	2-1. Generate ideas
3. Preparation for action	3-1. Select and reinforce ideas
	3-2. Make an action plan

According to Sasaki (2015), "In order to proceed with problem solving and task achievement, the 'direction' of where to go is the point. … In terms of which direction is desirable, it is roughly assumed that 'basic policy' is shown, and 'detailed guidelines' are shown in detail. This 'direction theory' is directly linked to the creation of an index of where the 'method' should be directed." (p. 3). This suggests the importance of discussing and defining the direction of the basic policy and specific guidelines for goal setting in problem solving.

In addition, referring to the survey by Sophonhiranraka, *et al*. (2014), it can be pointed out that the preceding research has paid much more attention to Phase 2 than Phase 1 [8]. Certainly, it is worth discussing how to extract creative ideas and ideas in Phase 2. However, based on the above review, it can be said that discussing the phase 1 process before extracting ideas can also lead to creative ideas.

Nakagawa (2007) conducted a case study using the USIT methodology [9]. USIT is one of the process models of CPS that includes two phases, generalized problem and generalized solution. This two phases are also separated in six steps, three steps for problem and three steps for solution. The case study of USIT was carried out through six processes. In this way, it can be said that detailed practice in the process of problem definition is also necessary.

Based on the discussion so far, the theoretical framework of this study will be broadly set in three positions on the premise that children will generate creative and novel ideas for problems to be solved. First, a learning process consisting of three phases and six steps, which is the method of CPS, will be introduced to a class in problem solving learning. Second, the activities related to Phase 1, goals and problem clarification, should be made more effective. In particular, they should have a focus on discussing and defining the goals and ideals. Third, based on the position of the first and second points, and it will be effective to introduce tools to assist the children's thinking in the process of discussing and defining the ideals and goals in the CPS learning. The aim is to develop an effective and efficient teaching method.

Based on these points, this study developed a thinking tool aimed at fostering children's CPS skills and put it into practice in programming education.

III. Materials and Methods

A. Participants

Eleven students in the 6th grade of elementary school in Shizuoka Prefecture were targeted. As a preliminary survey, we also practiced with 15 university students in Shizuoka Prefecture. The students were divided into groups of three or four, and the assignments were given in the class.

B. Training Procedure and Thinking Tools Design

The research was carried out in the context of programming education with the theme of thinking about "new play ideas and procedures" using the robot toy "toio". This theme accords with the goals of Japanese programming education, which include fostering children's programming thinking and developing the ability to generate new ideas about familiar matters. Table II shows the flow of the class activities.

Because it is a class that considers new play ideas and procedures, "new play" becomes a problem, and a design that can support the process of discussing and defining the goals and ideals is required. Therefore, referring to the four categories of play ("Search," "Feel," "Make," and "Compete") in Kubo and Iwamoto (2014) [10], we extracted six keywords from the four categories and created the original four keywords in Table III. Ten key words that indicate the fun of playing were added, and a thinking tool was developed as a set of 10 cards shown in Fig. 1.

In the class, the thinking tool is used in the activities shown in Table II. For the task of thinking about "new play ideas and procedures," it is possible not only to generate ideas but also to discuss and define new play images as goals and ideals as the previous process Designed like this. Children can use the thinking tool for group discussions and share the goals and ideals for the task of "new play and procedures" within the group. Moreover, it is expected that the goals and ideals defined by each group using the thinking tool will be used during the generation of ideas.

The thinking tool was implemented in a programming class. There were two types of practice: a "preliminary survey" conducted with 11 university students in Shizuoka Prefecture and a "main practice" held with 11 elementary school students in Shizuoka Prefecture.

TABLE II: Class Contents

Time	Activity
10 min.	1. Playing "toio" Form a group of three or four and play some games with toio.
15 min.	2. Development process of toio & how to create new games Think about what the joy of playing is. *Use thinking tools
20 min.	3. Create a new game with toio Consider new play ideas and procedure with toio.
45 min.	3. Create a new game with toio
45 min.	4. Present the idea (each group)

TABLE III: Keywords of the Joy of Playing

4 types	Subcategory	Keyword(s)
Look for	locate, catch	collectable
Feel	touch, ride, climb, throw, be surprised, hide, relax	exhilarating, thrilling
Create	shape, make sound, collect, harvest, cook, manipulate, imitate, flock, contact	customizable
Compete	bet on luck, kick, ride, defeat, hit, throw, use head	competitive, moving around
Original category		level up, unusual, with friends, easy rules

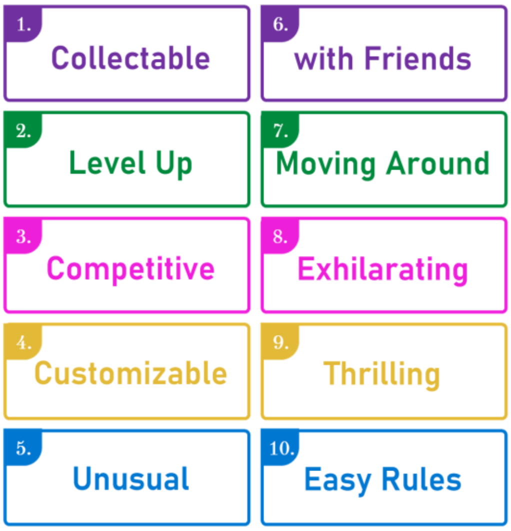

Fig. 1. Thinking tools for definition of ideals.

C. Measures

Three questionnaires were administered to evaluate the effects of the teaching materials. First, the words associated with "fun play" as a keyword were written in webbing format before and after the class. This was done in both the preliminary survey and the main practice.

Second, after the class, the students gave their impressions of the learning in a free description format. This was also conducted in both preliminary surveys and actual practice.

Third, we conducted a quantitative survey to investigate changes in the university students' awareness before and after the class. This was only carried out in the preliminary survey portion of the research. The survey consisted of 20 items. There were five items for each of the following dimensions: "Attitude of logical thinking" by Hirayama and Kusumi (2004) [11], "Attitude of creativity (uniqueness, adventurous spirit)" by Shiota *et al.* (2013) [12], "Coordination" by Tobari *et al.* (2015) [13], "Problem solving," and "Problem discovery / planning ability" extracted from the components of "Practice ability of information utilization" by Sakai and Nanbu (2006) [14]. For each item, the answer choices were "It is very applicable," "A little applies," "Neither," "Not so much," and "Not applicable at all."

D. Data Analysis

Three analyses were conducted. The five dimensions were scored, and t-test and the effect sizes (Cohen's d) were measured. In addition, the keywords associated with the word "fun play" were described in webbing format, the appearance words were classified, and the changes before and after were analyzed qualitatively. Finally, the subsequent impressions were freely described and analyzed by constructing a co-occurrence network using the free software KH Coder.

IV. Results

A. Preliminary Survey

The results of the preliminary survey are as follows; the co-occurrence network analysis (Fig. 2) and the webbing survey (Fig. 3).

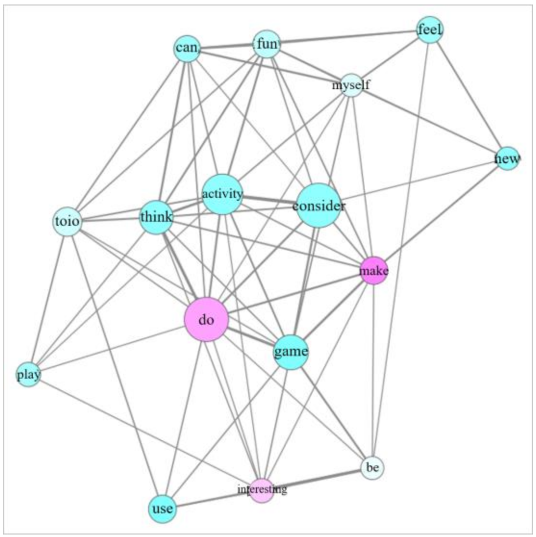

Fig. 2. Results of the co-occurrence network analysis.

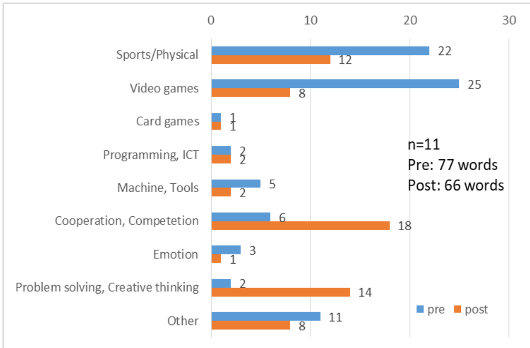

Fig. 3. Results of the webbing survey.

The co-occurrence network analysis suggested that the word "play" and the words "thinking," "interesting," "can do," "fun," "new," and "making" are strongly related; see Fig. 2.

Furthermore, the webbing showed that the total number of words decreased after the class, but the number of words related to competition, cooperation, problem solving, and creative thinking increased; see Fig. 3. Examples of the keywords related to problem solving and creative thinking include "same purpose" and "use the head."

B. Main Practice

There was no significant difference in the P value due to the small number of parameters. Concerning the value of effect amount D, the degree of self-centering decreased and awareness of listening increased. On the other hand, the values for explanations, problem discovery, and various viewpoints decreased. Table IV summarizes the results of the questionnaire survey.

In the results of webbing, the total number of words increased, especially the number of words related to tools, programming, problem solving, and creative thinking; see Fig. 4. Examples of words that appeared in problem solving and creative thinking include "forecast" and "imagine."

Furthermore, the co-occurrence network analysis suggested that the word "idea" and the words "think," "create," and "can" are strongly related; see Fig. 5.

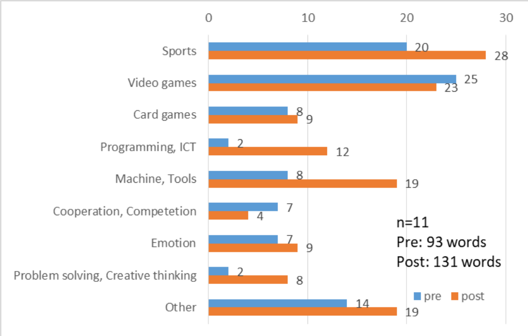

Fig. 4. Results of the webbing survey.

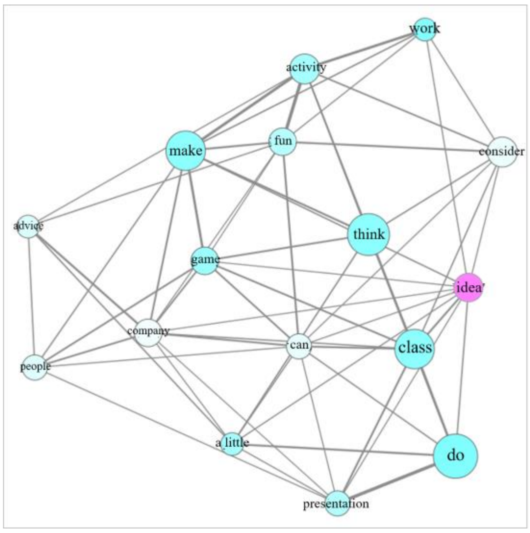

Fig. 5. Results of the co-occurrence network analysis.

TABLE IV: RESULTS OF THE QUESTIONNAIRE SURVEY

	Pre	Post	*p*	*d*
Logical Thinking	3.05 (1.18)	3.07 (1.35)	0.91	−0.01
Logical Thinking	3.36 (0.92)	3.55 (1.04)	0.34	−0.19
Summary	3.00 (1.34)	3.00 (1.41)	1.00	0.00
Accuracy	3.00 (0.89)	3.09 (1.45)	0.82	−0.08
Expression	**3.18 (1.25)**	**2.64 (1.69)**	**0.17**	**0.38**
Complex	2.73 (1.49)	3.09 (1.14)	0.27	−0.29
Creativity	3.53 (1.23)	3.36 (1.25)	0.25	0.13
Motivation	4.00 (1.18)	3.82 (1.08)	0.55	0.17
Answer	2.91 (1.30)	2.82 (1.33)	0.80	0.07
Originality	4.09 (1.04)	3.91 (1.22)	0.64	0.17
Novelty 1	3.18 (1.17)	3.18 (1.08)	1.00	0.00
Novelty 2	3.45 (1.21)	3.09 (1.38)	0.27	0.29
Collaborative Problem Solving	3.75 (0.95)	3.60 (1.27)	0.33	0.13
Cooperation	3.91 (0.83)	3.64 (1.12)	0.34	0.29
Mutual Benefits	3.55 (1.13)	3.82 (0.98)	0.47	−0.27
Self-centering	**3.55 (0.93)**	**3.18 (1.40)**	**0.22**	**0.32**
Listening	**4.18 (0.87)**	**4.45 (1.04)**	**0.19**	**−0.30**
Description	**3.55 (0.93)**	**2.91 (1.38)**	**0.19**	**0.57**
Practical Ability to Use Information	3.71 (1.07)	3.45 (1.15)	0.08	0.23
Opinion	3.82 (1.17)	3.73 (1.19)	0.80	0.08
Application	3.55 (1.04)	3.55 (1.44)	1.00	0.00
Plan	3.55 (1.04)	3.36 (0.92)	0.51	0.19
Problem Finding	**4.09 (0.83)**	**3.45 (1.04)**	**0.09**	**0.71**
Diverse Perspectives	**3.55 (1.29)**	**3.18 (1.25)**	**0.27**	**0.30**

V. DISCUSSION AND CONCLUSION

First, we will consider the results of the main practice. As Table IV shows, the degree of self-centering decreased and awareness of listening increased, but the average values for expression, problem finding, and diverse perspectives decreased. The average value increased for those who realized that their abilities were higher than they expected, and it decreased for those who realized that their abilities were lower than they expected. Although there is a position that the average value is effective when the average value increases and there is an adverse effect when the average value decreases, the pre- and post-questionnaire survey results show changes in the children's awareness and abilities. In other words, when they finished the class and looked back on their problem solving ability and creativity, they considered that their perspectives on their own abilities had changed. By using the thinking tool, the children felt that they had unexpectedly improved their abilities for explanation, problem discovery, and thinking from various perspectives.

In addition, regarding the classification of words that appeared based on the webbing in Fig. 5, it can be inferred that children's creative thinking, imagination, and associative ability have improved because the total number of appearing words has increased. Furthermore, in the co-occurrence network analysis, strong relationships are found between the word "idea" and the words "think," "make," and "can." This indicates the students could think of ideas and create new games through the CPS learning activities.

Overall, the thinking tool was not effective at increasing and improving the children's creativity and problem solving ability themselves in the short term in CPS learning, but it did change the children's perception of their own abilities. Therefore, it is desirable to use the tool with a view to long-term guidance. In this regard, the tool may be used to increase children's self-awareness and to focus their interest and motivation in CPS as well as help them to define goals and ideals, thereby engaging their creativity and problem solving skills. It can be assumed that the system will provide guidance in the long term.

Next, we will consider the preliminary survey. Similar to the results of the main practice, regarding the classification of words that appeared based on the webbing in Fig. 3, it can be inferred that university students' abilities or perceptions on problem finding and creative thinking have improved because the number of appearing words about these categories has increased. Furthermore, in the co-occurrence network analysis, strong relationships are found between the word "make," "consider," "think," "can," "activity," "fun." This indicates the students could find the fun of thinking ideas and create new games through the CPS learning activities.

In both practices, group discussions were the main format, so it can be inferred that this result has an impact on the difficulty of communicating their opinions and ideas to the other party through their activities.

The thinking tool developed in this study is a teaching material aimed at facilitating students' discussion and identification of goals and ideals in CPS schemes. The findings from the experiment show that the tool improved children's and university students' self-awareness of their problem solving ability and creativity and can be appropriate for long-term instruction. It is a versatile teaching material appropriate for use with a wide range of themes in classes that incorporate CPS learning and the programming education framework.

On the other hand, this study did not address the "confirmation of objectives" in Phase 1 of CPS learning framework. In other words, it is necessary to conduct some learning activities that students think about why they need to consider ideas in this activity at first. This activity needs to be conducted before the process of defining ideals because this can leads to make students' awareness more improved and ideas more creative.

Another limitation of this research is about the methodologies of analysis and evaluation. It was not conducted that the analysis of CPS and problem finding abilities themselves in detail. A mere questionnaire survey on individual awareness is not enough to strictly evaluate students' ability value itself. This is because this research methodologies can only analyze the subjective consciousness of the individual and are not an objective research method. In the future, it will be necessary to comprehensively evaluate by introducing creativity tests to evaluate CPS abilities and biometric measurements to evaluate the degree of concentration in classes.

In future work, the research should be expanded to consider these aspects.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

All of the authors conducted the research; K. Takase conducted practices and wrote the paper, T. Yasunaga and S. Shiota analyzed the data; all of the authors had approved the final version.

References

[1] M. Toyoda, "Report on considerations for promoting programming class at elementary school," Graduate School of Teacher Education Wakayama University bulletin of Course Specializing in Professional Development in Education, vol. 2, pp. 83-90, 2018.

[2] Ministry of Education, Culture, Sports, Science and Technology. (2017). The courses of study for elementary schools lower secondary schools. [Online]. Available: https://www.mext.go.jp/content/1413522_001.pdf

[3] Ministry of Education, Culture, Sports, Science and Technology. (2017). The courses of study for lower secondary schools. [Online]. Available: https://www.mext.go.jp/content/1413522_002.pdf

[4] K. Yumino, *Psychology of Learning & Creation*, Shizuoka, Japan: YUMINO Institute of Education, 2012.

[5] H. Sasaki, "How to lead to productive consensus building: Making the actuality clearly, making the ideal definitely and making the method lucidly," The Technology in Education, Utsunomiya University Bulletin of the Faculty of Education, vol. 1, pp. 147-154, 2015.

[6] Y. Kaneda, "Making home economics classes to nurture children who want to improve their lives independently: Through enhancement of the process of "task discovery" and "evaluation/improvement" in problem-solving learning," Completion Report, Aichi University of Education Graduate School, vol. 10, pp. 371-380, 2019.

[7] S. Murata, T. Nagata, and M. Aikawa, "Cognitive characteristics of student in problem finding: Through the practice of consumer life field in junior high school home economics," presented at Research Abstracts on the Annual Meeting, Regular Meeting and Seminar of the Japan Association of Home Economics Education, vol. 58, p. 123, 2015.

[8] S. Sophonhiranraka *et al*., "Factors affecting creative problem solving in the blended learning environment: A review of the literature," *Procedia - Social and Behavioral Sciences*, vol. 174, 2015, pp. 2130–2136.

[9] T. Nakagawa, "Education and training of creative problem solving thinking with TRIZ/USIT," *Procedia Engineering*, pp. 582–595.

[10] T. Kubo and K. Iwamoto, "Research on the classification of plays and association between playing environment and playing method: From a child's point of view to seek a "fun"," *Journal of the Faculty of Humanities and Social Sciences*, vol. 16, pp. 1-14, 2014.

[11] R. Hirayama and T. Kusumi, "Effect of critical thinking disposition on interpretation of controversial issues: Evaluating evidences and drawing conclusions," *The Japanese Journal of Educational Psychology*, vol. 52, no. 2, pp. 186-198, 2004.

[12] S. Shiota *et al.*, "Practice and effect of creativity education in each subject of elementary school," in *Proc. the 35th Research Conference, the Japan Creativity Society*, pp. 72-73, 2013.

[13] M. Tobari *et al.*, "Development of a multifaceted cooperativeness scale. Annual Convention of the Japanese Association of Educational Psychology, vol. 57, p. 637, 2015.

[14] B. Chen, Mulgrew, and P. M. Grant, "A clustering technique for digital communications channel equalization using radial basis function networks," *IEEE Trans. on Neural Networks*, vol. 4, pp. 570-578, July 1993.

[15] N. Sakai and M. Nanbu, "Development of the learning programs based on the children's evaluation activities for the skills to use information practically in the elementary school," *Japan Journal of Educational Technology*, vol. 30, no. 3, pp. 193-202, 2006.

Kazuya Takase was born in Atsugi city, Kanagawa, Japan on February 21, 1996. He received a bachelor's degree in education from the Faculty of Education, Shizuoka University, Japan (March 2018). He is expected to receive a master's degree in education from the Graduate School of Education, Shizuoka University (March 2020). His research fields: educational technology, programming education, ergonomics.