Effects of a Problem-solving Framework Based on Engineering Design of Japanese High School Students

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Abstract

Recently, the development of problem-solving ability is emphasized. We taught Japanese high school students a framework of problem-solving based on Engineering Design. As a result, we found that students' awareness of problem-solving ability and self-assessment of problem-solving activities were improved. The students are considered to be suitable for the problem-solving framework based on Engineering Design.

Keywords: Problem-solving, Engineering Design, Information

1. Introduction

There has been a lot of discussion about the qualities and abilities that should be developed for the children of the future. For example, ATC21s has defined 21st century skills. The 21st century skills are defined as ten skills in four areas that are considered necessary for living in the 21st century. One of them is the problem-solving skills (Griffin et al. 2012). In addition, the OECD tested problem-solving skills for the first time in PISA 2003. These indicate that attention is being paid to the development of problem-solving skills.

Problem-solving skills have been defined in many ways. The OECD (2012) defines problem-solving skills as the skills to understand and cognitively process problem situations where the solution is not immediately obvious, as well as a proactive attitude toward the problem. Thus, the problem-solving skills are widely considered to be the skills to find an answer to a situation where the answer is not yet known.

1.1 Problem-solving in Japan

In Japan, education is standardized throughout the country based on the contents of the Course of Study issued by the Ministry of Education, Culture, Sports, Science, and Technology. The Course of Study is revised about once every 10 years to improve the content of education. In the Courses of Study, problem-solving skills are listed as one of the qualities that form the basis of learning. Therefore, it indicates that problem-solving skills should be taught throughout the school to improve the quality of educational activities and increase the effectiveness of learning.

Problem-solving skills are intended to be cultivated throughout school education. In school education, information science has been cited as an important subject for developing problem-solving skills (MEXT 2016). In Information I, one of the goals stated in the Courses of Study is "to acquire knowledge and skills about how to find and solve problems" (MEXT 2018). Problem-solving skills have been treated with more emphasis over the years.

This problem-solving skills has been practiced in various ways in Japanese information science. The following are some of the issues that have arisen through the practice in Japan. These include teaching knowledge and skills related to problem-solving and the integration of lessons on problem-solving skills into the teaching plan.

1.2 Develop Problem-solving

To develop problem-solving skills, many studies have been conducted and challenges have been identified. First, it has been shown that explicitly presenting and teaching skills is effective in developing problem-solving abilities(Mathee and Turpin 2019). In addition, Schoenfeld (2013) showed that it is necessary to develop a framework for problem-solving. In addition, there is a need to assess problem-solving skills (Griffin et al. 2012). Happner and Peterson (1982) developed the PSI to assess individual behavior and attitudes.

From this, it is clear that there is a need for an explicit framework for problem-solving as a skill. Engineering design has shown promise as a framework for problem-solving.

1.3 Engineering Design

We focused on engineering design as a problem-solving framework that improves problem-solving skills. It is said that there is no unified definition of engineering design (Li et al. 2016). For example, NGSS (2013) defines three types of behaviors that students who have mastered engineering design can perform (A) Define the problem to be solved. (B) Generate several solutions. (C) Optimizing the solutions to improve their quality.

The effects of engineering design on the problem-solving process have been examined in previous studies. Problem definition and information retrieval can lead to better problem solving (Atman et al. 2007). Although the time spent on problem solving activities is longer, it led to better problem-solving activities(Atman and Bursic 1996). However, no conclusion has been reached that it improves problem-solving skills (Li et al. 2016).

2. Purpose

We suggest that Engineering Design is effective in developing problem-solving skills. However, there is a lack of research that examines whether engineering design improves problem-solving skills. The purpose of this study is to investigate the effect of teaching Engineering Design to high school students on their problem-solving skills.

3. Methods

3.1 Participants

In July of 2020, this study was conducted in 100 minutes at a private high school in Tokyo. The Participants were two classes of 82 third-year high school students, 54 (65.9%) boys and 28 (34.1%) girls, who were taking "Information".

3.2 Procedure

This practice was carried out according to the procedure shown in Figure 1. First, the participants answered a pre-questionnaire survey. The items of the pre-questionnaire were related to their perceptions of their problem-solving abilities. Next, the participants worked in groups of four or five on problem-solving activities. The problem-solving activity was conducted using a chat application on a smartphone. Afterward, the participants self-evaluated themselves and the group on the problem-solving activity. Then, we conducted a class to teach engineering design. In the class, we explained the framework of the problem-solving framework using PowerPoint and handouts. After the class, the students performed the same problem-solving activities as before and self-assessed the problem-solving activities in the same way. Finally, a post-questionnaire survey was conducted.

We prepared two types of group work topics. One was a problem-solving activity to think about what is needed to make life in a regular classroom more comfortable. I put a limit of 100,000 yen or less on the budget and asked them to think of something that could be installed in about two months. The second was a problem-solving activity in which students were asked to think of products that they would like to have in the school store. We put a limit on them to think of products within the range of what high school students can afford.

In teaching the problem-solving framework, the elements of the problem-solving framework based on engineering design were taught one by one. In addition, we taught the problem-solving framework by having the learners fill in the blanks on the handout that had blanks throughout the content. The framework of the problem-solving approach to be taught to the learners was developed based on Engineering Design (NGSS 2013, 2017) (Table 1). In teaching the problem-solving framework, the NGSS is written in English, it was translated into Japanese for teaching.

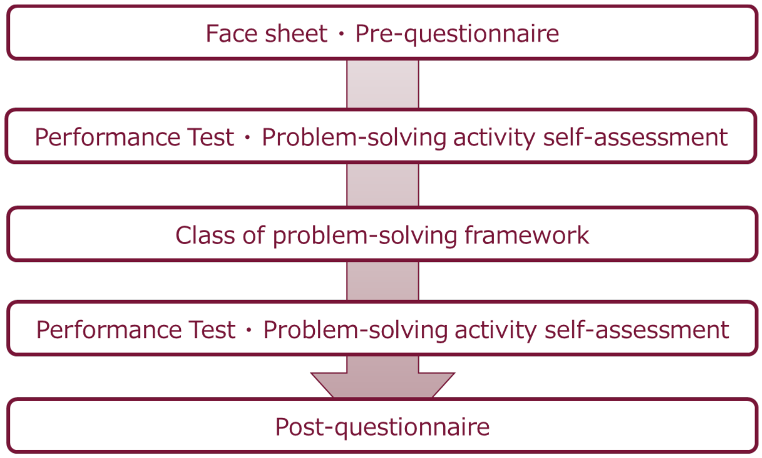

Figure 1. Procedure of research

Table 1. Framework for problem-solving based on Engineering Design

Define	Define a simple design problem that reflects the need, with specific success criteria and constraints on materials, time, and cost.
	・Understand what the problem is now.
	・Understand what is required to solve the problem.
	・Understand the conditions that must be considered when solving the problem.
Develop	Generate and compare multiple possible solutions to the problem based on how likely each solution is to meet the criteria and constraints of the problem.
	・To be able to generate multiple solutions
	・Compare the degree to which each solution satisfies the problem.
	・Share ideas to improve the solution.
Optimize	Plan and execute unbiased tests that control variables and account for failures in order to identify aspects of the prototype that can be improved.
	・Design tests to test solutions.
	・Identify problems with the solution from test results.
	・Collaborate to gather data for evidence.

3.3 Questionnaire

To investigate the changes in problem-solving skills, a questionnaire survey was conducted. First, a questionnaire survey on self-perception of problem-solving skills was conducted before and after the practice. In setting the items for the questionnaire, we selected 22 items out of a total of 47 items (32 items from the Problem-Solving Inventory (PSI) (Happner and Petersen 1982) and 15 items from the scale for measuring attitudes toward problem-solving (Emoto et al. 2005 in Japanese)).

In addition, self-evaluation of problem-solving activities was conducted. The self-assessment items included 9 items on the framework of problem-solving and 2 items on the self-confidence of the problem-solving activities. The students were asked to self-evaluate the degree to which they were able to perform problem-solving activities for their individual problem-solving activities and the problem-solving activities of the entire group.

In addition, a questionnaire survey was conducted after the practice to investigate the usefulness of the framework of the problem-solving approach. Five items were set as survey items to investigate the degree of usefulness through the problem-solving activities using the framework of the problem-solving approach.

4. Results

Based on the collected data, we investigated the impact of teaching the framework of problem-solving thinking on the learners. From the results of each questionnaire survey, those with missing values were excluded from the analysis, and data from 38 participants (46%) were used.

4.1. Problem-solving skills

The results of the pre- and post-questionnaires were used to measure changes in the perception of problem-solving ability. After processing the reversed items, Shapiro-Wilk's test for normality was conducted, but normality could not be confirmed. Therefore, Wilcoxon's signed-rank test was conducted on the pre- and post-questionnaires of self-perception of problem-solving ability (Table 2).

Table 2. Self-awareness of problem-solving skills

		Pre		Post		M_{post} - M_{pre}	Z		r
		M	SD	M	SD				
1.	I am able to look at a situation in different ways when solving problems. (R)	3.34	1.05	3.66	0.71	0.32	-1.87		0.35
2.	I am able to see things from different perspectives.	3.55	0.98	3.55	0.80	0.00	-0.02		0.00
3.	I try to think about the essence of things when I solve problems.	3.55	0.76	3.45	0.76	-0.11	-0.73		0.14
4.	Many of the problems I face are too complex for me to solve. (R)	3.03	0.79	3.26	0.95	0.24	-1.65	†	0.27
5.	When I make a plan to solve a problem, I am almost certain that I will succeed in doing so.	2.87	0.96	3.03	1.08	0.16	-0.92		0.15
6.	When I am faced with a problem, I am not sure that I can handle the situation. (R)	3.13	0.99	3.37	1.05	0.24	-1.52		0.23
7.	One of the first things I do when I notice a problem is to try to find out exactly what the problem is.	3.55	0.76	3.45	0.95	-0.11	-0.69		0.12
8.	When I am faced with a complex problem, I gather information so that I can define exactly what the problem is.	3.42	0.64	3.61	0.89	0.18	-1.29		0.24
9.	After I solve a problem, I do not analyze what went well and what did not go well. (R)	3.05	1.09	2.79	1.02	-0.26	-1.54		0.25
10.	When I am faced with a problem, I come up with as many ways as possible to handle it and think about them until I can't think of any more ideas. (R)	2.71	0.90	3.08	0.91	0.37	-2.38	*	0.41

11.	When I decide on an idea or possible solution to a problem, I do not take the time to consider the likelihood of success of each alternative. (R)	2.84	0.72	3.05	1.01	0.21	-1.28		0.24
12.	When I am faced with a problem, I stop and think before deciding on the next step. (R)	3.63	0.97	3.47	0.95	-0.16	-1.13		0.16
13.	I generally follow the first good idea that comes to mind. (R)	3.42	1.08	3.18	0.95	-0.24	-1.15		0.23
14.	When choosing a solution, I weigh the consequences of each alternative and compare them to each other. (R)	3.37	0.82	3.29	0.80	-0.08	-0.41		0.10
15.	I try to predict the overall outcome of implementing a particular solution.	3.18	0.77	3.50	0.80	0.32	-1.40		0.40
16.	When I try to think of possible solutions to a problem, I do not come up with too many alternatives. (R)	3.50	0.89	3.39	0.75	-0.11	-0.65		0.13
17.	I have a systematic way of comparing alternatives and making decisions. (R)	2.74	0.69	3.05	0.84	0.32	-2.00	*	0.41
18.	When confronted with a problem, I usually do not consider what external factors are contributing to the problem. (R)	2.79	0.66	3.18	0.73	0.39	-2.70	**	0.57
19.	When I am confused by a problem, one of the first things I do is to investigate the situation and consider all the relevant information.	3.11	0.73	3.42	0.76	0.32	-1.80	†	0.43
20.	Sometimes I don't stop to deal with my problems, I just mess around and move forward without taking the time to do so.	3.29	0.98	3.29	1.11	0.00	-0.04		0.00
21.	When I am working on a problem, sometimes I feel like I am groping or wandering and not getting to the real problem.	3.45	0.83	3.45	0.72	0.00	-0.07		0.00
22.	I sometimes make poor decisions and regret them later.	4.11	0.89	3.79	0.87	-0.32	-2.13	*	0.36

n=38, (R): Reverse score, 5-point Likert scale *†p<.100, *p<.050, **p<.010*

4.2. Problem-solving activities

Based on the results of self-evaluation of problem-solving activities, we measured the change in self-evaluation of problem-solving activities. As a result of Shapiro-Wilk's normality test, normality could not be confirmed. Therefore, Wilcoxon's signed-rank test was used for the pre- and post-questionnaires of self-perception of problem-solving skills (Table 3 for individual self-evaluation of problem-solving and Table 4 for group self-evaluation of problem-solving).

Table 3. Self-assessment of individual problem-solving activities

			Pre		Post		M_{post} - M_{pre}	Z		r
			M	SD	M	SD				
1.		I am satisfied with my problem solving.	3.21	1.06	3.55	1.02	0.34	-1.84		0.30
2.	Define	I was able to define a solvable problem that meets the needs of the problem conditions.	3.08	1.04	3.37	0.96	0.29	-2.07	*	0.34

3.		When defining the problem, I was able to identify what needs to be solved to be successful.	3.08	0.77	3.26	1.12	0.18	-1.79	†	0.29
4.		I was able to identify the constraints of the situation to be solved when defining it.	3.05	0.83	3.24	0.93	0.18	-2.64	**	0.43
5.	Develop	I can generate multiple solutions.	2.76	1.20	3.32	0.95	0.55	-0.83		0.14
6.		I can compare solutions in terms of success and constraints.	2.84	0.84	3.11	0.88	0.26	-2.03	*	0.33
7.		I can improve my solutions by sharing ideas.	3.03	1.09	3.37	0.98	0.34	-1.17		0.19
8.	Optimize	I was able to discover improvements to the solution.	3.16	1.06	3.32	1.00	0.16	-0.26		0.04
9.		I was able to improve the solution based on the improvement points	2.95	0.94	3.21	1.06	0.26	-3.41	†	0.55
10.		I was able to plan and execute surveys and other activities to discover improvements in solutions.	2.74	0.94	3.03	1.06	0.29	-2.11	*	0.34
11.		I think that my problem solving is better than others' problem solving.	2.58	1.14	2.92	1.09	0.34	-2.33	*	0.38

n=38, 5-point Likert scale *†p<.100, *p<.050, **p<.010*

Table 4. Self-assessment of the group's problem-solving activities

			Pre		Post		M_{post} - M_{pre}	Z		r
			M	SD	M	SD				
1.	Define	We are satisfied with our problem solution	3.61	0.90	3.76	0.87	0.16	-1.24		0.20
2.		We were able to define a solvable problem that meets our needs for the problem conditions	3.47	0.94	3.61	0.87	0.13	-1.54		0.25
3.		We have clarified what we need to solve to be successful in our definition	3.42	0.96	3.61	0.96	0.18	-1.22		0.20
4.		We were able to identify the constraints of the situation to be solved when we defined it	3.55	0.94	3.58	0.94	0.03	-2.45	*	0.40
5.	Develop	We were able to generate multiple solutions	2.92	1.11	3.24	1.06	0.32	-0.20		0.03
6.		We were able to compare solutions in terms of success and constraints	3.18	0.94	3.45	0.99	0.26	-2.06	*	0.33
7.		We were able to improve our solutions by sharing our ideas	3.24	1.01	3.63	0.96	0.39	-1.57		0.25
8.	Optimize	We were able to discover improvements to the solution.	3.26	1.07	3.34	1.06	0.08	-0.06		0.01
9.		We were able to improve the solution based on the improvements	3.47	1.04	3.39	1.01	-0.08	-1.17		0.19
10.		We were able to plan and carry out surveys and other activities that would enable us to discover improvements in our solutions.	3.11	1.07	3.34	1.06	0.24	-2.40	*	0.39
11.		We think that our problem solving is better than others' problem solving	3.05	1.02	3.29	0.94	0.24	-2.21	*	0.36

n=38, 5-point Likert scale **p<.050*

4.3. Usefulness of the framework

In the post-questionnaire survey, the evaluation of the problem-solving framework was conducted. The mean and variance of the results were calculated (Table 5).

Table 5. Usefulness of the problem-solving framework

		M	*SD*
1	I was able to understand the framework of problem-solving skills introduced.	3.76	0.85
2	I was able to solve problems using the introduced problem-solving framework.	3.42	0.89
3	The introduced problem-solving framework fits as a framework for problem solving.	3.61	0.82
4	I was able to solve problems easily by applying the framework of problem-solving skills introduced.	3.47	1.03
5	I was able to solve the problem better the second time than the first time.	3.79	1.12

n=38, 5-point Likert scale

5. Discussion

In this study, we investigated the impact of teaching a problem-solving framework based on Engineering Design on the students. From the results of the questionnaire survey, there was a change in the self-perception of problem-solving skills. It showed that the students' self-perception of their problem-solving skills changed, and they began to think that they were able to solve problems systematically after being taught the framework of problem-solving framework. In addition, they have come to believe that it is important to come up with multiple ideas for solutions when conducting problem-solving activities. They started to think about my own situation first when they started problem-solving activities. This was probably because they recognized the importance of defining the problem and developing ideas from the framework of problem-solving.

Self-evaluation of problem-solving activities also changed. In particular, the self-evaluation of problem-solving behavior related to define increased significantly. However, many items did not change in the self-evaluation of problem-solving behavior related to Optimize. Insufficient time for problem-solving activities and not being able to optimize problem-solving activities may have influenced the results. There was also a difference between the self-evaluations of individual and group problem-solving behaviors. This may be because they were not able to utilize the problem-solving behaviors that they were able to perform individually in their group problem-solving behaviors.

We found that the learners felt that the problem-solving framework was useful. However, they did not give it a high rating, indicating that it needs to be improved. The self-evaluation of the Optimize problem-solving activity also did not improve, indicating the need to improve the Optimize part in particular.

Several issues were found in this practice. First, there was no improvement in any of the problem-solving activities. In the framework of the current problem-solving approach, it was found that the "definition" problem-solving activity had a certain effect. However, the results for "generation" and "optimization" were not sufficient to say that they were effective. Therefore, the framework of problem-solving and its teaching methods need to be improved.

The fact that the individual problem-solving activities could not be applied to the group problem-solving activities indicates that there is a need for consideration when conducting group problem-solving activities. In this study, we used smartphones, and we felt the need to provide support so that discussions using smartphones could be conducted smoothly.

In addition, there were some problems in the subject matter and time setting of the problem-solving activities. In addition, there were some comments from the chat logs that there was not enough time for the problem-solving activities, which suggests that there was not enough time for the problem-solving activities. In this practice, the time for each problem-solving activity was short because we had to conduct two problem-solving activities and a lesson on the framework of problem-solving in a short time. To give learners enough time for problem-solving activities, it is necessary to clarify the time required for the activities by conducting preliminary experiments.

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