Teaching Strategies to Support the Development of Engineering Design for High School Students

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The development of problem-solving skills is required. In Japan, one of the goals of informatics is the development of problem-solving skills. In order to develop problem-solving skills, we aim for learners to acquire knowledge and skills related to problem-solving. Research has been conducted on a framework that summarizes knowledge and skills related to problem solving. Engineering Design describes the behavior of learners who solve problems, while IPS describes the behavior of learners who search for information on problem solving. In this study, we developed a problem-solving framework for developing problem-solving skills. Based on previous research on engineering design and IPS, we developed a problem-solving framework that should be taught in information science. In the future, we will investigate the effectiveness of this problem-solving framework and design lessons.

Keywords: Engineering Design, Information, Problem-solving

Introduction

The Need to Develop Problem-Solving Skills

There are a variety of skills that children need to develop to succeed at problem-solving and become an effective member of society. For example, we consider Assessment and Teaching in 21st Century Skills (ACT21's) proposed KASVE framework, which identifies 10 skills divided into four categories and defines them as 21st-century skills. The four categories are: Ways of Thinking, Ways of Working, Tools for Working, and Ways of Living in the world. The categories of Ways of Thinking consist of critical thinking, problem-solving in the 21st-century, and problem-solving related to decision-making (Griffin et al., 2011). The OECD's PISA survey of 2017 aimed to identify collaborative problem-solving. Furthermore, it has been shown that one of the objectives of Science, Technology, Engineering, Arts & Math (STEAM) Education, which has been the focus of attention in recent years, is focused on problem-solving skills (Bybee, 2011). This indicates the importance of developing problem-solving skills.

Jonassen (1997) distinguishes two types of problems that learners face in problem-solving: well-defined problems and ill-defined problems. A well-defined problem is one where the solution to the problem or the solution method is known and fixed. The ill-defined problem is that for which there is no fixed solution method, and for which more than one solution can be conceived.

Developing Problem-Solving Skills in Japan

In Japan, the necessity of fostering problem-solving skills has been recognized. MEXT (2018) has indicated that problem-solving skills should be included as one of the fundamental abilities for learning and should be encouraged throughout school education. It is expected that problem-solving methods will be taught especially in "Information", the learning goal of which is to solve problems using information and information technology problems students-solving and to acquire problem-solving abilities. Therefore, in "Information", students are expected to solve problems using information and information technology, and students are to acquire the problem-solving skills necessary to do so.

In "Information", for example, Murai and Ito (2017) designed problem-solving lessons by comparing various textbooks and examined their effects on students' problem-solving skills. The results revealed that students were more motivated to solve problems on problem-solving motivation, but the effect on their actual problem-solving ability was not verified. Yoshida and Nakai (2020) conducted activities to solve real-world problems using information systems. The PDCA cycle and other learning and problem-solving actions were explained as part of the problem-solving procedure. The PDCA cycle is cycle of problem-solving: Plan DO Check and Action. The problem-solving ability was measured through a questionnaire. However, It is a subjective survey of learners and does not measure actual problem-solving ability. Nagai and Kikuchi (2018) conducted classes to solve local problems using big data. As a result of this activity, they confirmed an increase in students' willingness to learn about problem-solving. These previous studies have shown that problem-solving skills have been studied in informatics courses and that students' motivation to learn and their problem-solving skills have improved as shown in subjective surveys. However, no objective investigation on problem-solving abilities has been conducted. In addition, the problem-solving framework that should be taught in informatics has not been determined.

Research on the Development of Problem-Solving skills

Various problem-solving methods have been proposed. For example, engineering design is mentioned as a relevant framework (Table 1). Engineering design has been particularly emphasized in STEAM education, and the National Research Council (NRC) (2011) recommends that engineering design be taught to all students to foster their problem-solving skills. Li et al. (2016) found that students' problem-solving behavior changed when they engaged in a Lego-based creation activity through engineering design. TAMAKI and Watanabe (2021) showed that teaching engineering design as a problem-solving framework improved problem-solving activities, suggesting an improvement in related skills.

Another relevant method is Information Problem Solving (IPS), a model for information retrieval and problem-solving by using information (Frerejean et al., 2018). Specifically, IPS is defined as a method in which information is retrieved and the results are used to solve the problem. The IPS-I model is shown in parentheses as a model of the cognitive process of IPS (Gruwel, 2009). IPS-I model consists of five actions: Defining Information Problems, Information Retrieval, Acquisition of information, Processing Information, Organizing and presenting information.

Another model that illustrates the cognitive process of the emergent cognition is the so-called generative model. This model divides the cognitive process of problem-solving into two stages: generation of preinventive structures and preinventive exploration and interpretation (Ward et al. 1995) (Figure1). In Generation of preinventive structures, an inventive prior structure is created, which produces various mental images for creative purposes. In Preinventive exploration and interpretation, the image created in Generation of preinventive structures is interpreted, explored, and made meaningful. These two processes are repeated, and the final image is created through a cycle of modification and revision. These two structures place constraints on the image.

The above models and studies have shown the necessity of fostering problem-solving skills, especially in Japan. In this country, one of the subjects that emphasizes the development of problem-solving skills is information science. Based on research on problem-solving frameworks, we believe that the development of a framework based on information science will contribute to the development of problem-solving skills.

Research Design & Methods

Design Problem-Solving Framework

The purpose of this study is to develop a learners' problem-solving framework in Japanese "nformation"and to design effective guidelines for teaching problem-solving skills.

Design Problem-Solving Framework

The following research questions are addressed in this study.

(1). What is a problem-solving framework that supports learners' problem-solving?

(2). How should lessons be designed to teach problem-solving skills?

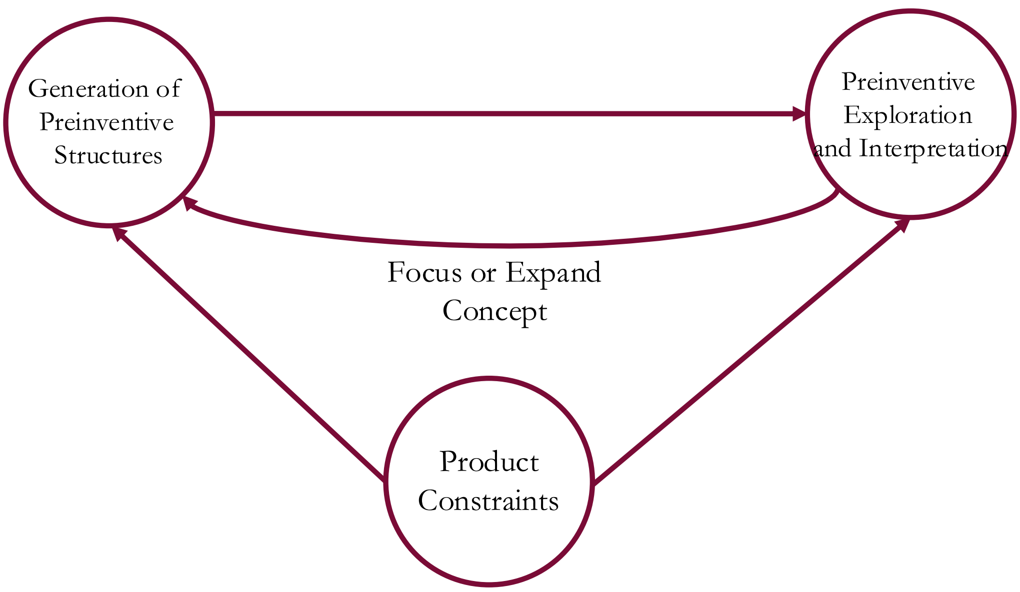
Table 1

Engineering Design

Define	Defining a simple problem to solve that meets your needs, considering success and constraints ・Define problems that can be solved to meet your needs ・When defining, be able to clarify what can be resolved and succeed ・When defining, be able to clarify the constraints of the situation to be solved
Develop	Generate multiple solutions and compare how well the success conditions and constraints are met ・Generate multiple solutions ・Compare solutions based on success and constraints ・Improve your solution by sharing your ideas
Optimize	Investigate the improvement points of the solution and optimize the solution based on the improvement points by the success condition/constraint condition ・Discover solution improvements ・Improve the solution based on the improvements ・Plan and execute surveys so that you can find improvements to the solution

Figure 1

Geneplore model



Design Problem-Solving Framework

We develop a problem-solving framework to support learners' problem-solving behavior.

To achieve this objective, this study first develops a problem-solving framework to support learners' problem-solving behavior. Then, we design lessons to support the learning of the said skills. It has been suggested that practical problem-solving activities are effective in teaching complex correlated skills (Matthee and Turpin, 2019). Therefore, we create problem-solving materials that allow students to perform these activities in accordance with the problem-solving framework we develop. We investigate the changes in learners' problem-solving abilities throughout the lessons and verify their effectiveness through an evaluation method of learners' problem-solving.

Results

Design Problem-Solving Framework

In developing the problem-solving model, we referred to previously studied representations of problem-solving behavior. Ward et al. (1995) developed the "geneplore model", which represents the cognitive process of human problem-solving. It consists of two steps: the generation phase, where an abstract mental image is generated, and the exploration phase, where the generated mental image is explored, interpreted, and modified.

With regard to frameworks, NRC (2013) demonstrated that engineering design is a problem-solving method that all students should learn in order to successfully solve problems. Li et al. (2016) show that the effect of teaching engineering design is a change in learners' problem-solving behavior. Many definitions of engineering design exist. NGSS (2013) identified the behaviors that can be performed by learners who have acquired skills in engineering design. The three behaviors are (A) Defining and delimiting engineering problems, (B) Designing solutions to engineering problems, and (C) Optimizing the solution. NGSS showed that engineering design is the process of incorporating these components, as necessary.

In Japanese "Information", it is required to utilize information and information technology in the process of problem-solving. Therefore, it is necessary to include the content related to information, for which IPS is a suitable model of information-based problem-solving (Gruwel et al., 2009). Among them, there is a model that deconstructs the cognitive skills of IPS. This model includes problem definition, information retrieval, information selection, information processing, and information presentation.

Using the problem-solving framework above as a reference, we modeled learners' problem-solving behavior (Figure 2). In addition, we represented the related skills as the problem-solving behaviors that are likely to be used in each situation(Table 2)

Figure 2

Problem-solving framework

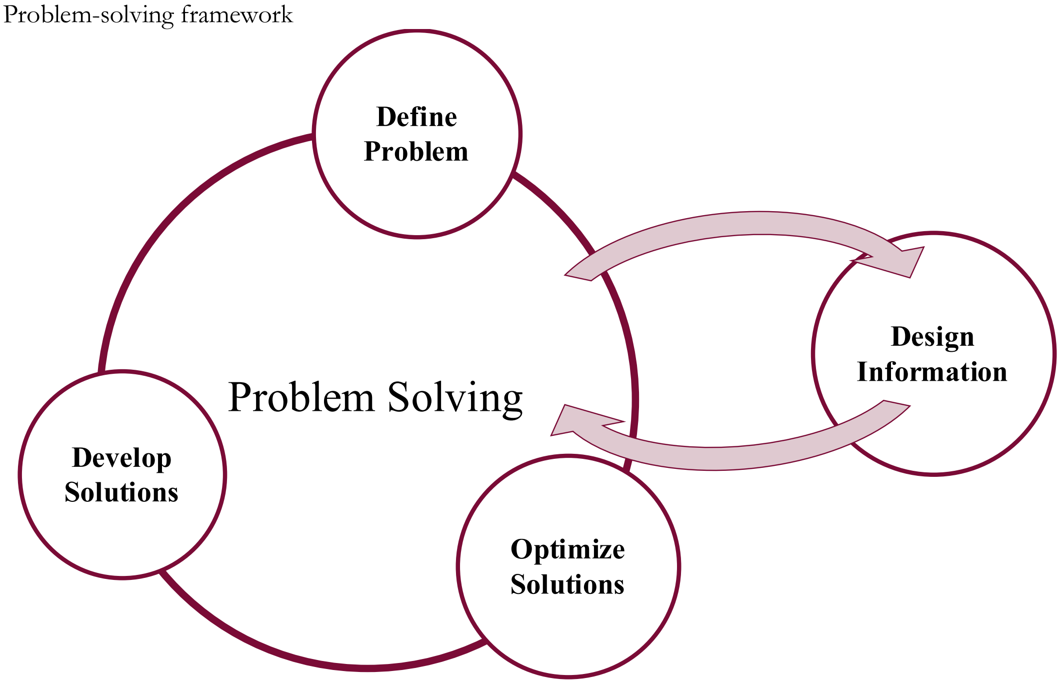


Table 2

Problem-solving skills

Define Problem	**Define the problem to be solved and the constraints of the problem** ・Define the problem to be solved ・Identify constraints to consider when solving problems
Develop Solutions	**Generate solutions to problems** ・Generate ideas that satisfy the definitions, constraints, as much as possible from knowledge and experience ・Comparing ideas and evaluating better ideas ・Creating new ideas by combining multiple ideas
Optimize Solutions	**Optimize solutions to make them more problem-solving** ・Anticipate the consequences of implementing the solution ・Ability to identify areas for improvement based on actual results, and forecasts. ・Improving solutions based on improvements.
Design Information	**Searching for, processing, and obtaining information that can be applied to the knowledge needed** ・Definition of information needed ・Searching for information ・Acquisition of information ・Processing information ・Organizing and presenting information

The first problem-solving stage was "Define Problem". In this stage, the learner defines what the problem is based on a given problematic situation. Specifically, it is a behavior in which the learner discovers and clarifies what the problem is and how to successfully solve it. In addition, we also define the constraints of the problem-solving process.

The second problem-solving stage is "Develop Solutions". Here, solutions are generated for the defined problems. It is not limited to a single solution but includes the generation of multiple ideas that could help solve the defined problem, comparing the ideas with one another to determine which one would be the best solution and then making a decision accordingly. It may also involve combining multiple solution ideas. "Develop Solutions" also includes identifying the effects of the generated solutions to other problems, not only the defined one.

The third problem-solving stage is "Optimize Solution". This refers to the optimization of the generated solution to one that is closest to successful conditions and one that is feasible to implement within the constraints. The solution is improved by either anticipating the future with the implemented solution or by prototyping and implementing the said solution. Based on the improvements, the problem-solving behavior is to optimize the solution.

Lawson and Dorst (2013) shows that problem-solving is not a linear but an iterative approach that is repetitive. Therefore, these problem-solving actions are repeated by the learner as needed until an optimal solution to the problem is determined.

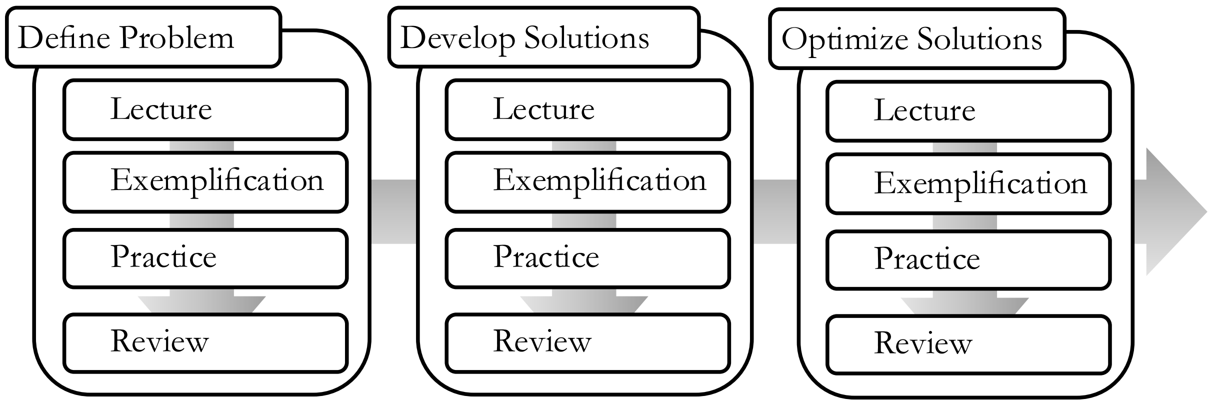
Furthermore, it is assumed that knowledge and information that the students discover new knowledge each time they perform the problem-solving actions. Therefore, "Design Information" is the fourth problem-solving activity that is performed as needed. In this stage, learners search for information they need using the Internet and then design information as that which they can use and cannot use. It involves not only searching for information, but also crosschecking multiple pieces of information to see if they are reliable, collecting correct information, and processing it into information that can be used by the learners.

Design Problem-Solving Framework

Consider a lesson design that teaches a problem-solving framework. We know that problem solving is more effective when skills are used (Matthe and Turpin, 2019). Therefore, we believe that lessons should be developed that focus on a single problem activity, rather than teaching and utilizing skills in a single unit and using all the skills at once (Figure 3). After that, a problem-solving class that encompasses all skills in a single sequence of problem-solving is required.

Figure 3

Instructional Design



Discussion

In this paper, we developed a problem-solving informatics-related framework for learners. First, a learner problem-solving model was developed. Then, the problem-solving skills included in the model were identified for each problem-solving stage.

This paper does not examine the effectiveness of this problem-solving model. Therefore, it is necessary to verify the effectiveness of the problem-solving model by conducting classes in which the said model is taught.
Moreover, this model was developed to achieve the learning objectives of the Japanese information science course. Therefore, when using this model in other contexts, it is necessary to consider whether it can be used as a problem-solving framework as it is, or whether it needs to be modified to suit different learning objectives.

Conclusion

In this study, we developed a problem-solving framework to support learners' problem-solving behavior in Japanese information science.

First, we developed a problem-solving framework that is considered to achieve the learning objectives of the information science course by referring to previous studies of problem-solving models. The learning objectives of the course are to conduct problem-solving activities using information and information technology problem-solving and to acquire the knowledge and skills necessary for such activities. In the future, it is necessary to verify the effectiveness of this problem-solving framework when taught to learners.

Second, it is necessary to design effective classes for teaching these problem-solving skills. The problem-solving skills were presented as concrete actions in the said framework, and the actions that should be taught to the learners were clarified. As a result, it is necessary to consider instructional strategies for effectively teaching these skills. In addition, it is clear that there is a need to create problem-solving materials that utilize the abovementioned framework. Problem-solving materials. The subject matter should be prepared in such a way that the problem-solving framework can be applied to it. This problem-solving framework emphasizes the use of information and information technology. Therefore, it is necessary to prepare problem-solving materials that will generate information retrieval and other problem-solving activities, so that students will not be able to complete the problem-solving process only with their own knowledge.

Future Tasks

The first task is to improve the problem-solving model so as to enhance the problem-solving skills. The problem-solving model presented in this paper is still in the development stage and will be subject to improvement and change depending upon future research. It is hoped that more research on problem-solving will succeed in developing a more effective model. It is also desirable to develop a method to present the specific skills used at each problem-solving stage in a form that is easy for learners to understand.

Next, topics and lessons should be designed based on this problem-solving model. Guidelines for designing lessons are required to facilitate the teacher's teaching of this problem-solving framework. Since it is said that complex skills, such as problem-solving, should be acquired through practice, it is also necessary to create situations in which students will have to actually solve problems utilizing this model.

In addition, a scale for measuring problem-solving skills, such as the Problem-Solving Invebtory (PSI) (Happner & Petersen, 1982), is also necessary. However, it has been pointed out that PSI questionnaires rely on subjective evaluation (Pérez et al., 2017); therefore, objective evaluation is needed in future research to evaluate problem-solving performance. Specifically, it is necessary to develop an index that can correctly evaluate the problem-solving ability of learners.

On the basis of the above, our future studies will focus on developing a problem-solving ability model and problem-solving skills, and design courses aimed at the acquisition of these skills. Subsequently, we will evaluate the learners who have taken the classes and investigate to what extent their problem-solving skills have changed. On the basis of the results, we will develop a model that can contribute to the improvement of the learners' problem-solving skills.

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