The Effectiveness of Engineering Design Based Instruction on Problem-Solving Actions in High School Information Class

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Abstract
This study focuses on the teaching of problem solving in “Information” in Japan. One of the issues is that the retention of problem-solving skills in information science has not been explained, and it is not known what kind of problem-solving framework is effective in teaching problem-solving skills. In this study, we developed a problem-solving framework based on engineering design. We have proposed a problem-solving model that explicitly instructs students to search for information to solve problems and to select and use information that they can use when teaching the problem-solving framework. It is necessary to design lessons using this model and to verify its effectiveness for learners.

Keywords: Problem-solving, Information, Engineering Design, Information Problem-solving

1. Introduction

1.1. Problem-solving ability

Various definitions of the abilities that we want to develop in children of the future include 21st century skills, key competencies, and so on. For example, 21st century skills and key competencies are listed, and the 21st century skills list ten skills in four areas that children should develop. One of these is problem-solving ability (Griffin et al., 2013). The key competency is the ability to deal with complex problems. These indicate that children are required to develop problem-solving skills.

This problem-solving ability is defined in many places. For example, the OECD (2012) defines problem-solving skills as "To understand problems for which solutions are not immediately apparent, cognitive processing to generate a solution, and a proactive approach to solving problems."

A distinction is also made in terms of the problem to be solved (Jonassen, 2000). distinguishes between well-defined and ill-defined problems. A well-defined problem is one for which the solution and the process leading to it are clear. Poorly defined problems are those for which there are multiple possible solutions or processes leading to a solution, or for which no single solution has been determined. In contrast to good-definition problems such as
mathematical problem solving, there has not been much research on ill-defined problems, suggesting that we should focus on problem solving for ill-defined problems, since problem solving is the ability to solve problems that do not yet have solutions, according to the OECD and 21st Century Skills. This suggests that the focus should be on problem solving for ill-defined problems.

1.2. Problem-solving ability in Japan

In response to international trends, problem-solving skills are also being emphasized in Japan. The Ministry of Education, Culture, Sports, Science and Technology (MEXT) (2018) has identified language skills, information use skills, and problem-solving skills as the abilities that form the foundation of learning. MEXT indicated that it aims to develop these abilities through school education.

In particular, “Information” is a subject that fosters problem-solving abilities. The goals of this subject are to acquire the problem-solving skills necessary for problem solving and to utilize information and information technology for problem solving.

Efforts are being made to develop problem-solving skills in information science. For example, Murai and Ito (2004) used Excel to solve problems at a school festival based on the problem-solving content generally presented in textbooks. Yoshida and Nakai (2009) taught the PDCA cycle as a problem-solving flow and conducted problem-solving using an information system. Nagai and Kikuchi (2009) solved local problems by utilizing big data. These practices were conducted as problem-solving in the information science course, and the students' motivation for problem-solving was found to have improved. In addition, knowledge of the subject matter was improved. However, the improvement of problem-solving skills was not evaluated. Therefore, these studies do not reveal whether learners are actually able to solve problems. Nor do they provide instruction in problem-solving skills. In fact, a comparison of Japanese “Information” textbooks shows that some do not teach problem-solving skills, suggesting that teaching methods are not well-defined.

These findings suggest that there is a need for teaching problem-solving skills in informatics in Japan. However, it is not clear what should be taught for problem-solving skills when teaching problem-solving. It is necessary to clarify the framework of problem solving and how to teach it in order to develop problem solving skills.

1.3. Problem-solving Framework

Many studies have been conducted on problem-solving frameworks. For example, Polya's (1945) mathematical problem solving and Schoenfeld's (2013) mathematical problem solving are based on problem solving for mathematical problems. These summarize solutions to mathematical problems. They are also considered to be applicable to problem solving in everyday life. From the perspective of cognitive psychology, there is also a model called the Geneplore model (Finke, 1999), which summarizes research on human creativity and models the process of creative emergence (Figure 1). The model divides the cognitive process of problem solving into two stages: generation and exploration. In Preinventive Exploration and Interpretation, the images created in A are interpreted and explored to make them meaningful. These two processes are repeated, and the final image is created through a cycle of modification and revision. These two structures provide constraints on the image. There is also the IDEAL
problem-solving step. This is a summary of the five steps of problem solving: I; Identifying Problems, D; Defining problems, E; Exploring alternative approaches, A; Acting on a plan, L; Looking at the effects.

Thus, efforts are being made to capture the framework of human problem solving from various perspectives. In this study, we would like to use a framework in which problem solving can be taught as a skill. The NRC (2013) emphasizes that engineering design is a problem-solving skill that should be taught to all children.

The NGSS (2013) defines engineering design as (A) Defining and delimiting engineering problems (B) Designing solutions to engineering problems (C) Optimizing engineering problems. These problem-solving actions are considered to be iterative until the problem is solved (Table 1). The effectiveness of teaching this engineering design has also been studied.

Atman and Bursic (1996) showed that, using a textbook, learners who learned engineering design showed more sophisticated problem-solving behavior than learners who did not learn engineering design, although they took longer to solve problems. Furthermore, Atman et al. (2007) reported that when problem solving according to engineering design, proficient problem solvers spend more time on problem definition and information gathering problem solving behaviors. In addition, Li et al. (2016) demonstrated that engineering design can support problem-solving behavior by having learners practice designing a crane and a fan with LEGO bricks according to an engineering design, showing the potential of engineering design to enhance problem-solving skills. Based on these results, we hypothesized that teaching engineering design as a framework for problem solving may lead to the acquisition of problem solving skills by learners.
| **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 |

Tamaki and Watanabe (2021) taught engineering design as a framework for problem solving in an information science course in Japan. They conducted a class by specifying the problem-solving skills that enable the problem-solving behaviors included in engineering design. Before and after the class, groups of four or five students engaged in problem-solving activities, and the difference between the two problem-solving behaviors was investigated. The results showed that the problem-solving behavior was refined. However, it was found that there were differences between the groups due to the teaching of engineering design. One of the reasons for this is that the group that actively searched for information considered necessary for problem solving tended to have more sophisticated problem solving behavior. Therefore, it is considered necessary to provide additional guidance on the use of information for problem solving in addition to engineering design.

1.4. Information Problem Solving

Information Problem-solving The concept of information problem-solving is described as combining the skills needed to access and use information. It is described as a concept that combines the skills needed to access and use information (Gruwel et al., 2009). The IPS-I model summarizes this IPS, which consists of (a) defining information problem, (b) searching information, (c) scanning information, (d) processing information, (e) organizing and presenting information. From these five, it is said to be able to search for information to be used for problem solving and to process information until it can be used for problem solving.
2. Purpose

To develop a problem-solving framework to improve problem-solving skills for teaching information science in Japanese high schools. Based on Tamaki and Watanabe (2021), we will investigate the impact of teaching engineering design, including information retrieval, on learners' problem-solving skills.

3. Methods

We determined the problem-solving process based on the engineering design. We divided the problem-solving process into four categories: (A) Define Problem (B) Develop Solutions (C) Select the Solution (D) Predict Solution's result. The skills required for each problem-solving process are listed (Table). The relationship between the problem-solving process and IPS is modeled (Figure). (Fig.) We believe that teaching these skills will help learners refine their problem-solving processes and improve their problem-solving skills.

The first problem-solving situation is Define Problem. This problem-solving behavior is a problem-solving behavior in which the learner defines what the problem is based on the situation in which the learner is engaged in problem-solving. Specifically, it is a behavior in which the learner discovers and clarifies what the problem is that needs to be solved and how to successfully solve the problem. In addition, we also define the constraints for problem solving.

The second problem-solving situation is Develop Solutions. This problem-solving behavior is to generate solutions to the defined problems. The solution is not a single solution, but rather multiple solution ideas that are thought to solve the defined problem. It is also possible to generate new solution ideas by combining multiple solution ideas. It also includes identifying the effects of the generated solutions on problems other than the defined one.

The third problem-solving behavior is Select Solution. This is the process of comparing, examining, and deciding which of the solutions will bring the solution closest to a successful state.

The fourth problem-solving behavior is Predict Solution's Result. This problem-solving behavior is to predict the outcome of the generated solution, identify points for improvement, and optimize the solution. The solution is improved by either anticipating the future with the solution implemented or by prototyping and implementing the solution. Based on these improvements, the solution is optimized.

It has been shown that problem solving is not a linear approach, but an iterative one. Therefore, these problem solving actions are repeated by the learner, as needed, until a solution to the problem is determined.

In each of these problem-solving activities, it is assumed that knowledge and information that they do not know will be needed. At that time, they are required to search for and utilize information as indicated in the IPS-I model. They are required to search for information they need using the Internet, etc., and to select information that they can use themselves. It involves not only searching for information, but also cross-checking multiple pieces of information to see if the information is reliable, collecting correct information, and processing the information into information that can be used by the learners themselves.
### Table 2. Problem-solving skills

<table>
<thead>
<tr>
<th>Define Problem</th>
<th>Define the problem to be solved and the constraints of the problem</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Define the problem to be solved</td>
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<tr>
<td></td>
<td>• Identify constraints to consider when solving problems</td>
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<tr>
<td>Develop Solutions</td>
<td>Develop solutions to problems</td>
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<td></td>
<td>• Generate ideas that satisfy the definitions, constraints, as much as possible from knowledge and experience</td>
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<tr>
<td></td>
<td>• Creating new ideas by combining multiple ideas</td>
</tr>
<tr>
<td>Select Solution</td>
<td>Select the solution that is considered most optimal</td>
</tr>
<tr>
<td></td>
<td>• Comparing ideas and evaluating better ideas</td>
</tr>
<tr>
<td>Predict Solution’s Result</td>
<td>Make predictions using the solution</td>
</tr>
<tr>
<td></td>
<td>• Identify improvements based on predicts</td>
</tr>
<tr>
<td></td>
<td>• Improve solutions based on improvements</td>
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</tbody>
</table>

**Figure 2.** Problem-solving model
4. Conclusion

In this study, we proposed a problem-solving model based on engineering design. In addition, the problem-solving skills considered necessary for each problem-solving behavior were specified. These models were developed based on previous research, but have not yet been verified by a survey. In the future, it is necessary to verify the effectiveness of the model by implementing it in many classroom situations, such as information science classes in Japan.

It is also necessary to consider how to design classes in which this problem-solving framework is actually taught. It is believed that complex skills such as problem solving cannot be acquired immediately. Therefore, it is necessary to design classes in such a way that learners can acquire them without fail.

References


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