Examination of the Theoretical Framework for Science Learning Material Incorporating Activity of Engineering in Elementary School STEM Education

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Abstract

The national curriculum guidelines in Japan were set as a standard by the Ministry of Education, Culture, Sports, Science and Technology, and the subject matter studied in schools must comply with them. The science curriculum guidelines emphasize the relevance of science in society and everyday life, but in many science lessons, students are learning to solve problems only in the context of science, and not that of society and everyday life. Therefore, we developed a learning material that would cover this aspect, in compliance with the learning contents stipulated in the Japanese curriculum. In this study, we showed the theoretical framework of STEM education that applied to the learning material and clarified how STEM education could be realized in Japanese science lessons. First, based on previous studies, we adopted the context of problem-solving in society and everyday life into science lessons and introduced engineering activities. Next, we chose a model of Learning-by-Design (LBD) proposed by Kolodner as a theoretical framework for STEM education, which fits the purpose of this study. Based on these examinations, we developed a learning material named 'Science MIRAI', which includes Gigo blocks (made in Taiwan), a control box with Arduino for programming, a lesson plan in compliance with the Japanese curriculum, and worksheets. There were three important points in the development of the learning material: (1) selecting the learning contents of electromagnets, (2) adopting the context of separating steel and aluminium cans for recycling, and (3) devising how to introduce engineering, while retaining the science learning contents. The learning plan of Science MIRAI based on LBD enabled students to learn and apply science in the context of problem-solving in society and everyday life, triggered by engineering activities. Furthermore, the results also demonstrated that science lessons incorporating engineering raised students' awareness of science in practice.

Keywords: *STEM, LBD, relevance to society and everyday life, problem solving, engineering.*

1. Introduction

In 2005, an organization supporting the collaboration between industry and academia in education was established In Tokyo, Japan, with an aim of returning the intellectual property of universities (e.g. Tokyo Gakugei University) to society. It was named Tokyo Gakugei Univ. Children's Institute for the Future and has promoted research and development of organized STEM education for school and social education and playgrounds since 2013.

One of the practices promoted in the STEM education project of the Institute is the development of learning materials such as the 'MIRAI (future)' series for STEM education in compliance with the Japanese curriculum. 'TECH MIRAI' is intended for junior high school students learning technology, and 'Programming MIRAI' and 'Science MIRAI' are intended for elementary school children. This study will focus on Science MIRAI: a science learning material that incorporate engineering activities. Japan has national curriculum guidelines applied as a standard that are issued by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), and the subject matter studied in schools must comply with them. Recent science curriculum guidelines emphasize the relevance of society and life, but the blueprint is not shown. Thus, in many science lessons, students are learning to solve problems only in the context of science, while pragmatic application in society and everyday life is lacking. Therefore, we have developed Science MIRAI to help students explore science in the context of problem-solving in society and everyday life. It is also in compliance with the learning contents as stipulated in the Japanese national curriculum guidelines.

This study showed the theoretical framework of STEM education applied to Science MIRAI. Furthermore, it will clarify how STEM education was realized in Japanese science lessons.

2. Examination of the theoretical frameworks of STEM education for developing Science MIRAI

It is well known that STEM education integrates multiple disciplines: science, technology, engineering, and mathematics. However, there are various perspectives regarding the integration of STEM education. For example, STEM only means science (or mathematics); STEM means science and incorporates technology, engineering, or mathematics; STEM means coordination across disciplines; STEM means complementary overlapping across disciplines; or STEM means a transdisciplinary course or program [1]. This indicates that the perspective and the framework of STEM education differ depending on its position and purpose.

This study examined the theoretical frameworks of STEM education for the development of Science MIRAI, considering the background of Japanese science education. In Japan, the relevance of science education in society and everyday life is emphasized for raising students' interest in learning through realizing the significance and usefulness of learning science [2], [3]. In addition, the training of innovators who could solve unexperienced problems in society and life was anticipated in 'The 5th Science and Technology Basic Plan' adopted by the Japanese Cabinet in 2016. Therefore, based on previous studies, first, we decided to incorporate the context of problem solving in society and life into science lessons and introduce engineering activities [4], [5], [6].

Next, we chose a model that would fit the purpose of this study, Learning-by-Design (LBD) proposed by Kolodner [7], as a theoretical framework for STEM education. Previous studies have examined some STEM education theoretical frameworks [8]. In this research, engineering (i.e. creative activity) was introduced into science lessons (i.e. exploratory activity). Hence, we focused on LBD as the learning model. LBD's learning process consists of different two cycles: 'design/redesign' and 'investigation'. These cycles are bridged by 'Need to do' and 'Need to know'. Investigation is caused by 'Need to know'. Furthermore, Yata et al. [9] showed that in the context of Japanese subject principles, the engineering process was relevant to each STEM discipline. Therefore, LBD was considered effective in motivating Japanese students in science learning and hence chosen as a theoretical framework in this study.

On the other hand, we found that there is a challenge in adopting LBD directly into Japanese elementary school science classes. If LBD is introduced as it is while complying with Japanese curriculum guidelines, time will be insufficient. Thus, in this study, we adjusted LBD to practice it in a limited time by reducing and simplifying the engineering activities of each stage with scaffolding. The model is presented in Figure 1 as Adjusted-LBD.

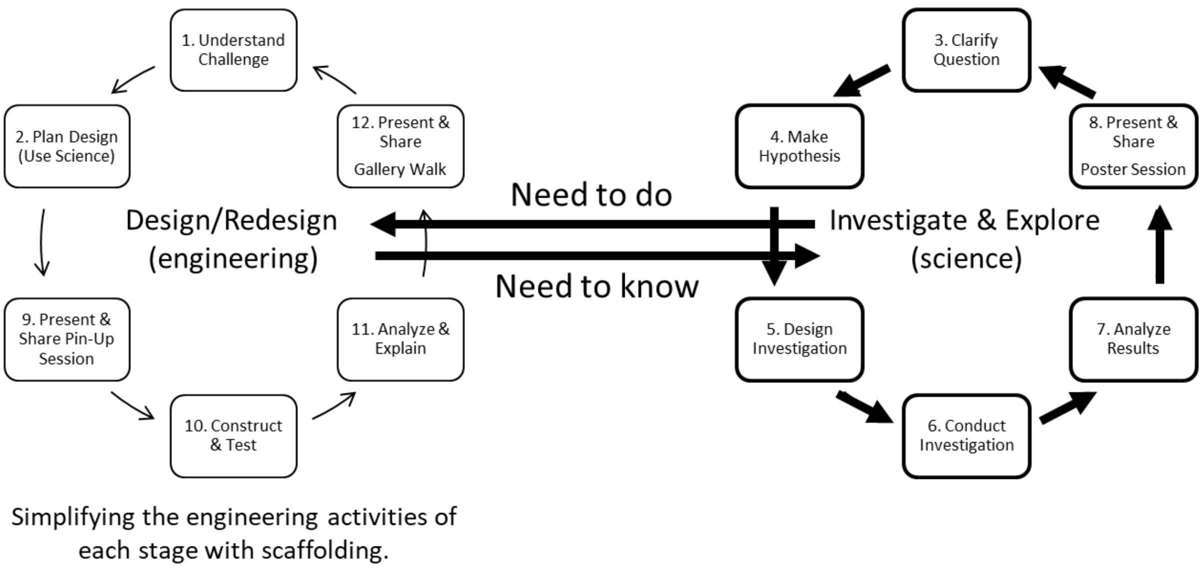

Fig. 1 Adjusted-LBD

3. Application of theoretical framework and development of a learning material

Based on the assessments, we adopted Adjusted-LBD as a theoretical framework and developed a learning material named Science MIRAI for STEM education in elementary school science. It consists of Gigo blocks (made in Taiwan), a control box with Arduino for programming, a lesson plan in compliance with the Japanese curriculum, and worksheets. The development of the lesson plan was based on the following three important points:

Point 1: Selecting learning contents
Some science learning contents may easily adopt engineering activities, while others may not. Thus, we selected engineering activities that are easy to introduce. Specifically, we developed a learning material that conforms to the Grade 5 curriculum on electromagnets in Japan.

Point 2: Adopting the context of recycling
As a context for solving problems in society and everyday life, we chose the context of improving garbage and resources problem, and labour shortage problems due to a declining birth rate and aging population in Japan. Specifically, we planned science lessons incorporating engineering activities: creating lifting magnets and tackling the issue of efficient separation of steel and aluminium cans.

Point 3: Devising how to introduce engineering while retaining the science learning content
The main purpose of the lesson is to study science, and not the engineering activities. Therefore, we carefully ensured that students would learn the learning contents (e.g. types of magnetic poles; generation of magnetic intensity with an electric current flow; and the effects of magnitude of electrical current and number of coil turns on the strength of an electromagnet) specified in the Japanese curriculum. In addition, we considered the standard number of hours (11–13 hours) that would be assigned to this lesson. Hence, we designed and prototyped simplify engineering activities by presenting a prototype machine (basic model) with its building manual as a scaffolding for 'Challenge 1' to the students so that they could learn within the limited time. Students could revise the basic model and solve problems with less time spent in trial and error. No model or manual would be presented in the subsequent challenges. Students have to revise the first basic model to solve the next challenge. In this manner, we devised a mode to learn within the specified time by reducing the cost of initial design and trial production.

The main parts of the lesson plan were as follows:

Challenge 1: Separate steel and aluminium cans for recycling
- Consider how to separate cans and make a basic lifting magnet (see Fig. 2)
- Separate steel and aluminium with the lifting magnet

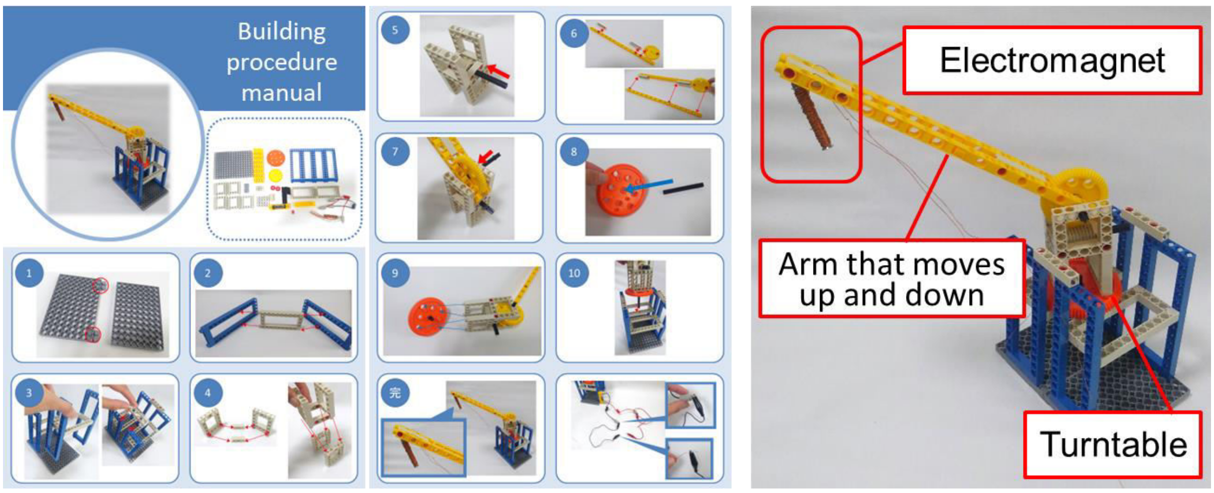

Fig. 2 Basic lifting magnet model and its building manual

Challenge 2: Separate more efficiently
- Investigate the relationship between the number of batteries (magnitude of electrical current) or the number of coil turns and the strength of the electromagnet's magnetic force
- Improve the lifting magnet for more efficient separation

Challenge 3: Operate the lifting magnet automatically using a computer program

In this paper, we focus on Challenge 2 and outline the lesson plan applied in the Adjusted-LBD in order to show when 'Need to do' and 'Need to know' occur and how student back and forth of learning processes (see Fig. 3). Here, 'Need to know' occurs at the stage '2. Plan Design' in the Design/Redesign process, leading to a switch to science exploratory activities.

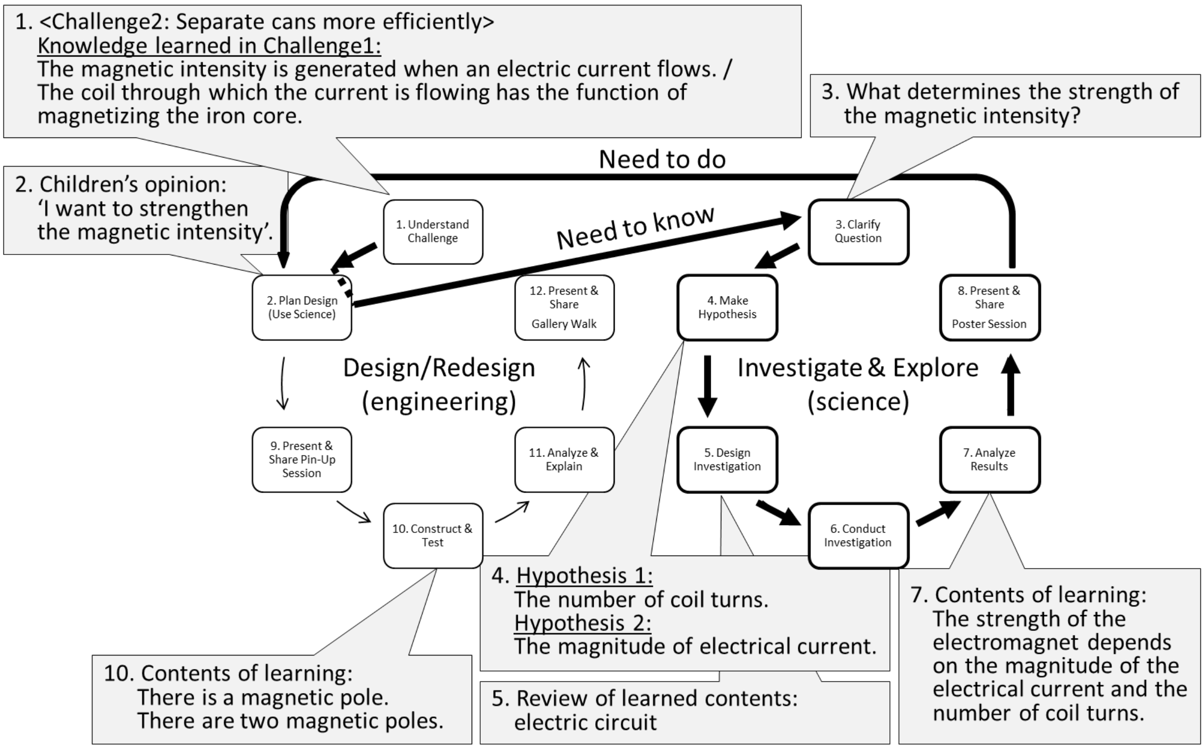

Fig. 3 Learning process of Science MIRAI focused on Challenge2

4. Conclusion

This paper considered a theoretical framework for science learning materials that incorporates engineering activities in elementary school STEM education. As a result, an important point of the theoretical framework was clarified: simplifying engineering activities by introducing scaffolding in order to retain learning contents of science even after introducing engineering. In addition, the results of the test practice showed that the learning plan of Science MIRAI enabled students to learn science in the context of problem-solving in society and everyday life, triggered by engineering activities. Furthermore, the results also showed that science lessons incorporating engineering raised students' awareness of the practicality of science [10].

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