Engaging STEM Education for High School Student in Japan: Exploration of Perception to Engineer Profession

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Engaging STEM Education for High School Student in Japan: Exploration of Perception to Engineer Profession

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Abstract

While Science-Technology-Engineering-Mathematics (STEM) education is expanding worldwide, engineering reminds as both valuable and difficult element to integrate. Understanding students' perceptions of the engineer might be key to enhancing their interest in engineering careers in the future. These perceptions also could be a valuable insight to science educators who demand to develop more STEM activities. In our framework, a case study was used to explore the perceptions of 16 students as they participated in STEM activities at a Junior High School in Japan. After participating in the activities, students completed a questionnaire about the profession. Data analysis was guided by a focus on general perceptions of engineering, it's clusters, and discussions of how it related to the literature and socio-cultural of Japan. Text analysis was conducted, especially in terms of frequency network and hierarchical cluster analysis. Our findings indicate that students' perceptions were related to making or creating, technology, and machines. Five clusters of responses were found. The "design" and "solve the problem faced by society" clusters were influential. There were disparities between the students' perceptions and the definition of engineering, especially regarding constraints and the use of science and mathematics concepts. Therefore, STEM education needs to be promoted especially in problem solving and designing activities to support positive perceptions in engineering profession.

Keywords*:* Engineering, Engineer Profession, STEM Activities, Students' Perceptions

INTRODUCTION

Preparing students to deal with future situations has become a continuous challenge for educators. As initial steps, some worldwide organizations defined certain goals and sets of skills or knowledge that would be needed in the future called 21st-century skills (Partnership for 21st Century learning 2009; Suto & Eccles 2014; Chalkiadaki 2018). Those skills are expected to bridge our present and future needs. In our daily lives, humans are constantly immersed in the process of designing something to fulfill our needs. This activity is closely related to engineering and technology, without which the life expectancy of humans would only be around 27 years (Miaoulis 2010). This highlights the essential roles of engineering and technology, which are based on scientific and mathematical concepts (Goold & Devitt 2012; Kelley & Knowles 2016; Strimel & Grubbs 2016; Doko Gjonbalaj 2018). Therefore, to prepare the young generation for an unpredictable future, integrating engineering and technology in the education system is vital (Chu et al. 2016; Abdulwahed & Hasna 2017).

Integrating the engineering, mathematics and technology education in science classes is one of the realistic ways to do so. STEM education became promising approach to conduct that achieve positive perception from teachers (Khuyen et al. 2020). One of method to implement STEM education is through Engineering Design Process (EDP). Recent researchers found that EPD could bridge students in group activities (Wieselman et al. 2020) and problem-solving skills (Syukri, Halim & Mohtar 2018). However, in many Asian countries, emerging engineering is a rare feature of the K-12 curriculum (Lee, Chai & Hong 2019; Ngan et al. 2020). Therefore, researches related engineering are important to conduct to support STEM education in Asia.

There is a global concern that students appear to be unenthusiastic about science-related fields. In Japan, this issue has been gaining attention since the 1980s. Several projects attempted to address it, such as the Super Science High School program (Naganuma 2015) and elective science classes, but the problem persists. Recently, the Organization for Economic Co-operation and Development (OECD) concluded that Japanese student enrolment in science, technology, engineering, and mathematics (STEM)-related classes had declined (Ishikawa, Fujii & Ashlyn 2013) and there was a negative attitude toward science at the junior high school (JHS) level (Harada, Sakamoto & Suzuki 2018). Due to the limited opportunities for engineering and technology education, introducing those concepts in science classes as part of STEM lessons could be a promising first step.

In contrast with the attention paid to increasing students' interest in science-related professions, deeper investigation into how students perceive these professions has been limited, especially regarding the engineering profession. The importance of students' perceptions of professions, particularly science-related professions such as engineering, has been well established (Shanahan & Nieswandt 2011; Sadler et al. 2012; Mohtar, Halim & Rahman 2019).

Research shows that students' perceptions of the engineering profession demonstrate a lack of clarity. Elementary school students believed that engineering is a closed profession for certain people (Capobianco et al. 2011). The engineering profession has also been pictured as involving manual work in an outdoor setting (Fralick et al. 2009). While students' interest can be sparked at a younger age (Griethuijsen et al. 2015; Sakata & Kumano 2018), high school is a particularly valuable time for students to further their interest and possibly decide to enter or reject the engineering profession (Verdín, Godwin & Ross 2018). While for younger students, pictures could be an effective way to explore their perceptions of the profession, we argue that high school students can explain their perceptions clearly through writing.

The current study was guided by the following research questions, after following the STEM activities; how do students describe their general perception of an engineer? and what clusters, if any, are found from their responses?

METHOD

This research was conducted with a single case study to explore students' perceptions of the engineering profession after they had participated in STEM lessons. Case study research uses a qualitative approach in which the investigator explores a case over time through detailed, in-depth data collection and reports a case description and case-based themes (Yin 2014). In this study, the elective science class that tries to infuse STEM lessons represents our case and the unit analysis is each student, as shown in Figure 1. After students had completed two introductory STEM projects, their perceptions about the engineering profession were explored from their responses to an open-ended questionnaire. Individual analyses were conducted to understand the responses and a case-level analysis was conducted to capture the general idea of their perceptions and the clustering of those perceptions, and to relate the perceptions with literatures.

Context

This research was situated in an elective science class supported by the science education department of one of Japan's national cooperation universities. Although no school in Japan declares itself a STEM school, elective classes have become one of the ways to introduce STEM integration to students. This elective science class is conducted in weekly, 50-minute sessions for one semester. The purpose of this activity is to facilitate students who are interested in science to be involved in STEM projects. Because this activity is separated from regular science class, the activities are designed more flexibly than the science curriculum guidelines and are considered an introduction to integrated STEM activity. The projects followed the EDP steps laid out in Figure 1. The two introductory projects were planned by a team of three graduate students and three science teachers, who considered former similar projects. The graduate students are licensed as science teachers and had participated in professional development for STEM education. The teachers have more than five years of experience and are actively involved in teaching science lessons. Student participants interacted with both their teacher and the graduate students who collected the data.

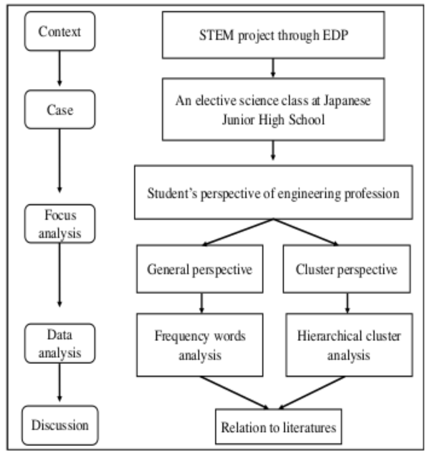

Figure 1. Research Framework

Curricular Context

Each project was conducted with the consistency of EDP steps. The overview of our activity as a curricular context can be seen in Figure 2. The project started with an introduction to a problem through a problem letter, which explained the problem, and specified criteria and constraints of the client's need. A worksheet was also provided for each group of students. For Project 1, the problem is "how to design an effective aluminum foil boat" and for Project 2 "how to clean the water from oil spill". Some specific science concepts that were needed for designing the solution were explored, such as the Archimedes principle in Project 1 and the density of fluids in Project 2. Each group worked together to design and redesign a solution to achieve the best result.

Participants

The 16 students that participated in this study had chosen science as their elective class. They were third-grade students at a JHS affiliated with the National University in Japan. In the elective science class, they worked in groups of four students. There was a mixed group, a female-only group, and two male-only groups. The classroom setting during the project is illustrated in Figure 3.

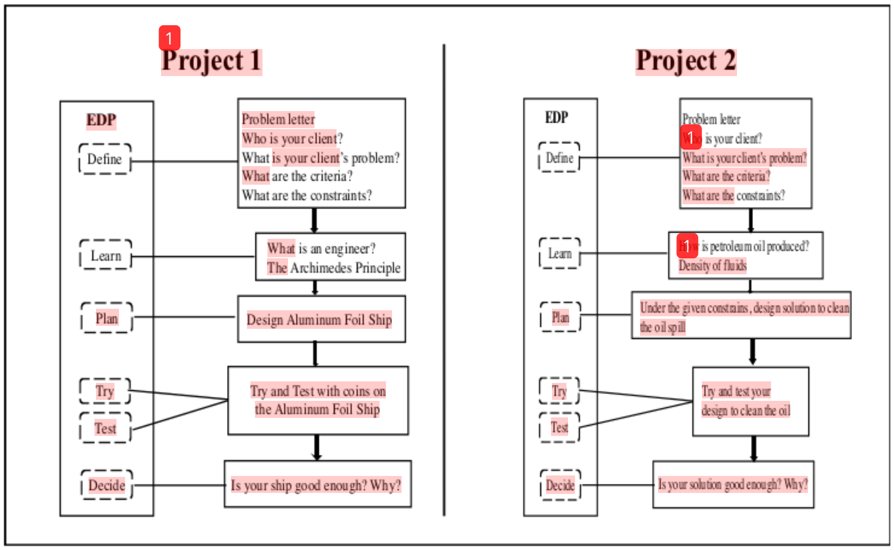

Figure 2. Circular Context

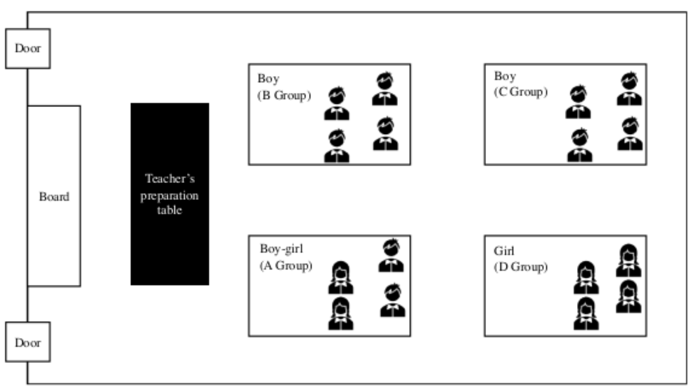

Figure 3. Classroom setting

Data Analysis

All students participating in our project were given a questionnaire asking them to describe their perception of the engineering profession. The questions are "What do you think an engineer does?" and "What are the main job of engineer?". Our participants wrote their answers on a piece of paper in our last session. After collecting the responses, two researchers collaborated to type those responses into an MS. Excel file. This file became our input for analysis.

The text analysis consisted of two steps: preliminary analysis for finding stop words and data visualization. Since the students' responses were in Japanese, to maintain authenticity, the input for the software analysis was in Japanese characters. Therefore, all qualitative analyses were performed using KH Coder software that could analyze several language inputs, including Japanese. This software uses Stanford POS Tagger to extract words, R for statistical analysis, and MySQL to manage the data (Higuchi 2016a). In the preliminary analysis, two researchers proficient in Japanese briefly analyzed the responses. To gain the core of their response, some words that did not have direct significance in terms of their perceptions were identified, such as "a little bit", "around", and "call". These words were inputted in the software as stop words and excluded from our analysis.

To discover the general perception of engineering and the clustering of those perceptions, and to relate the perceptions to theory, two different data visualizations were conducted. First, a frequency words network was performed to produce a more readable representation of the responses. The network approach is especially applicable to be used in analyzing the complex relationships among components in a system (Bullmore & Sporns 2009) and in identifying the most influential pathway (Paranyushkin 2011). Second, a hierarchical cluster analysis was performed to build a tree diagram where similar words were placed on nearby branches (Tullis & Albert 2013). This analysis enabled the researchers to analyze combinations or groups of words that had similar patterns (Higuchi 2016b). This is considered the most widespread technique, because it can determine how entities (sentences, words, subjects, etc.) can be grouped into smaller clusters based on their (dis)similarities (Gries 2015).

RESULTS AND DISCUSSION

In this section, highlights of students' descriptions of what it means to be an engineer are presented. In answering Research Question 1, an overview of students' responses was gained through analyzing their choice of words and how those words were arranged in a frequency network. From the network, general perceptions could be clearly described. We also argued that students' responses would possibly be divided into several clusters. Therefore, in answering Research Question 2, hierarchical cluster analysis was conducted. The result of this analysis was displayed in a tree diagram that facilitated our understanding. Each cluster was named based on the main idea of the words in those clusters. These clusters clarified the students' perceptions of the engineering profession.

General perceptions of the engineering profession

To understand general perceptions of the engineering profession, words frequently appeared is one of the important indicators. In students' responses, the 10 words used most frequently were: a) making, b) machine, c) technology, d) AI (artificial intelligence), e) robot, f) design, g) develop, h) car, i) repair, and j) know. In terms of frequency, "making" was the most common word, followed by "machine", "technology" and so on. These words describe the students' perceptions of an engineer. Focusing on a single word could open the interpretation of students' responses, so it was necessary to confirm how words were used to enable a deep understanding. As the most used word, "making" was further analyzed to confirm how it was used in the original responses. Key word in context (KWIC) concordance was conducted to check the context in which the word "making" was used.

Clusters of perceptions of the engineering profession

Although the result of the word frequency analysis revealed the words that students frequently used, how those words were connected remained unclear.

To understand more deeply how these words were used, a word frequency network analysis was completed, as shown in Figure 4. In this network, each word is illustrated as a node. The size of a node indicates the value of its degree. In other words, the bigger the node, the more frequently that word was used in students' responses. Node degree is one of the key indicators to measure the importance of a node in the network (Li et al. 2018). In Figure 4, three nodes are bigger than the others. These are "making", "machine," and "technology". The word "making", with the highest frequency, is illustrated as the biggest node.

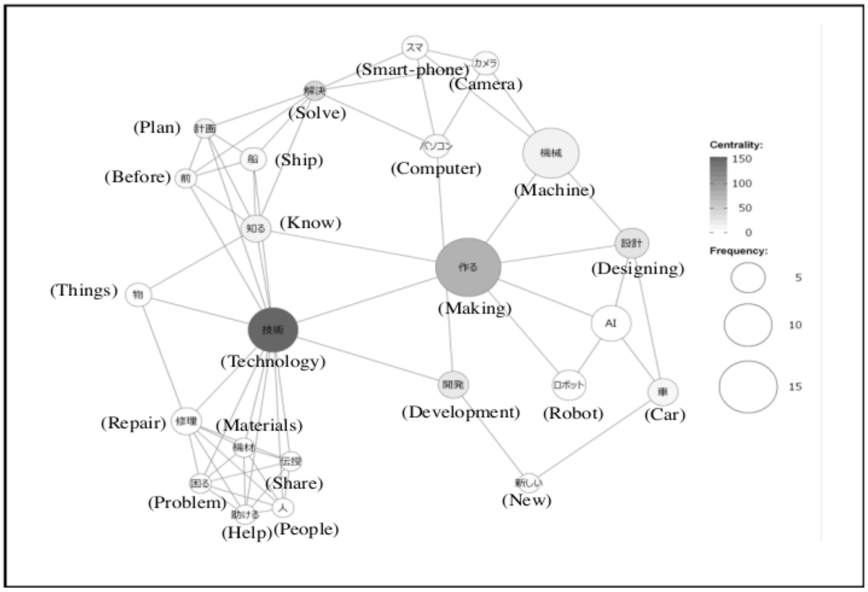

Figure 4. Word frequency analysis result

Aside from frequency, another important indicator is data centrality. Centrality measures how often a node appears between any two random nodes in the network (Paranyushkin 2011). Higher centrality means that the node is more influential as a junction within the network (Brandes 2001). This is an important indicator, because it is possible for a node to be connected to many nodes in a cluster but have few connections to other clusters. In Figure 4, color gradation is used to show centrality. The darker the node, the more that word was a central idea. Even though the node "making" is bigger, the node "technology" has a higher centrality. Therefore, the word "technology" plays a central role that connects other nodes to explain students' perceptions of engineers.

As a result of the hierarchical cluster analysis, the software created a dendrogram that is shown in Figure 5. The dendrogram shows which words were viewed as the most similar by placing these on branches that are close together. The dissimilarity line indicates the (dis)similarity among the words. Words that join together sooner, such as "robot" and "AI," are more similar to each other than those that join later, such as "make" and "robot".

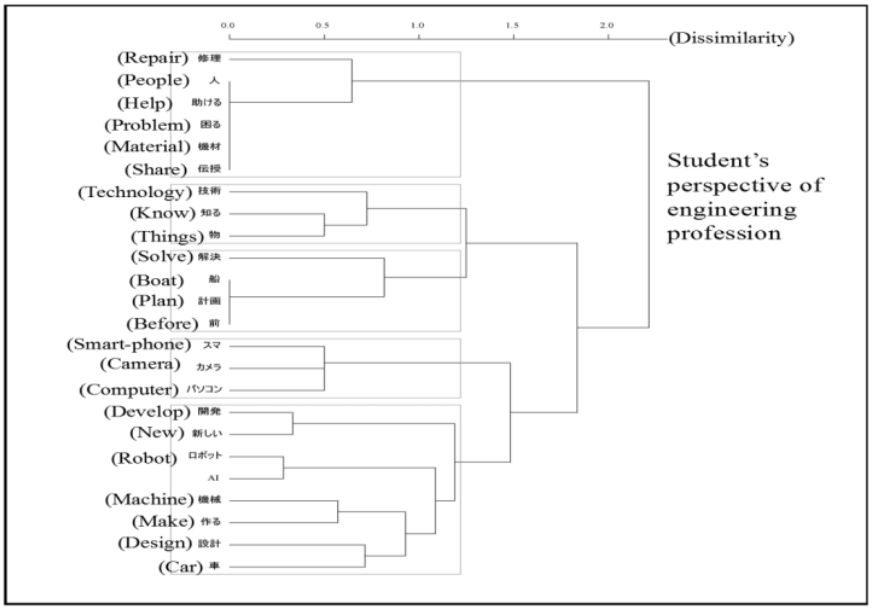

Figure 5. Hierarchical cluster analysis result

After an iterative process, the words with the highest similarity values were identified and merged into five clusters. Considering the words that categorized in the same cluster, a simplified dendrogram was created. The five clusters showed that students' perceptions of the engineering profession were related to:

a) Making, designing, developing activities;

b) Examples of technology products; c) Solving problems by making scientific plans;

d) Technology;

e) Solving problems faced by society.

From the definition of engineering in K-12, several key points could be extracted. Engineering related to the process of problem-solving under constraints using science, mathematics, and technology concepts (Miaoulis 2010; Moore et al. 2014; Whitworth & Wheeler 2017). Based on the results, students' perceptions of the engineering profession can be described using the three most frequently mentioned words: "making," "machine," and "technology". Although the word "making" was most commonly used, "technology" played a more central srole in students' responses, as seen in the word frequency network analysis. Furthermore, from the hierarchical cluster analysis, five clusters of students' perceptions were presented.

Consistent with the former analysis, "making activity," "technology," and "technology products" clusters were extracted from the responses. Interestingly, two other clusters related to "problem-solving" appeared. Even though the words "solve" and "problem" were not frequently used, the idea of an engineer as a problem-solver for society was recognized as important.

Problem-solving is one of the 21st-century skills that could be nurtured through STEM activities (Hammack et al. 2015; Priemer et al. 2020) especially Engineering Design Process (Syukri, Halim & Mohtar 2018). This is supported by a former study which revealed that problem-solving is effective in engineering processes that involve planning, designing, constructing, and evaluating for a specific problem (Bagiati & Evangelou 2015; English & King 2015). In comparing the results to the definition of engineering, constraints and applying science or mathematics concepts were not mentioned by the students. In line with our results, former explorations of students' perceptions through interviews also revealed that students tend to explain the practical applications of engineering (Verdín et al. 2018). In summary, the students in this study expressed their perceptions of the engineering profession as a job related to technology, the process of making something, machines, and problem-solving.

Application of Technology Content to the Perception

An adequate link between the engineering profession and technology is clearly expressed from the students' perceptions. Technology, as defined in Table 1, is easily understood by students with observation of technological objects. Although the word "making" was used most frequently, from the network (Figure 3) the word "technology" played a more central role in students' perceptions. This word connected with many other words used by the students to describe the engineering profession. Consistent with the network, out of five clusters, two were closely related to technology. We urge that this perception also influenced by sociocultural factors (Brand, Glasson & Green 2010; Wang, Guo & Degol 2019). Therefore, our result also could be explained by the historical perception of science and technology in Japan and the brief logic of Japanese characters, especially at the JHS level. The history of science and technology can be traced from the 16th century, when Japan and many countries around the world were involved in war. Japan's history can be divided into several distinguishable eras: a) stone age to statehood (0-710), b) the period of courtiers and warriors from the Nara-Heian-Kamakura-Muromachi-Azuchi-Momoyama era (710-1600), c) the closed country period in the Tokugawa-Edo era (1600-1868), d) the beginning of the modern nation in the Meiji period (1868-1912), and e) the pacific war era and post-war era (Kenneth 2004). Numerous records of highly innovative ideas became the foundation of modern technology in Japan, starting from the Azuchi-Momoyama era with the production of guns, to infrastructure in the Edo era, to the worldwide fame of scientists in the Meiji era (Maruyama 2000). The separation between scientists and engineers is also reflected in Japan's history. Hideki Yukawa, the first Japanese Nobel Prize winner (for physics in 1949), led to the image of the pure scientist profession becoming more appealing (Low 2001). These historical facts are studied by young Japanese students from elementary school to JHS. Therefore, from the very beginning, technology is seen as closer to the engineering profession. Students rarely mention science in explaining their perceptions of engineers. A brief introduction to the logic of Japanese characters could help explain how technology has become an important concept in explaining the engineering profession. The origin of Japanese characters can be traced back to ancient Chinese characters in the 4th century that were adapted (Heisig 2007). Two sets of characters are used to express "engineer," as shown in Figure 6. Most of the JHS students in this study use the first set of characters, which is commonly used in younger students' textbooks. For example, in the students' 9th-grade science textbook, one of the topics is "For the bright future of the earth: Nature, humans and technology," which uses this set of characters (Arima 2015). This set consists of two parts: the "technology" character and the "person" character. When the Japanese assume that two items are related (items could be physical entities, ideas, persons, social structures, etc.), they commonly begin by examining how the items overlap internally, rather than by looking for something additional that externally connects them (Kasulis 2019). This possibly affects the students' perception of the engineering profession as strongly related to technology.

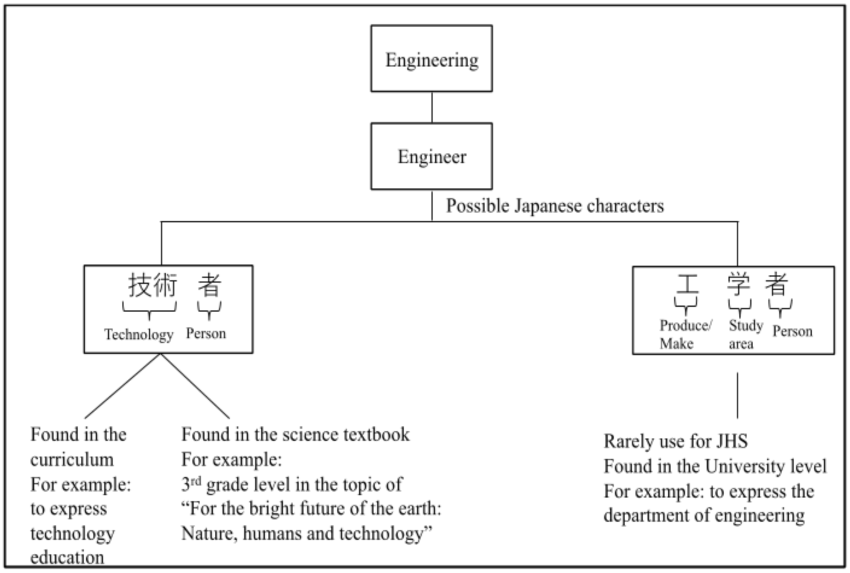

Figure 6. Rationale from language

While the connection between technology and engineering was common in the students' perceptions, the application of science and mathematics content was rare. The worksheet used during the project included a section about the science concepts related to the project. However, this part did not directly support the students' design challenge. As the students applied their science and mathematics concepts to their design process, surface understanding was required. Therefore, the group activity likely did not advance the science and mathematics part. Several former studies have also revealed that during group activities, students discussed the project but rarely conveyed ideas based on science or mathematics concepts (Woods-McConney, Wosnitza & Sturrock 2016; Wieselmann et al. 2019). This needs to be further explored in future research. More comprehensive projects that continue during each grade in JHS will allow for more meaningful STEM experiences (Corbett & Coriell 2013). Elective science classes are one of the options for infusing EDP at JHS level. However, the deep application of science and mathematics concepts needs to be nurtured over a longer period.

LIMITATIONS

This research provides an understanding of how students describe their perceptions of the engineering profession. Although clear perceptions were found, some limitations occurred in this study. First, students' exposure to integrating engineering affects their perceptions (Honey, Pearson &

Schweingruber 2014). Exposure through two short projects was insufficient to completely build their perceptions. A longer project could deepen understanding and build more comprehensive perception. Others research also showed that longer project could build students critical thinking (Mutakinati & Kumano 2018; Hartini, et al. 2020). Second, while our project used EDP, our focus was not on students' perceptions of the process. Further research on EDP would allow for a more complete perception of engineering. Third, since the application of science and mathematics concepts is unclear in students' perceptions, additional questions are probably needed in future questionnaires, such as "how is the engineering profession related to science and mathematics concepts?". Lastly, since the participants were in the 9th grade in JHS, there was no accurate information on how their perceptions interfered with their choice of Senior High School.

CONCLUSION

Our findings indicate that exposure to STEM activities could bring positive perception of engineer perception to JHS students in Japan. The students' perceptions were related to the activity of making or creating, technology and machines. Five clusters of responses were found, of which the "design, make, develop new technology" and "solve problems faced by society" clusters were influential. The EDP steps in which students participated were clearly illustrated in the students' responses. There were disparities between the students' perceptions and the definition of engineering, especially regarding constraints and the use of science and mathematics concepts. Immerging more STEM activities to nurture the positive perception of STEM carrier is needed to the future research. Moreover, STEM education needs to promote more to the engineering aspect especially in problem solving and designing activities.

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