Toward Interdisciplinary Teamwork in Japan: Developing Team-based Learning Experience and Its Assessment

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Abstract

Over the last ten years, the Japan Accreditation Board for Engineering Education (JABEE) has increasingly emphasized the importance of multidisciplinary teamwork abilities. Despite heavy investment to improve mechanical engineering education in Japan, the effectiveness of the education has not been sufficiently discussed. Traditionally, students are assessed on their in-depth understanding of specialized knowledge. With the surge of project-based learning, evaluation is largely focused on students' final product or research results. We take a different stance and join the emerging call to foster engineering students' abilities of knowledge acquisition, communication, teamwork, and creativity. To evaluate these abilities, we have combined cultural perspectives with a student-centered approach to inquire what constitutes engineering and its practice in Japan. We discuss the challenges and propose qualitative and quantitative methods to evaluate student learning in Japanese engineering design education.

Introduction - Who is an engineer? Today and future

The engineering educational situation in Japan is quite unique. Japan has a disproportionately large post graduate student body pursuing natural science and engineering as compared to social sciences and humanities. This is uncommon in other countries, such as US, Germany, France, UK, and South Korea [1]. In addition to an extremely large number of other technical workers, Japan has an estimated 400,000 engineering researchers leading the field through technology development as shown in Fig.1. This number is close to the total number of doctors and dentists in Japan. Ohashi gives an estimate of technical personnel composition in Japan [2]. While engineering is popular in school, it is intriguing that students do not associate engineers with real images, according to a study, "Who is an engineer?" conducted with 1048 junior high and high school students in Japan [3]. We recently replicated this study and found that half of the freshmen in the mechanical engineering department at Kogakuin University could not answer the question, "What is an engineer?." The elusiveness of the term "engineer" is undoubtedly a cultural product of Japanese upbringing and K12 education. This is certainly concerning, because if future engineers cannot identify with the concept of engineering, they might not understand their role, not just as a technical persons, but also as key collaborators for solving complex, interconnected societal problems in the world. Japanese engineering education has a huge responsibility for this, and it can play a pivotal role to improve the situation.

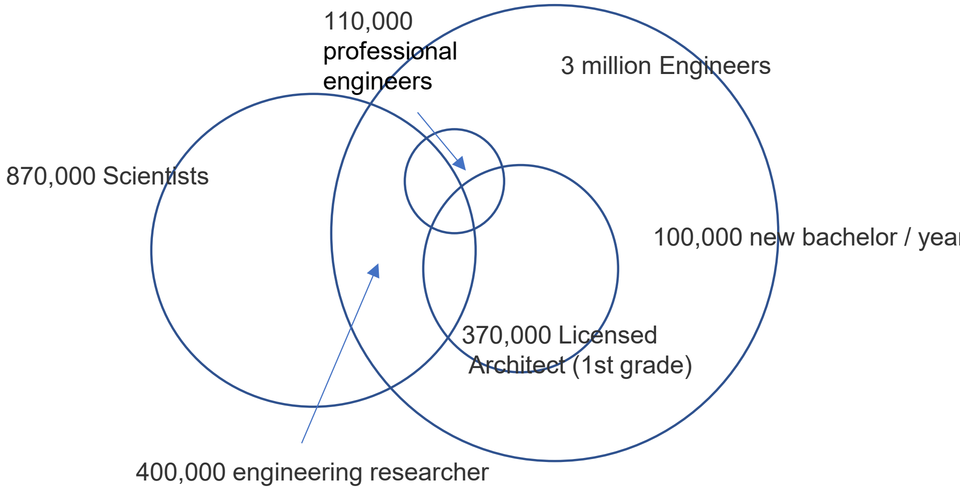


Fig.1 : Quantitative components of science and technology personnel in Japan (Source:[2])

The question, "What constitutes engineering?", is more difficult to answer today than it was fifty years ago. Japanese engineering societies have called for educational transformations to respond to the changing society within the country and in the world. In the chairman's greetings of the Journals of Japan Society of Mechanical Engineers and the Japan Society for Precision Engineering[4, 5], the necessity of workforce training in the engineering field and its adaptation to meet the changes brought about by AI and globalization, has been emphasized. In November 2018, the Ministry of Education, Culture, Sports, Science, and Technology announced the "Grand Design for Higher Education for 2040 (report)," and in June 2019, the Government Council for the Promotion of Integrated Innovation [6] stated the importance of rebuilding engineering education, regardless of the existing frameworks, for universities to respond to the challenges raised in the Sustainable Development Goals and to support the AI based society. New education models have been proposed for human resources development in response to changes in the structure of science and technology (for example, the fourth Council for the Promotion of Human Resources Development for Industrial Revolution in Japan [7]). Despite these initiatives, we feel that the value of engineering education and engineering education research are not sufficiently recognized in Japanese academia.

Obstacles of interdisciplinary teamwork in Japanese engineering education

As the Japanese economy is slowing down and there is a decline in the working-age population, academic and industrial entities have been actively looking for ways to revitalize the economy. For instance, a large number of Japanese educators and corporations have visited Silicon Valley, which has played a key role in many of the transformations that have been attempted by Japanese organizations in recent years [8]. Design thinking has been included in the curriculum for engineering schools at top universities in Japan, such as the University of Tokyo and the Kyoto Institute of Technology. Also, problem-based learning (PBL) [9, 10] and active independent learning have been actively adopted in the country [6]. An example is the industry-academia collaborative implementation of PBL [11] as exemplified by ME 310 at Stanford University. A central theme across these hands-on experiential learning models is teamwork. Multidisciplinary teamwork forms the base of innovation as innovation requires collaboration between innovators with highly specialized expertise from a heterogeneous background. The introduction of interdisciplinary teamwork education in Japanese engineering education has been discussed and implemented for about ten years to comply with the global engineering education standards, as stated by ABET and others. The JABEE has proposed that students should foster the ability of being team members as well as the abilities of a leader. It is suggested that, "Japanese engineering students should acquire the ability to interact with people of diverse cultures, values, and interests, and to collaborate with people from a wide range of specialties, which is necessary when working in a globalized world" [12]. JABEE has also proposed rubrics to evaluate teamwork abilities[1]. However, when it comes to teaching and learning teamwork, especially for innovative problem-solving projects that have high degrees of uncertainty, we lack the essential understanding of what good teamwork is and how to foster it in a group of students. In addition, the assessment of teamwork ability is much lower in priority than the traditional focus on fostering deep domain knowledge. For instance, at this point, master's education is still heavily anchored on the evaluation of research results and in-depth understanding of specialized knowledge, rather than problem-solving and interpersonal skills [6].

Student diversity in Japanese universities, especially in engineering universities is extremely low and this makes multidisciplinary teamwork education harder. Also, there is lot of gender disparity in these schools [13]. In an interdisciplinary design innovation workshop we conducted in 2018 at Kogakuin University, because of the lack of disciplinary diversity in the engineering student body, students of business and art and design background from other universities, some of whom travelled from other cities, had to be drawn in. In addition, all the engineer participants were males. At leading research universities, such as the University of Tokyo, there is very little diversity in various areas, as a large percentage of students advance from the same high school. In addition, many engineering faculty in Japan do not recognize the importance of student diversity in their classrooms, and that this diversity is the basic element to learning teamwork. In traditional Japanese educational curriculum, engineering educators themselves do not collaborate across disciplines or departments. The lack of gender and background diversity in engineering faculty is also another limitation. The lack of recognition of the problems and the under-examined social realities of engineering classrooms in Japan are all practical obstacles for teamwork education.

Cultural considerations of interdisciplinary teamwork and its evaluation for Japanese engineering education

When it comes to PBL outcome evaluation, a team of students may get very different grades in the US as compared to Japan. Unlike assessing fundamental science knowledge, the evaluation of interpersonal abilities is highly subjective, and thus culturally dependent. A common view is that Japanese prioritize quality over novelty, and conversely, Americans celebrate novel ideas more than quality. As increasing cross-cultural research is conducted on cultural psychology and engineering education, it has been observed that while Americans desire high-arousal emotions, the ideal emotion for the Japanese is regulated calmness [14]. This implies that in the US, to impress the instructors during the final presentations, student groups are advised to show excitement and to smile. On the other hand, this would certainly confuse the teachers in Japan. Similarly, in terms of creativity in the US, emphasis is laid on empowerment and positive energy, as seen in design thinking educational programs. However, in Japan, creativity is based on reprimand and high pressure. As delineated in [15], an executive in charge of development at Honda remarked, "It is like putting team members on the second floor, removing the ladder, and telling them to jump or else. I believe creativity is born by pushing people against the wall and pressuring them almost to the extreme." Forrester also found self-censorship plays an important role in Japanese innovation teams [16].

Although the necessity of learning to work in a team in higher education is profoundly stated (such as in [7]), in many cases the methodology to teach is a copy of the successful educational model of the US, without much deliberation on cultural differences. This is especially problematic given that teamwork is not a simple, abstract concept. Many of the good practices in teamwork education are rich and subtle and these may be lost in translation and cross-cultural modeling. For instance, in Japan, cooperation is historically and culturally considered an important teamwork skill. Therefore, when it comes to teaching teamwork and its evaluation, engineering educators who fail to reflect on their own cultural perspectives may understate the importance of conflicts and instead favor respectful, harmonious cooperation. However, task conflicts, when modulated well, can function as sources of creativity and innovation, a necessary engine in the early, diverging phase of innovation [17]. We believe that it is important to enable Japanese students to learn both collaboration and cooperation with people from diverse backgrounds.

Given the complexity of teamwork and its context dependency, we believe that a simple rubric as proposed by JABEE is not enough. It is necessary to develop a method to measure teamwork learning while taking into consideration the cultural context of the country.

Methods

To develop team-based learning curriculum and its evaluation in Japanese engineering education, we first replicated Ohashi's survey [2], "What is an Engineer?." The answers to the questionnaire reflect the sociocultural value of engineering in Japan from the perspective of future engineers. More specifically, we asked a hundred freshmen in the Department of Mechanical and Systems Engineering at Kogakuin University, the following question, "Who do you associate with the word 'Engineer'? Please write down the names of three people. If the person is not popular, please add a brief explanation."

In response to the lack of interdisciplinarity in the pipelines of our default educational system, we developed a high-quality interdisciplinary curriculum for engineers, with adequate cultural considerations. We conducted the first prototype of the curriculum in the form of a two-day workshop in summer, 2018. We then developed it into a full-semester engineering course at Kogakuin University. Recently, it has also been adapted into a shorter workshop. This interdisciplinary PBL program emphasizes the sharing of information through need-finding and storytelling prototypes in the field. In addition, to allow rich, in-depth learning of teamwork, we designed a PBL project timely relevant to Japanese society, yet which is also grounded in students' daily experiences, and accessible in terms of collecting data and effecting class-level intervention. This project is related to the Shinjuku Station (Fig. 2) near Kogakuin University. Interdisciplinary student teams are challenged to address the following question, "How to radically improve the experiences in the Shinjuku station for the elderly?" (Fig. 3(a)). In typical Japanese engineering education, there is not enough learning about the art element shown in the left part of Fig 3(b). We are proposing a curriculum that will effectively study the four quadrants, such as Engineering,Production, Design, and Social Sense. Within that curriculum, interdisciplinary teamwork workshops are an important part of the curriculum.

We performed a comparative analysis between a single-specialty team and a multidisciplinary team. The evaluation method of Team-based Engineering Design Projects in this study is as follows. Based on the results of, the "What is an engineer?" questionnaire, the students attended a lecture on design thinking and a PBL task of Shinjuku Station was assigned to them. Teamwork learning can be evaluated in a variety of ways, including with the use of a rubric (Table. 1) at the beginning and end of classes, student reports and artifacts, video analysis of movements and facial expressions, speech recognition, and student interviews. An example of teamwork learning is provided by JABEE, which evaluates the acquisition of teamwork skills by the VALUE Rubric [18]. However, in Japanese universities, the number of classes is very large and students have to answer numerous questionnaires. It is very important to use a questionnaire that takes into account the context of engineering education. We believe that students would be able to understand the acquisition of creativity and divergent thinking through the difference between the rubric of design thinking [19] and the mindset questionnaire in Table 2.

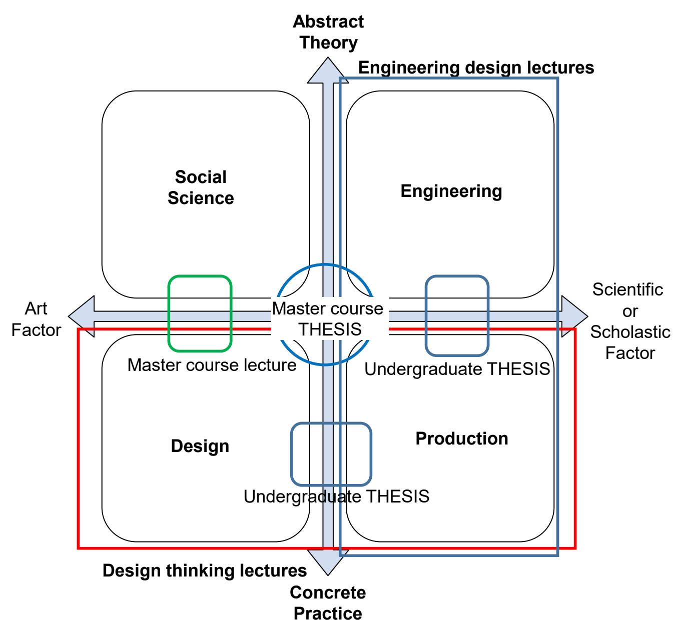
(a)A view of station ticket gate

(b) A view of a train leaving Shinjuku Station during commuting time.

Fig. 2 : Shinjuku Station is the busiest station in the world. (This culturally adapted design project asks a team of students from diverse backgrounds to radically improve the Shinjuku Station experiences for the elderly through engineering and design interventions. Shinjuku Station, the busiest station in the word, is conveniently located near Kogakuin University, and to solve problems for the elderly is a societally relevant and timely project topic.)

	Day1	Day2
Morning	Getting to Know Each Other + Teamwork Experiences	Design Challenge Part Ⅱ
Afternoon	Design Challenge Part Ⅰ	Presentation + Reflection

(a) Interdisciplinary design workshop schedule (two days workshop)



(b) Proposed framework for engineering education with design thinking [24]

Fig.3 : Interdisciplinary design workshop and proposed framework for engineering education with design thinking

Table 1 : Example of rubric of design thinking lecture [19]

「Lecture Name：Design Engineering 」

Rubric

ID：________________ Name：________________

For each of the levels below, please select a close match from the choices 1-7

能力

	Evaluation item	Level 1 ① Missing	Level2 ②	Level3 ③ Towards	Level4 ④	Level5 ⑤ Meets	Level6 ⑤	Level7 ⑥ Exceeds
1	**Empathy**	Difficulty in explaining empathy to the user		Be able to describe a limited range of empathy for the user, including insights or needs about the user that are not expected		Be able to explain human emotions, physical needs, and unexpected insights or needs about the user, and through this show empathy for the user		In addition to the level 5 evaluation items, a more rich description that includes a variety of surprising insights and deep needs, as well as deeper user empathy can be demonstrated.
2	**Define**	Difficulty in reframing initial goals (unframing things and seeing things in a different framework)		Inability to clearly reflate (redefine) the initial goals. Inaccurate use of nouns to describe needs.		The initial goal can be clearly reframed by responding to the user's needs by using "verbs" to describe activities and requests for areas where the user needs help.		In addition to the level 5 evaluation items, it is possible to discover and explain complete and novel user needs.
3	**Ideate**	Difficulty in creating ideas		Generating ideas with convergent thinking that comes down to a certain limited range of ideas and concepts		Divergent thinking results in a large, diverse range of ideas and concepts. Selec4ng a few ideas and concepts to move forward with that represent that diversity.		In addition to the level 5 evaluation items, the ideas created can produce an overwhelming amount of ideas, ranging from very practical to unfeasible (if not impossible).
4	**Prototype**	No experience in completing prototypes		It can provide a partial solution to the user's needs. Only one prototype produced or a very small number of iterations.		By taking what is learned from each user test and repeating simple prototypes, more advanced prototypes can be created to provide a solution to the user's needs.		In addition to level5 prototypes are tested in a thorough,engaging manner.
5	**Test**	Using prototypes to determine how ideas work		Be prepared to get an effective prototype and to hear and gather opinions for a feasible outcome.		It is possible to solicit opinions on certain features of the prototype, build up a proper test situation to validate it, and obtain results that will form the basis for future iterations.		Determine the optimal situation for testing for real-world use, test against multiple features, and obtain complex results that will form the basis for future iterations.
6	**Team**	When doing a team activity, I don't know what to be aware of in order to get along in a team		Team functions as a whole most of the time. Some members are more engaged than others.		Team functions as a whole with all members contributing.		In addition to Level5 members work to encourage and teach one other.
7	**Story telling**	The team is not able to tell the story of the solution.		Team can describe their solution with some connection to P.O.V. and/or empathy.。		The team can describe the solution in relation to the prototype, the user's perspective and feelings.		The team can tell a story that engages people by relating it to the prototype, the user's perspective and emotio

Table 2 : Example of mindset survey of deign thinking lecture

Mind

※Present awareness (please choose the closest one)

8 Are you good at "designing"? ☐①Bad ☐②If anything,bad ☐③Neither ☐④If anything,good ☐⑤Good ☐⑨ I don't know because I haven't done much design work.

Design thinking

9 Have you ever had the opportunity to design anything? ☐①Never ☐②Very few ☐③Not very often ☐④Some of the time ☐⑤Most of the time

10 Are you familiar with the phrase "design thinking"? ☐①Never ☐②Very few ☐③Not very often ☐④Some of the time ☐⑤Most of the time

11 How do you feel about "design thinking"? ☐①Not at all important☐②I'm not interested in design, so not very important☐③I'm not interested in design, bad very important ☐④very important

12 I guess I'm good at thinking of new ideas. ☐①Not at all. ☐② Not applicable ☐③Neither ☐④Applicable ☐⑤Absolutely right

13 Confidence to solve problems in a creative way. ☐①Not at all. ☐② Not applicable ☐③Neither ☐④Applicable ☐⑤Absolutely right

14 I' m acquiring a knack for developing other people's ideas. ☐①Not at all. ☐② Not applicable ☐③Neither ☐④Applicable ☐⑤Absolutely right

Personality (optional)

15 I' m shy. ☐①Not at all. ☐② Not applicable ☐③Neither ☐④Applicable ☐⑤Absolutely right

16 Mostly, I don't doubt people. ☐①Not at all. ☐② Not applicable ☐③Neither ☐④Applicable ☐⑤Absolutely right

17 Have a lazy habit ☐①Not at all. ☐② Not applicable ☐③Neither ☐④Applicable ☐⑤Absolutely right

18 I'm calm and able to deal with stre ☐①Not at all. ☐② Not applicable ☐③Neither ☐④Applicable ☐⑤Absolutely right

19 I have few artistic interests. ☐①Not at all. ☐② Not applicable ☐③Neither ☐④Applicable ☐⑤Absolutely right

20 Be diplomatic and social. ☐①Not at all. ☐② Not applicable ☐③Neither ☐④Applicable ☐⑤Absolutely right

21 I often find fault with others. ☐①Not at all. ☐② Not applicable ☐③Neither ☐④Applicable ☐⑤Absolutely right

22 I'm a perfectionist ☐①Not at all. ☐② Not applicable ☐③Neither ☐④Applicable ☐⑤Absolutely right

23 I' m prone to nervousness. ☐①Not at all. ☐② Not applicable ☐③Neither ☐④Applicable ☐⑤Absolutely right

24 Be creative. ☐①Not at all. ☐② Not applicable ☐③Neither ☐④Applicable ☐⑤Absolutely right

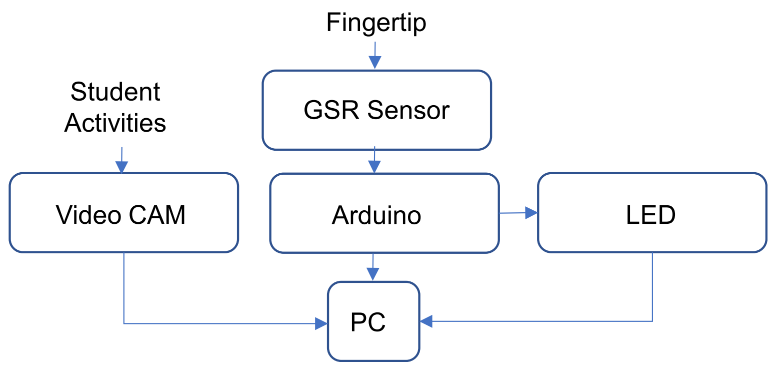


Fig.4 : Using biometric information to analyze team activity

In addition to questionnaire and observational measures, skin electrical activity is obtained to gain access to the subjective experiences of students during the learning experience. This is achieved through the system proposed in Fig. 4, which measures the psychoneurosis effect. The reason for selecting this method is as follows.
(1) This indicator has been used in a relatively classical manner, and hence, there are many related studies and it is easy to obtain evidence.
(2) To measure reactions during work and conversation, it is desirable to use a small device rather than a large one.
(3) It is desirable to be able to construct a wearable system at a low cost to simultaneously record multiple devices.
(4) As it is desirable to obtain conflicts among interactions, it is important to consider the reaction (autonomic response) of the autonomic nervous system, which has been measured and evaluated as an index of mental events such as emotion, emotion, fatigue, and stress.
(5) It is easy to organize the results because the difference of the amplitude to the stimulus can be evaluated.

Additionally, facial expression analysis using a cloud service has also been used in this study. The validity of the results was confirmed by verifying the reaction of skin electrical activity and obtaining other secondary information.

Results

Survey result of "What is an engineer?"

In response to the question, "Who do you associate with the word 'Engineer'? Please write down the names of three people. If the person is not popular, please add a brief explanation," we were surprised to learn that about 40 percent of the freshmen students could not give names of any engineers. On the basis of Fig. 5, it can be seen that global innovators such as Steve Jobs and Bill Gates are collectively recognized as engineers. Some students mentioned Japanese engineers, such as the father of a student, Soichiro Honda, and the operator of Toyota Motors, but the number is rather small. Senior students gave a limited number of answers about engineers and also described global innovators as engineers. In addition to IT innovators, many students consider Edison as an engineer. Although many studies [1,8,15,20,21] have been conducted on the cultural differences between Japan and the US in relation to innovation, we believe that this result is very important to understand the difference in the cultural background of the countries in relation to engineering education.

The results of this questionnaire are important data for engineering education teachers in Japan. In the previous chapter, it has been identified that the problem of limited diversity in Japanese university students and the uneven distribution of education due to the limited diversity of teachers are major problems. In secondary and higher education more emphasis is placed on science than on engineering. Based on the model by the Pasteur Quadrant [22], we propose an educational method that students can reach in the Pasteur quadrant, which can both explore basic understanding and consider practical applications, taking into account the use of design thinking and cultural background.

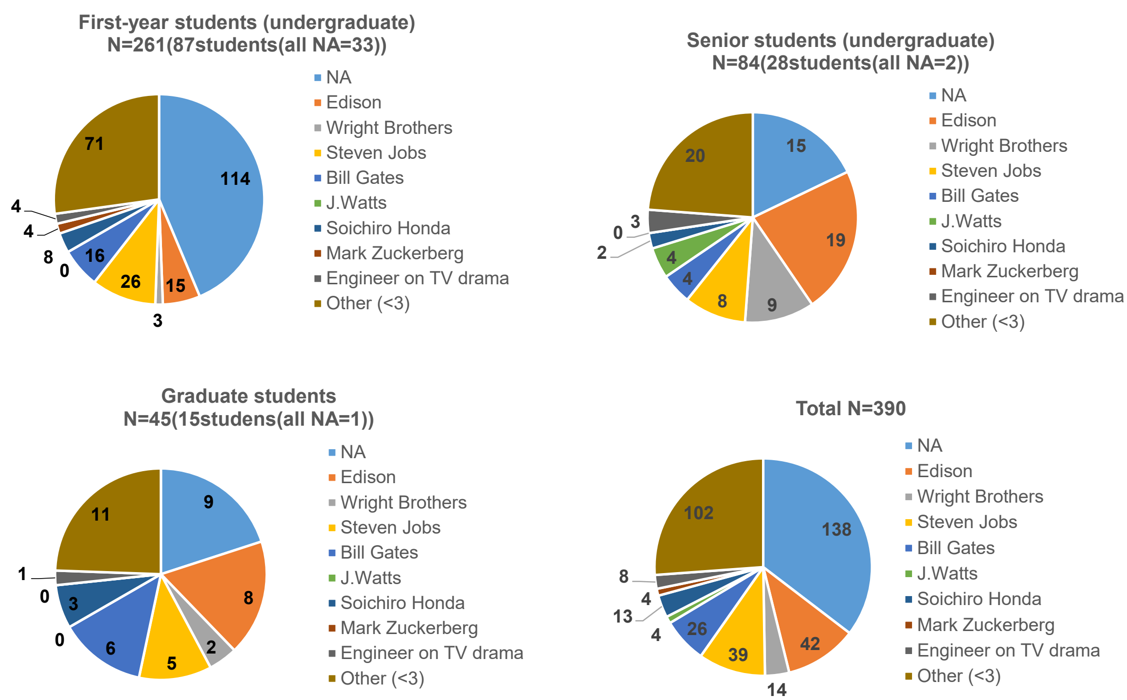
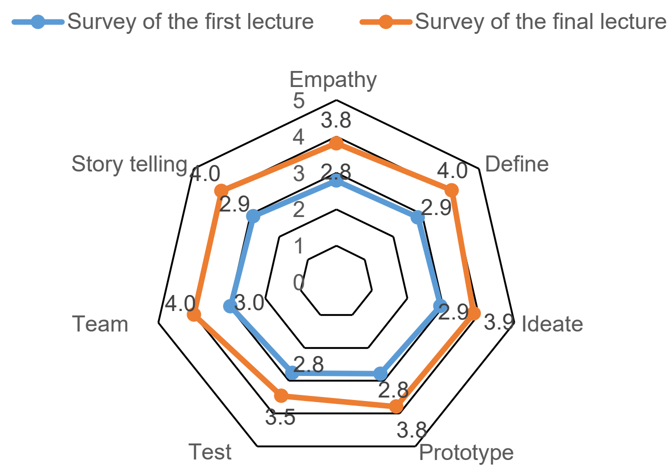


Fig.5 : Engineering students' views on engineers (Mechanical engineering department students at Kogakuin University) (NA indicates no answer)

Rubric of interdisciplinary teamwork learning

An example of the use of rubric in the evaluation of teamwork design education in PBL lectures is shown in Fig. 6. It shows how a third year mechanical engineering undergraduate evaluates the rubric in relation to his design thinking process in the first and last class. We have made these assessments over a number of years, and although they recognize the power of teamwork, they are unable to reveal the specific capabilities of teamwork. The results of the rubric of teamwork show that students could learn about teamwork, but the results of PBL by Japanese engineering students show that there are many conservative outcomes and do not generate enough ideas. We have reported the results of our research so far, and it is considered that the measurement of the effect of teamwork learning is insufficient only by rubric [23] .



1: Missing: To require effort
3: Towards : Some results are acceptable, but more effort is needed.
5：Meets ：Satisfactory
7: Exceeds: Beyond expectations.

Fig.6 : Evaluation by using the rubric in the design engineering class (senior undergraduate students)

Interdisciplinary design innovation workshop regarding Shinjuku Station

Previous studies on the learning effect of PBL have not been able to sufficiently analyze the effect of teamwork learning, because the analysis is based on a single workshop. In this study, five groups participated in a workshop regarding the elderly at Shinjuku Station as shown in Fig. 7. Students worked on the same PBL tasks with different teams, and by comparing their experiences, students learned how group creativity and idea selection changed when teams were different. In Japanese universities, the introduction of PBL activities by teams to education is spreading, but the proportion of teaching methods in the conventional lecture format is very high, and we consider that experiencing the difference from participation in multiple PBL is very less and a big challenge.

(1)Freshman Group A (before participating in robot PBL class (engineering students only)) (2) Freshman Group B (after participating in robot PBL class (engineering students only)) (3) Third year undergraduate design students (engineering students only) (4) Graduate School of Engineering and designers and business students (5) Graduate School of Engineering and Business students. In addition, some students in the above groups participated in multiple workshops, and the trends of interviews and questionnaires were analyzed. Evaluating the characteristics of the above groups from the final outcomes of the design assignments, it was found that the curriculum context and the composition of team members influenced the students' designs[24].

Fig. 7 : Interdisciplinary design innovation workshop regarding Shinjuku Station

Use of biopsychology sensor

Considering the cultural characteristics of Japanese, it has been observed that students of this generation (Generation Z in USA) do not express their feelings. Yet, emotional experience is a critical factor in student learning. Therefore, in the first three experiments, it was difficult to correctly understand the characteristics of the team during the interdisciplinary fusion. To address this, we conducted basic experiments in biopsychology. Fig. 8 shows the skin conductance data of a student wearing a sensor while solving a mathematical calculation problem as a basic experiment. The left waveform in Fig. 8, shows the explanation of the experiment, preparation, calculation, and rest after the end, and it is confirmed that the date is acquired by the sensor which indicates the psychological changes while working. We also measured skin conductance of two students at the Interdisciplinary Workshop in Fig. 7. However, while the experiment shown in Fig. 8 was conducted by sitting down, the measurement at the workshop indicated disturbances due to physical movements. Therefore, we intend to analyze the data in future after examining methods for eliminating noise by moving the equipment wirelessly.

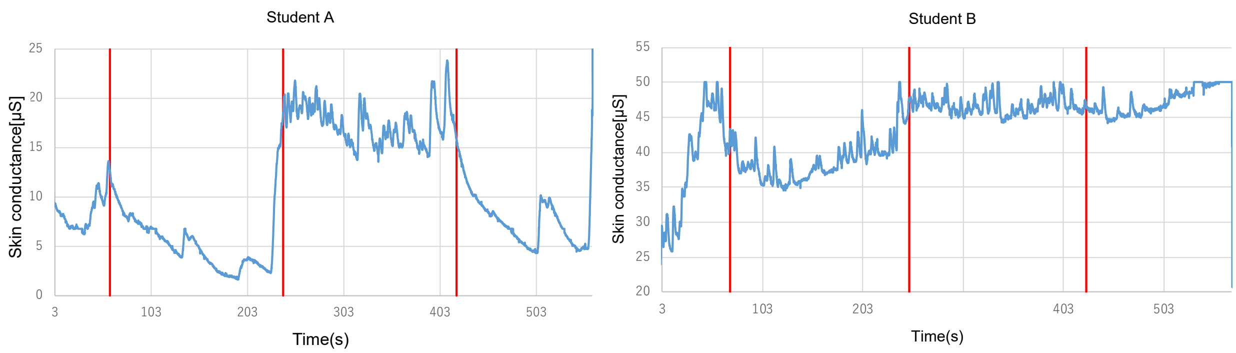


Fig.8 : Results of skin conductance

Discussion

This working paper presents the development of a teamwork learning program for Japanese engineering students and its evaluation. Our work is a testbed for understanding how to best enable science-focused, disciplinary-divided engineering students in Japan to learn to work in groups of people from diverse backgrounds and specialties. By instrumenting a real-world project (i.e., design for elderly at Shinjuku Station), our engineers would be able to establish a richer sense of who they are as an engineer, find meaning in the skills they learn at school. By embedding their learning in an interdisciplinary groupwork setting, they would acquire critical skills and experiences for future career that would otherwise be missing in the sterile environment of traditional Japanese education.

To successfully achieve these goals, it is critical to develop the right curriculum evaluation and student assessment. In recognition of the limitations of existing teamwork evaluation rubrics, we are investigating more comprehensive ways of evaluation, including other relevant surveys, as well as methods that would make student experiences more accessible for research, e.g., physiological measures. As the effectiveness of each element has been confirmed individually, it is possible to introduce appropriate interdisciplinary teamwork education in Japan in future by increasing the number of subjects and conducting more detailed analysis using AI techniques. The final goal of the research is to analyze PBL learning through a design research approach to determine the core of engineering education and to redesign the curriculum for appropriate acquisition of that core, based on qualitative and quantitative data.

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