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REQUIREMENTS FOR TEACHING MATERIALS FOR HIGH SCHOOL STUDENTS WHO ARE UNFAMILIAR WITH THE DESIGN PROCESS

Moe SHIMOMURA, Leon LOH, Yanfang ZHANG and Noriko TAKANO
Kyushu University, Japan

ABSTRACT
This study evaluated the worksheets used in the Sustainable Development Goals (SDGs) Challenge Project from the students' perspective and identified requirements for teaching materials to help students who are unfamiliar with design-based learning learn about the SDGs. We analysed students' and teachers' feedback in worksheet surveys. The findings revealed that the ideation process was the most difficult aspect for high school students. The reported reasons were categorised as originality, idea diversification, idea convergence, consistency with problems, feasibility, specificity, iterability, complexity, and procedure. Teachers mentioned that students did not sufficiently focus on problem identification, causing subsequent difficulties in the ideation process. Teaching material should meet the following requirements: (1) demonstrating methods for diversification and convergence of ideas to specify scaffolding, (2) clear goal setting in the problem identification process, and (3) iterability to allow for change according to the design process.

Keywords: Design education, design process, problem identification, ideation, Japan, high school

1 INTRODUCTION
The subject of design is not taught in Japanese high school curricula [1]. The Courses of Study (curriculum guidelines) for High Schools [2] published in 2018 changed the emphasis from knowledge and skills to three educational objectives: knowledge and skills; thinking, making decisions, and expressing oneself; and self-learning and humanity in perspective. The guidelines include a newly established subject called *Period for Inquiry-Based Cross-Disciplinary Study*. In accord with these new guidelines, a new education programme was implemented from 2022. However, high schools are still in the search phase of realising integrated quality learning and have been criticised for their lack of teaching methods and materials [3]. The Sustainable Development Goals (SDGs) Design School of the Faculty of Design at Kyushu University has collaborated with public high schools in Japan to develop teaching materials for high school students to learn about the SDGs using design thinking [4] [5]. In the rapidly changing and unpredictable society, design education is expected to foster adaptability to complex social issues. This pedagogy introduces design methods into Inquiry-Based Cross-Disciplinary Study. In addition to self-directed learning, students acquire the ability to think and express themselves through the process of identifying issues and exploring solutions.
Using descriptive worksheets, Fukusho High School implemented the *SDGs Challenge Project*, a design learning programme for all third-year students, from April to October 2022. It is a typical public high school consisting of students with a mix of academic abilities. There are supportive teachers who are willing to explore the use of design education as a form of learning for high school students [1]. The whole school focused on this programme as the pilot project started in 2018, and 27 teachers with various specialisations led the classes. The teachers consisted of a combination of one teacher with experience of this programme or a veteran and one new teacher for each classroom. They were professional educators who had a good understanding of general pedagogical knowledge, knowledge of learners and their characteristics, and knowledge of the educational contexts [6] of the high school. The lesson time for the Period for Inquiry-Based Cross-Disciplinary Study was examined in this project. Prior to the start of the project, guidance was provided for teachers covering content, curriculum, educational purposes, assessment methods, instructional plans, and schedule. The rubric outlines the competences

that students should acquire through this programme, in line with the three educational objectives described above. The ideal levels of achievement are: 1) to gather information and use it to solve a problem, 2) to clearly define the problem by understanding its context, and 3) to accept different perspectives and learn in an equitable manner. This rubric was explained in the introduction and included in the worksheets, which students could refer to at any time. The current study is part of a broader project exploring how design-based learning can be introduced and implemented in the Inquiry-Based Cross-Disciplinary Study curriculum in Japanese high schools. The current study evaluated the worksheets used in the SDG Challenge Project from the students' perspective and identified requirements for teaching materials to help students unfamiliar with design-based learning to learn about the SDGs.

2 LITERATURE REVIEW: INQUIRY-BASED CROSS-DISCIPLINARY STUDY

The Period for Inquiry-Based Cross-Disciplinary Study in Japan is in the early stages of implementation. The objectives stated in the Courses of Study for high schools are as follows [7]:

1. In the process of inquiry, acquire the knowledge and skills necessary for identifying and solving problems, formulate concepts related to problems, and understand the significance and value of inquiry.
2. Discover questions from the relationship between society, life, and oneself, identify issues on one's own, and gather, organise, analyse, summarise, and express information.
3. Cultivate the ability to work actively and collaboratively in inquiry, create new value, and improve society while making use of each other's strengths.

Specific educational content is to be determined by each school in line with these objectives. Tamura et al. [8] examined a Period for Inquiry-Based Cross-Disciplinary Study class and identified time constraints as an issue. Nishizawa [9] started the learning process with teachers presenting students with a trigger problem, which cut out the process of problem identification and shortened the required time because problem identification was challenging for high school students with limited experience. These studies examined evaluations from the teachers' perspective. Although various studies have surveyed university students taking teaching courses about integrated learning in junior or high school [10] [11], no studies have examined evaluations by high school students. The voices of high school students regarding the actual state of learning should be listened to.

The objectives of the Period for Inquiry-Based Cross-Disciplinary Study overlap with the design process practised by the SDG Design School. Education using design methods is not yet common in Japanese high schools, partially because of the lack of teaching materials using design methods in Japanese [4]. The current study evaluated the Period for Inquiry-Based Cross-Disciplinary Study from the students' perspective as a case study to provide a reference for high school teachers developing teaching materials when implementing this curriculum.

3 METHOD

We employed a qualitative research approach to build a case study around the SDGs Challenge Project implemented in the Period for Inquiry-Based Cross-Disciplinary Study in Fukusho High School. We examined the following research question: What do students find difficult in design process worksheets? Questionnaires were sent to 310 high school seniors who participated in the SDGs Challenge Project. Among the 30 processes (Table 1) described in the programme worksheet, respondents reported which was the most difficult and why. A comparable questionnaire was also administered to the 27 teachers who conducted the classes. The open-ended responses were categorised and interpreted to examine patterns or links in students' perceptions.

4 FINDINGS & DISCUSSION

300 students and 22 teachers responded to the question "Which of the 30 processes used in the programme worksheet was the most difficult?" The most common response was ideation, which 59 students found the most difficult of all the processes (Figure 1). The worksheet for the ideation process (Figure 2) required students to describe an idea to be realised in 2030, inspired by the latest technologies. The most common issues that students were expected to solve were the natural environment, followed by education and health and well-being. Examples of subjects under the natural environment included the negative impact of marine plastic waste on marine life, littering in the city, and damage to crops caused by typhoons. Open-ended responses regarding the reasons for difficulties with ideation were categorised using naturalistic inquiry [12] (Table 2). The results showed that, in order of most frequent

Table 1. Design processes in the worksheet

Consideration of issues	Selection of the team name Summarising content and thoughts on the reference materials Creating a mind map Exploration of problems Sharing problems Selection of a problem by the group Refining the articulation of the problem
Exploring the background of the issue	Historical perspective Social perspectives Sharing the research
Determining targets for problem solving	Whose problem is this? What is this problem about? Prospects for problem solving Group sharing
Research on case studies	Research on case studies Sharing case studies
Generating ideas for problem solving	Ideation Deepening ideas Sharing ideas Summarising ideas Creating a poster
Validating ideas	Third-party verification of ideas Thinking about the problems of ideas Improvement of ideas Improvement of poster
Preparing a presentation	Determining presentation role assignments Creating a PowerPoint presentation Improving posters and prototypes
Toward the final presentation	Idea improvement Creating final presentation poster

responses, originality (15 respondents), idea diversification (12 respondents), idea convergence (nine respondents), consistency with problems (six respondents), feasibility (four respondents), specificity (four respondents), iterability (three respondents), complexity (one respondent), procedure (one respondent), and other (four respondents) were identified.

The same questionnaire was also administered to the teachers who conducted the programme. Of 27 teachers, 22 responded (Figure 3). The most common response was "exploration of problems around us" by five respondents, followed by "selection of problems in groups" (four respondents) and "ideation" (four respondents). One teacher who chose ideation reported that "because students defined the problems abstractly, it was difficult for them to imagine, and the ideas were shallow. No matter how much they discussed problems, they could not seem to avoid vague themes, such as hunger and poverty in other countries, and could not come up with solutions". Three of the four respondents who selected ideation cited the vagueness of problem identification as the reason. Teachers who reported the most difficulty in the problem identification phase gave the following reasons: "At this stage, students did not have a clear idea of what the problems would be, and I felt that they gradually understood the meaning from the later processes (historical perspective or social perspectives)"; "It was hard to identify target users and to consider solutions afterwards, because the problems were not sufficiently focused on a forward-looking perspective."

5 CONCLUSIONS

The evaluation of the worksheets used in the SDGs Challenge Project from the students' perspective revealed that many students found the ideation process difficult. Requirements for teaching materials were categorised as follows: (1) demonstrating methods for diversification and convergence of ideas to

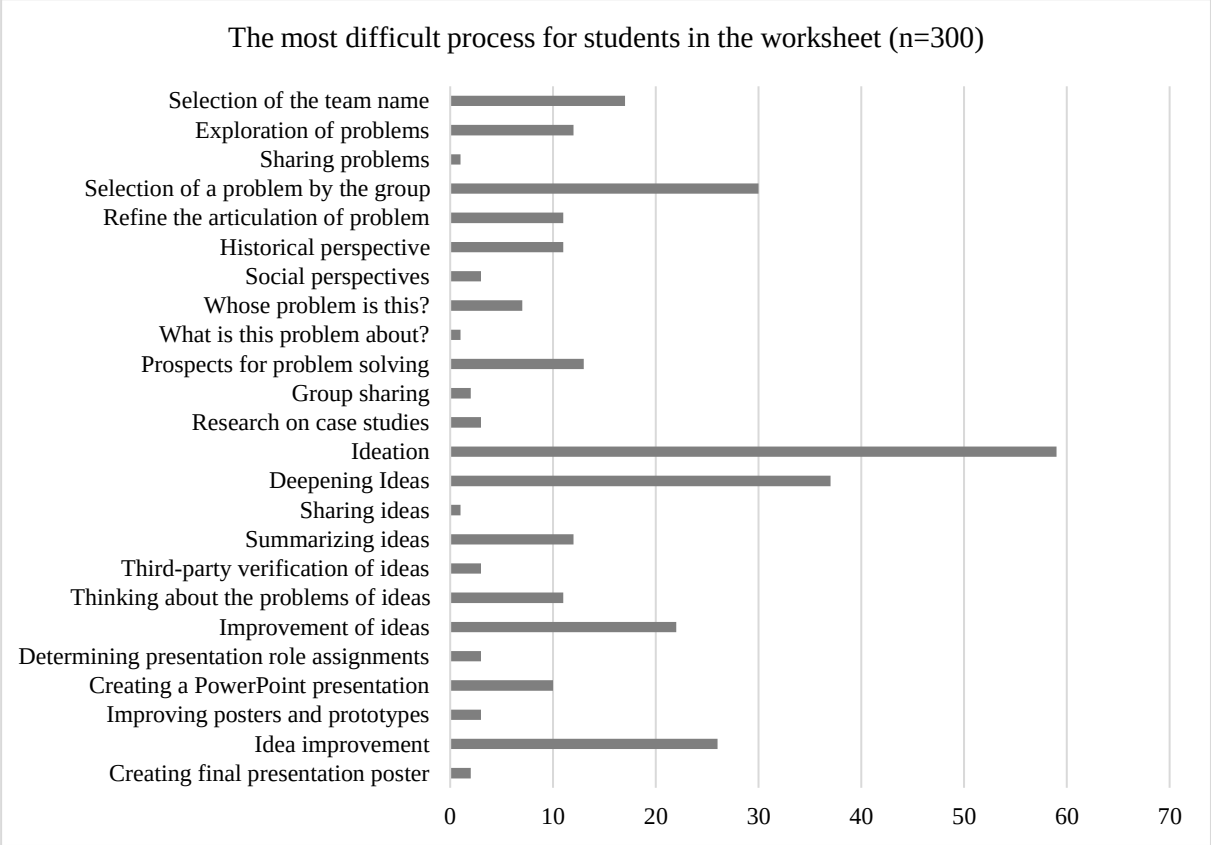

Figure 1. Students' feedback on the worksheet

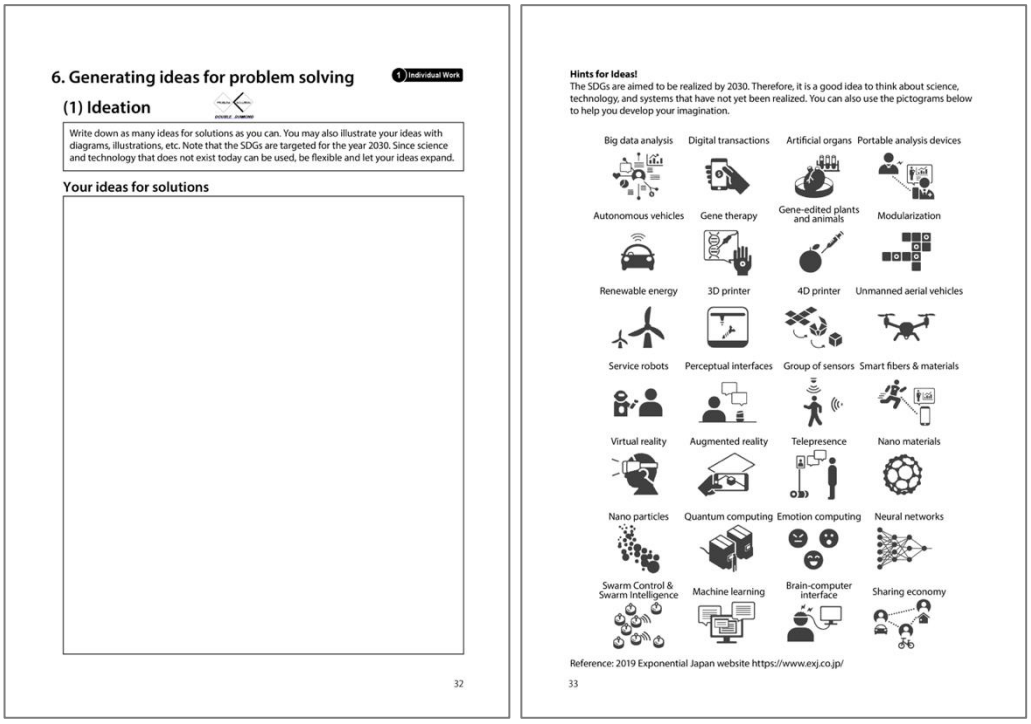

Figure 2. Worksheet for ideation adapted from Reference No. 13 translated into English

specify scaffolding, (2) clear goal setting in the problem identification process, and (3) iterability to allow for change according to the design process.

First, students did not know how to undertake tasks in the idea divergence, idea convergence, and procedure categories. The worksheet for the ideation process was open-ended. This approach proved

Table 2. Challenges faced by students in the ideation process

Category	Reasons
Originality (15)	It was difficult to come up with original ideas because some of the ones I came up with were not new or were similar to those of other groups.
Idea diversification (12)	I couldn't come up with any ideas.
Idea convergence (9)	It was difficult to come up with ideas because everyone had their own ideas, and it was difficult to focus on just one.
Consistency with problems (6)	The ideas did not match the problem.
Feasibility (4)	Some of the ideas that came up were infeasible or had many disadvantages, and it took a lot of time and thought to come up with ideas that everyone in the group could agree on.
Specificity (4)	It was difficult to come up with specific ways to solve problems, even though we identified a lot of them.
Iterability (3)	Even when we came up with ideas, flaws were often quickly found and rejected.
Complexity (1)	Finding a solution created gaps with people who were not subject to that solution.
Procedure (1)	It was difficult to know where and how to start.
Other (4)	It was difficult.

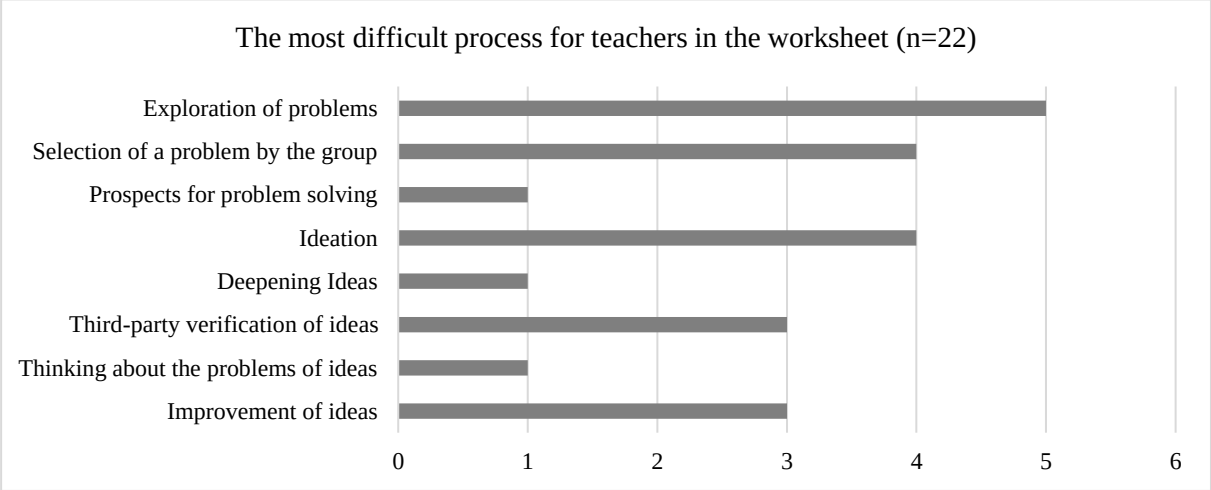

Figure 3. Teachers' feedback on the worksheet

difficult for students who were unfamiliar with design-based learning. It is necessary to demonstrate methods for diversification and convergence of ideas, how to perform each step, and to specify scaffolding so that students can work autonomously in groups.

Second, as pointed out by teachers, ideation can be affected by an insufficient focus on the problem in the problem identification process, which is the preliminary stage of ideation. Consistency with the problem category showed that it was difficult for students to connect problems and ideas. Thus, the problem identification process is critical. The goal of the process must be clarified, and the problem should be clearly described in detail, identifying whose problem it is, enabling high school students to relate it to their own experiences.

Finally, the categories of originality, feasibility, specificity, iterability, and complexity showed that students are unfamiliar with the characteristics of the design process. In the design process, ideas are realised not through a one-way process but through back-and-forth iterations to solve complex problems. For high school students, it was difficult to create original ideas and consider feasibility while following such a complex process. The survey responses confirmed that students came up with ideas but gave up on them, assuming that they had already been implemented in society or that they were unlikely to be realised. Thus, students stopped at the first round of the iterative process, which is critical to the design process. To improve the ideas generated by students, it is essential to strengthen originality and

feasibility through further group discussions, advice from teachers, and additional research. For example, it is difficult to come up with a completely new idea from scratch, but it is possible to develop a new idea by combining existing ideas. The worksheet did not accommodate this iterative process because it was formatted for students to write down ideas once then move on. Thus, the worksheet should allow for additions and flexible changes according to ideas generated by students.
Shulman [6] described the seven categories of the knowledge base for teacher as content knowledge, general pedagogical knowledge, curriculum knowledge, pedagogical content knowledge, knowledge of learners and their characteristics, knowledge of educational contexts, and knowledge of educational ends, purposes, and values, and their philosophical and historical grounds. Of these, the development of teaching materials of this study was able to contribute to the categories of curriculum knowledge and knowledge of educational ends, purposes, and value. However, the pedagogical content knowledge for teachers needs to be improved, as evidenced by the fact that the students did not understand the specialized methods unique to the design field. For future study, elucidation of how to present the design process for instruction is necessary.

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REFERENCES

[1] Loh W. L., Shimomura M. and Zhang Y. Unlocking Creative Minds to Engage SDGs Through Design Education in Japanese High School. *Proceedings of the 22nd International Conference on Engineering and Product Design Education,* 2020.
[2] Ministry of Education, Culture, Sports, Science and Technology. *Koutougakkou Gakushu Shidou Youryou (Heisei 30 Nendo Kokuji).* Available: https://www.mext.go.jp/content/20230120-mxt_kyoiku02-100002604_03.pdf [Accessed on 2022, 8 February] (2018, March).
[3] Tanaka K. Improvement and Preservation of Environment Through School Education: Environmental Conservation Activities by High School Students and Their Effects. *Trends in the Sciences,* 2018, 23(2), 2-27.
[4] Shimomura M., Loh W. L. and Zhang Y. Co-creation of Education Tools for SDGs Design School: Based on a Pilot Program in Collaboration with Fukuoka Municipal Fukusho High School. *Cocreationology,* 2022, 4(1), 1-11.
[5] Zhang Y., Shimomura M., Takano N. and Loh W. L. Case Study of Design for SDGs Project: Development of Visualization Tool for High School Students on SDGs Education with Design Thinking. *Geijutsu Kogaku: the Journal of Design,* 34, 2021, 73-78.
[6] Shulman L. S. Knowledge and Teaching: Foundations of the New Reform. *Harvard educational review,* 1987, 57(1), 1-23.
[7] Ministry of Education, Culture, Sports, Science and Technology. *Koutougakkou Gakushu Shidou Youryou (Heisei 30 Nendo Kokuji) Kaisetsu Sougoutekina Tankyu no Jikanhen.* Available: https://www.mext.go.jp/content/1407196_21_1_1_2.pdf [Accessed on 2023, 28 January] (2018, March).
[8] Tamura H., Morita C., Bonkobara Y., Arai M., Sugamoto K., Sakamoto M. and Iishizu T. Evaluation and Issues of "Period for Inquiry-Based Cross-Disciplinary Study" for High School Student at Faculty of Engineering, University of Miyazaki. *Memoirs of the Faculty of Engineering, University of Miyazaki,* 2020, 49, 17-22.
[9] Nishizawa S. A Study on Effectiveness of Inquiry Learning Activities in Creativity Education. *Studies in Art Education: Bijutsu Kyoikugaku Kenkyu,* 2021, 53, 177-184.
[10] Nishimura S. Assessment of Learning in "Inquiry-Based Cross-Disciplinary Study" in Upper Secondary Schools 1: Assessment in Cooperative Learning (Japanese) Koutou Gakkou ni okeru "Sougouteki na Gakushu no Jikan" ni okeru Gakushu Hyoka 1: Kyoudou Gakushu ni okeru Hyoka. *Kitazato University kyoushoku katei center kyouiku kenkyu,* 2016, 2, 55-67.
[11] Kuga K. Problem of "Periods for Integrated" Study and Consideration About Improvement. *Bulletin of Osaka Yuhigaoka Gakuen Junior College,* 2017, 60, 23-35.
[12] Lincoln Y. S. and Guba E. G. Naturalistic Inquiry, 1985 (Sage, Newbury Park).
[13] Exponential Japan cooperation. *exponential Japan,* Available: https://www.exj.co.jp/ [Accessed on 2022, 1 November], (2019, 1 May).