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DETERMINING THE COMPETENCIES IN DESIGN LITERACY AND PEDAGOGICAL LITERACY FOR NON-DESIGN-TRAINED HIGH SCHOOL TEACHERS TO EFFECTIVELY FACILITATE DESIGN-BASED COMPLEX PROBLEM-SOLVING IN GENERAL EDUCATION

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ABSTRACT
The purpose of this research is to determine the competencies required by non-design-trained high school teachers to effectively facilitate design-based complex problem-solving projects in an inquiry-based subject offered in high school education. Using a Japanese high school as a case study, it was believed that a clear understanding of the objectives and the expected learning outcomes for each stage of the design-based process is necessary to develop the design literacy necessary to evaluate and critique students' progress in the design-based project. In addition, the development of design literacy may enhance teachers' content knowledge in the design process. These competencies will in turn develop the teachers' abilities associated with pedagogical literacy to read, understand, evaluate and modify existing instructional materials to better facilitate the design-based project.

Keywords: Pluriversal design, complex problem-solving, design literacy, pedagogical literacy

1 INTRODUCTION
In Japanese high school education, students are taught to solve real-world problems through the *Period for Inquiry-Based Cross-Disciplinary Study* subject, commonly known as *Soutan* (総探) in Japanese. *Soutan* is a cross-disciplinary and inquiry-based subject, where high schools have autonomy to design the programme with reference to the national curriculum guidelines [1]. When implementing *Soutan*, all high school teachers can be assigned to facilitate and teach the content. The objectives of *Soutan* are to allow students to go through the iterative process of *problem definition, information collection, data organisation and analysis* and *consolidate and express their findings*. High schools implement a variety of projects to fulfil the objectives, and some schools implemented complex problem-solving (CPS) projects in the *Soutan*. While in-service training may provide teachers with a good understanding of the objectives and the learning outcomes of the subject. But teachers faced significant anxieties and challenges implementing this subject in class, as there was a lack of training in preparing them to teach and facilitate the inquiry-based learning in *Soutan* [2]. This is because teachers have to teach and facilitate students to identify problems to solve, and there can be multiple solutions to engaging in the problems, which is something they have not experienced in their previous educational experience.
Since 2021, the authors and their colleagues, referred to as the research team in this paper, have collaborated with F High School to implement a yearly school-wide design-based CPS project in *Soutan*. F High School adopted design thinking in the CPS project, as the design process would allow students to go through the iterative process required in the curriculum guidelines. The research team served as consultants and are involved in working with the school in planning and designing the project. One of the main challenges faced by F High School is to prepare different subject teachers who are not trained in design to facilitate the design-based CPS project. Training workshops for teachers were not conducted due to the school's time constraints. To mitigate such challenges, all teachers received a set of instructional materials, which they could use to prepare each lesson. The instructional materials were created by the school's project coordinating team in consultation with the research team. The instructional material contains lesson plans, simple explanatory notes, and student worksheets for each

student activity. To further support teachers, a resource webpage was created by the school to contain materials such as videos explaining the design process, problem identification, brainstorming methods, and idea generation. The research team contributed to some of the content in the resource webpage. During lessons, the programmeme coordinator and the research team would conduct lesson observations to clarify teachers' challenges. After each lesson, the programmeme coordinator would clarify teachers' concerns by posting advice on the resource webpage. Despite these interventions, the research team discovered the following needs that require to be addressed [3].

1. Developing teachers' understanding of the design process and the pedagogical competencies to teach and facilitate the design process.
2. Developing educational resources to support teachers in facilitating the project. Such resources should (a) provide knowledge and methodology of the design process, including problem identification and ideation, (b) offer student-centred pedagogical strategies, and (c) include clear explanations of each design-based task and exemplars of student outcomes.

In 2024, the research team proposed and worked with the school to revamp the instructional materials to address the needs mentioned above. The detail related to the development of the new instructional materials is to be published in a separate research output. The new instructional materials updated the explanatory notes for the design process for CPS, suggested relevant design approaches (lesson plans included) for different parts of the CPS process, and provided exemplars to provide clearer student learning outcomes. While the new instructional materials may address the needs of providing the teachers with resources to teach and facilitate the CPS projects, it was observed that teachers still face challenges in facilitating processes, particularly the problem exploration, problem definition, and ideation. As teachers are facilitating students to engage CPS through design thinking, teachers will require the competencies to comprehend the process of designing. At the same time, teachers need to be able to understand the considerations and thoughts behind students' proposed solutions. Such competencies are associated with design literacy [4]. By equipping teachers with the necessary design literacy, teachers would then be able to employ relevant pedagogies to teach students to use the design process to engage in CPS. The purpose of this research is to determine the competencies required by non-design-trained high school teachers to effectively facilitate design-based CPS projects using the Japanese context as an example. From the competencies identified, this study will then determine how these competencies may be associated with design literacy and pedagogical literacy.

2 LITERATURE REVIEWS

2.1 Design literacy and its relevance to general public

Design literacy is seen as a competency that is not only required by design professionals but also by the general public. Different scholars have articulated the concept of design literacy, but there is no general definition of design literacy for the general public [5]. The purpose of developing design literacy in the general public is to obtain a sustainable society by being aware and able to evaluate the impacts of design solutions on people and the natural environment in a sustainable way [6]. In addition, stemming from the sustainability point of view, the general public require design literacy to move away from being passively accepting of the designed world created by design professionals to being a change agent to critique and shape the design of our current world [7][8]. To be able to critique design, perhaps, a person would need to possess competencies to examine, question and hypothesise the considerations and rationale behind the designed solutions and, at the same time, consider the consequences and impact that the solution may make towards the societal, environmental, political and economic aspects [9]. To shape design, a person would need to possess the competencies to create solutions through the process of design. Design literacy are competencies that are relevant for the general public to understand the process of design and the consequences and impact of design. Thus, design literacy will promote the pluriversal views of those outside the profession of design.

2.2 Pedagogical Literacy for teachers

Pedagogical literacy is an important competency for teachers in teaching and learning in a classroom. Teaching and learning are different from each other [10]. Learning involves the acquisition of and improvement of knowledge and competencies in a subject matter. While teaching involves the use of strategies to ensure learning of the content of a subject matter takes place. Thus, the competencies of teachers to turn what they know about the subject matter into the content for instructions and determine what kind of instructions are suitable to deliver the content are critical. Such competencies are closely

related to pedagogical content knowledge. Pedagogical content knowledge is to possess the instructional expertise to synthesise subject matter knowledge and pedagogical knowledge. In other words, successful teachers are able to transform their knowledge of the subject into forms that learners can understand [11][12]. Development of pedagogical literacy is crucial in the development of pedagogical content knowledge. To possess the competencies of pedagogical literacy, teachers should possess the competencies to read, understand and critique documents associated with pedagogical content knowledge and use this ability to reason for the success or failure of the pedagogical practices [13]. Thus, through the analysis and reflection on the successes and failures in pedagogical practices, teachers may develop and update their own pedagogical content knowledge in the subject area.

3 RESEARCH METHODOLOGY

To achieve the purpose of research, the key research questions (RQ) are constructed as below.

- *RQ 1. What are the challenges teachers faced in facilitating the design-based CPS project?*
- *RQ 2. Based on RQ1, what kind of competencies related to design literacy and pedagogical literacy do teachers need to allow them to facilitate design-based CPS project effectively?*

This paper used F High School as a case study to address the RQs. Focusing on the CPS project implemented in the academic year of 2024, a focus group discussion was conducted after the completion of the project to solicit qualitative feedback from the project coordinating team from the school. The focus group discussion mainly involved the authors and four teachers; namely the lead project coordinator, and three teachers who have also taught and facilitated the CPS project.

Table 1. CPS weekly lesson outline and number of teachers involved

Week	Period 1 Lesson Content (Lesson duration: 50 mins)	Period 2 Lesson Content (Lesson duration: 50 mins)	Number of subject teachers involved in facilitating the project
1	**Understanding SDGs** - Research on case studies related to SDGs	**Exploring Problems** - Using a mind map to explore problems	1. Japanese language : 5 2. Mathematics : 3 3. English : 4 4. Social : 2 5. Science : 2 6. Health and Physical Education : 4 7. Art : 1 8. Business and Information : 2 Total number of teachers involved : 23
2	**Selecting a Problem** - Using the Axis Frame method to shortlist problems based on two most important criteria	**Selecting a Problem** - Using Decision Matrix to select a problem	
3	**Understanding the Problem** - Planning research approach and division of work	**Understanding the Problem** - Creating questionnaires/interview questions	
4	**Understanding the Problem** - Conduct survey/interviews	**Understanding the Problem** - Consolidate and organising data	
5	**Understanding the Problem** - Conduct survey/interviews	**Understanding the Problem** - Consolidate and organising data	
6	**Understanding of Problem** - Data analysis	**Define Problem Statement**	
7	**Generating Ideas** - Using How-Might-We method	**Generating Ideas** - visualisation of ideas	
8	**Generating Ideas** - Using How-Might-We method	**Generating Ideas** - visualisation of ideas	
9	**Creating Prototype and Presentation Poster**	**Creating Prototype and Presentation Poster**	
10	**Creating Prototype and Presentation Poster**	**Creating Prototype and Presentation Poster**	
11	**Preparation for Presentation**	**Preparation for Presentation**	
12	**Mid-Term Presentation** - external commentators were invited to view the presentation and provide feedback	**Mid-Term Presentation** - external commentators were invited to view the presentation and provide feedback	

F High School is a co-ed school that is considered a typical public high school. The scale of the CPS project involved about 300 high school students in the second grade (17 years old). Lessons are conducted once (100 minutes) a week. The project is organised as a 12-week programme. When implementing the CPS project, 23 high school teachers will be assigned to facilitate the project. Two or three teachers, who are teaching different subjects, will be assigned to facilitate a class of around 20-30 students. Students from different classes are grouped together based on their interest in a specific area of the Sustainable Development Goals (SDGs). After being grouped by interest, the students are then divided into about eleven classes. In each class, the students form teams of 3-5 students to engage in solving issues related to their surrounding communities. Table 1 provides a brief outline of the content of each lesson and the number of subject teachers involved in the project.

During the focus group discussions, RQ1 was broken down into sub-questions to guide teachers in sharing about their challenges faced when facilitating the project, particularly in the problem phase and ideation phase. The feedback was recorded, transcribed and translated from Japanese to English. The transcript was analysed to elucidate meanings through coding [14][15]. In Vivo and Descriptive methods were used in the first cycle coding. Pattern coding was used in the second cycle coding to group codes

with similar categories. Then after, the categories were assigned to high-level codes before conducting thematic analysis to clarify the research questions.

4 FINDINGS AND DISCUSSIONS

Based on the teachers' feedback, the emerging themes related to challenges and concerns during the project can be drawn from two large categories, design process and pedagogy. Refer to Table 2 and 3.

Table 2. Categories and related codes with respect to design process

High-Level Category	Second cycle codes	First cycle codes
design process	iterative process	encouraging failures
	research and data analysis	conducting research and analaysis; unsure about what to do after collecting data; not all teachers have the expertise; specialized knowledge in data science; able to collect data; how do we analyze the data; data analysis methods; we ourselves aren't that knowledgeable either; introducing tools like AI text mining
	prototyping and testing	beyond conceptual ideas; digital fabrication; prototyping
	ideation	ideation only at conceptual level; insufficient existing knowledge
	problem exploration and definition	superficial understanding of problem; lack of competency to understand complex problem; issues with problem definition process; ability to link daily problems with SDGs; unable to unpack SDGs; able to follow the design process; ability to conduct research to understand problems; inability to scope the problem; ability to understand complexity of problems and solutions; inability to explore wide range of problems; ability to scope the problem; difficulty in using design approach; deepen their understanding of the issues; bundled into a big topic; able to identify issues in their immediate surroundings; connect them to specific SDGs goals; concept of SDGs too strongly fixed in their minds; tried to tackle overly large-scale issues; followed a proper process; identifying a local issue they genuinely wanted to address; tackle enormous issues like infectious disease

Table 3. Categories and related codes with respect to pedagogy

High-Level Category	Second cycle codes	First cycle codes
pedagogoy	process focus	differentiated instructions; multiple approaches to achieve learning outcomes; process rather than outcomes
	external feedback	external validations
	cooperative learning	organisation of group work; group dynamics; group member aren't very familiar with each other; collaborative learning across levels; setting expectations
	student profile	students in the humanities course; stop taking math from the second year onwards
	project implementation	operational challenges
	educational resources	common understanding among teachers; consistency in teaching and learning; teaching and learning strategies
	project consultation	teachers' role in consultation; teacher-student communication

All teachers reported facing significant challenges in guiding students to explore real-world problems and define them more specifically. Most students were able to use divergent thinking tools such as mind maps to brainstorm and explore possible real-world problems around them. But they were unable to consider the problems with more details during the brainstorming session. For example, some students identified daily real-world problems such as food loss or infectious disease in their community. However, teachers were not successful in helping students deepen their understanding of the specific issues related to food loss or infectious disease within their community. Furthermore, teachers felt that getting students to consider SDGs during problem exploration further increased the level of complexity for students. This is because students tend to view problems related to SDGs as large-scale problems rather than linking SDGs to specific real-world problems around them. While teachers felt that they were able to guide students to conduct research to understand the problems, most of them were unfamiliar with various research methods. The most commonly used research method was questionnaire surveys. Although students were able to collect sufficient data through questionnaire surveys, teachers lacked knowledge in teaching data analysis. In addition, teachers felt that students in the school are mainly humanities majors, and picking up knowledge of data science will be challenging.

Teachers recognised that ideas needed to be developed beyond the conceptual level. Teachers were able to facilitate students in generating ideas, but to test the solutions, models or prototypes are necessary. Most ideas were developed up to the conceptual level, but few got to become models or prototypes. The

school has currently set up a digital fabrication lab that includes equipment such as 3-D printers, laser cutters, and a large-scale plotter. But teachers are required to be trained in using such prototyping tools. On a positive note, teachers understand that the design process is iterative. Even though students may encounter failures during the problem-solving process, teachers feel that it is important to encourage students to navigate problem-solving through making mistakes rather than expecting students to complete the project smoothly. However, some teachers may prioritise achieving the outcomes of the project rather than the process. As such, some teachers would follow strictly the suggested design-based approaches during the problem-solving process, rather than exploring different teaching and learning strategies to guide students. Teachers reflected that as different groups of students are engaging in different problems, the guidance provided during the consultations should be more differentiated to cater to the different needs of the students. This led teachers to reflect on their roles during project consultations. The teachers were questioning how much advice they should give when facilitating the project. They were concerned that providing too much advice might indirectly lead students to take cues from teachers as an indication of getting into the "correct" direction.

The teachers agreed that educational resources are necessary to guide teachers in facilitating the project. The educational resources provided allow teachers to achieve consistent standards in project guidance and management across all the different classes. But some teachers who were unclear about the design process merely followed strictly the approaches and strategies suggested in the educational resources.

Finally, pedagogical considerations that were not related to the design process, such as cooperative learning strategies to improve group dynamics and learning and seeking external commentators to provide feedback for students and other operational issues of the project, were also surfaced.

Based on the feedback, not all concerns shared by the teachers are related to design literacy. Strengthening knowledge of research methods, effective group learning, and creating encouraging learning environments are not confined within design. These are related to general pedagogical approaches to enhance students' research abilities, group learning and motivations in learning during CPS. But three distinctive areas can be viewed as related to design literacy and may impact teachers' ability to determine the use of relevant pedagogical approaches to guide students to navigate specific parts of the design-based process.

Firstly, teachers need to understand that how a design problem is perceived can be relative based on different individuals. Thus, all teachers need to understand that it is not sufficient for students to just merely describe the current state of the problem. But the causal reasons for the problems are required to be described. In other words, teachers need to understand to what extent the problem should be broken down so as to facilitate students unpacking the problem. Without developing competencies to dissect the design problem, teachers would be handicapped in understanding the required learning outcomes of the design approaches suggested in the instructional resources. In addition, they would also be merely trying to follow the facilitation process suggested in the instructional materials without being able to modify the strategies to cater to the students to guide them to analyse and define the problems. Secondly, the technical knowledge for prototyping will be important content knowledge for teachers to suggest appropriate prototyping techniques and evaluate students' prototypes. Thirdly, being able to provide effective feedback in a design-based CPS project is more than just formative assessment. Effective feedback guides students to navigate the design process. Thus, teachers need to be equipped with a clear understanding of the objectives and the expected learning outcomes for each stage of the design-based process. Teachers may build on such understanding to develop competencies to evaluate and critique students' progress in each part of the design-based process. In addition, as part of the pedagogical literacy for implementing design-based projects, teachers would also develop competencies to evaluate the effectiveness of the design approaches suggested in the instructional materials and modify them appropriately based on the needs of the students.

The current paper suggests that to develop non-design-trained teachers' ability to teach and facilitate design-based CPS projects, it is more than just providing teachers with pedagogical approaches through instructional materials. In order to be able to facilitate the design-related processes in the CPS project, teachers need to acquire the necessary content knowledge related to design. This content knowledge can be acquired through the development of relevant design literacy. Only with the necessary content knowledge related to the design process can teachers acquire the competencies to read, understand and critique the instructional materials and hypothesise the success of the suggested design-based strategies with respect to the needs of the students. As part of the competencies for pedagogical literacy, this may

strengthen teachers' pedagogical content knowledge to modify instructions accordingly to suit the progress of their students in any part of the design process for the CPS.

6 CONCLUSIONS

Using a public Japanese high school as a case study, the purpose of this research is to determine the competencies required by non-design-trained high school teachers to effectively facilitate design-based CPS projects. Through a focus group discussion, the findings suggested that teachers require to develop competencies that enable them to evaluate and critique students' progress in each part of the design-based process by building on a clear understanding of the objectives and the expected learning outcomes for each stage of the design-based process. In addition, teachers also need to develop competencies to analyse and dissect the design problems and prototyping. The competencies mentioned are believed to be part of design literacy necessary to develop content knowledge related to the design process. Only with the necessary content knowledge related to the design process can teachers acquire the necessary pedagogical literacy to read, understand and critique the instructional materials and hypothesise the effectiveness of design-based strategies used in the classroom with respect to the needs of the students.

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