The Characteristics of Curriculum Design for STEM/STEAM-Based Learning to Develop Complex Problem-Solving in Japanese High School

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Abstract

The aim of this research is to identify the characteristics of curriculum design in Japanese high schools that effectively implement STEM/STEAM-based learning in the Period for Inquiry-Based Cross-Disciplinary Study. Using a qualitative approach to conduct a collective case study that compares three case studies, it was clarified that the autonomy and flexibility in designing the STEM/STEAM curriculum within the Period for Inquiry-Based Cross-Disciplinary Study allowed Japanese high schools to integrate STEM/STEAM fields through multidisciplinary, interdisciplinary, and transdisciplinary approaches. By having autonomy and flexibility in curriculum design, schools create new subjects or modify existing ones to further support STEM/STEAM-based learning. As such, the curriculum can also incorporate necessary scaffolds to engage students in learning and at the same time provide the depth and breadth in subject areas to further interest students in STEM/STEAM learning. While students were able to engage in real-world problems by integrating STEM/STEAM fields using design thinking. It is uncertain to what

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extent the full design process is used within the STEM/STEAM-based projects.

Keywords: STEM/STEAM education, complex problem-solving, inquiry-based learning, integrative curriculum, high school education

1. Introduction

STEM and STEAM education is seen by many countries as a means in K-12 education to develop students with critical thinking, creativity, and problem-solving. STEM education is an interdisciplinary teaching approach that intentionally integrates knowledge and skills from the fields of science, technology, engineering, and mathematics (STEM). STEAM education is an iteration of STEM education that integrates the arts ("A") among fields of science, technology, engineering, and mathematics. In a comparative study of STEM education in ten countries led by Lee and Lee (2022), it was highlighted that the learning of the different STEM fields through a transdisciplinary approach is rare, as the different STEM fields are often learned through discipline-based curricula and teaching. Secondly, a lack of formal curriculum time that is dedicated to STEM education is prevalent. Thirdly, there is a lack of interdisciplinary collaboration among teachers. While different countries are implementing STEM education into K-12 education, formal curriculum time dedicated to STEM education and implementing STEM as an integrative approach remains a challenge.
Recently, STEM and STEAM education has garnered widespread attention in Japan due to its interdisciplinary nature. The most recent national syllabus for high school education by the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) proposed that school curricula should be organized from an interdisciplinary perspective to cultivate students' problem-solving skills (MEXT, 2018a). The *Period for Inquiry-Based Cross-Disciplinary Study* is an inquiry-based subject in the Japanese high school curriculum that allows each high school to set its own objectives, learning outcomes, and content in alignment with the subject's overarching goals (MEXT, 2018a). The overarching objectives of the subject for students are t

- acquire the knowledge and skills necessary to solve real-world problems and propose appropriate solutions;
- develop independent and cooperative learning; and
- develop an attitude to new values and a better society.

MEXT suggested that STEAM education could be implemented in the Period for Inquiry-Based Cross-Disciplinary Study in high school education, due to the subject's cross-disciplinary and integrative learning nature aimed at complex problem-solving (Central Council for Education, 2021). However, how STEM and STEAM (STEM/STEAM) related curricula for the *Period for Inquiry-Based Cross-Disciplinary Study* can be designed and implemented is not clearly stated.

While not all Japanese high schools in Japan implement STEM/STEAM education through the *Period for Inquiry-Based Cross-Disciplinary Study*, prefectures such as Oita Prefecture in Kyushu support public high schools to implement STEM/STEAM education through the *Period for Inquiry-Based Cross-Disciplinary Study*. While dedicated curriculum time for STEM/STEAM-based learning may be lacking in some countries (Lee & Lee, 2022), the *Period for Inquiry-Based Cross-Disciplinary Study* in Japanese high schools serves as the dedicated subject for STEM/STEAM-based learning. But similar to other countries, high schools need to figure out how STEM/STEAM curricula can be designed and implemented. In an attempt to address the need for a curriculum model for STEM/STEAM-based learning in formal school curricula, this study will focus on the STEM/STEAM-based learning developed in the *Period for Inquiry-Based Cross-Disciplinary Study* in Japanese public high schools as case studies. Based on the analysis of these case studies, the study aims to identify the characteristics of curriculum design in Japanese high schools that effectively implement STEM/STEAM-based learning in the *Period for Inquiry-Based Cross-Disciplinary Study*. Based on the characteristics of STEM/STEAM curricula identified, the high schools in Japan and other countries may use them as a reference to design and implement STEM/STEAM-based learning in their curricula.

2. Literature Reviews

2.1. Defining STEM and STEAM Education for this study

The acronym STEM was first introduced in 2001 in the United States (Breiner et al., 2012). STEM education aims to enhance the workforce related to STEM fields and nurture 21st-century competencies (21CC) (Bybee, 2010; Yata et al., 2020). The definition of STEM education is interpreted in different ways, and there is no consensus. For example, some may define STEM as the traditional disciplines of science, technology, engineering, and mathematics, where considerations for cross-disciplinary integration are low (Breiner et al., 2012). On the other hand, other concepts of STEM education emphasize the purposeful integration of these academic fields to address real-world problems (Labov et al., 2010; Sanders, 2009; Yata et al., 2020). This integrative perspective on STEM education views the independent fields of STEM as a unified whole. STEM education in this study adopts the latter definition, emphasizing the integration of STEM fields to develop students' abilities to solve real-world problems. STEAM is an iteration of STEM that integrates the arts into STEM disciplines with benefits to enhance student engagement and develop

21CC (Yakman & Lee, 2012; Sousa & Pilecki, 2018; Quigley & Herro, 2019; Perignat & Katz-Buonincontro, 2019; Matsuura & Nakamura, 2021). In addition, STEAM education equips students with essential skills for future career and industrial demands (Ando & Kim, 2014; Perignat & Katz-Buonincontro, 2019).

The arts field within STEAM may be viewed differently. According to Yakman and Lee (2012), the arts ("A") in STEAM cover language, physical, liberal (social), and fine arts. In a more design-oriented perspective, "A" is viewed in the form of art and design (Maeda, 2013). In fact, based on a review by Perignat and Katz-Buonincontro (2019), the "A" within STEAM may even be categorized into three main categories, such as a) arts education, b) arts as any non-STEM discipline, and c) arts as a synonym for project-based learning, problem-based learning, technology-based learning, or making. The meaning of "A" in STEAM in Japan seems to align more closely with the perspective mentioned in Yakman and Lee (2012). The Central Council for Education (2021) proposed to define 'A' in STEAM as not only in the arts and culture but also in a broader scope of liberal arts and to include life, economy, law, politics, ethics, etc.

2.2. Integrated STEM/STEAM Education

STEM/STEAM education implies an integrated curriculum, and knowledge integration is one of the key considerations (Herschbach, 2011). Integrated STEM education can be considered an approach that may integrate two or more STEM fields in learning activities that explicitly make connections between STEM fields and real-world problem-solving (Sanders, 2009). In addition, learning activities that make connections between a STEM field and one or more other school subjects may also be considered integrated STEM (Sanders, 2009). The initial interpretation of STEAM education is as an integrated STEM education with the addition of the arts (design, sensibility, etc.) (Matsubara & Kosaka, 2017). In recent years, to promote creative real-world problem-solving learning, various forms have emerged with STEM as the core, such as robotics into STEAM to become STREAM and the Environmental field into STEM (E-STEM) (Arai, 2020). These forms have expanded the scope of STEM, addressing issues related to language and society, and breaking the boundaries between the arts and sciences (Arai, 2020). In this study, learning activities that explicitly integrate learning content using one or more STEM/STEAM fields as an anchor are considered integrated STEM/STEAM-based learning.

2.3. Determining effectiveness of Integrated STEM/STEAM-based projects

Existing literature commonly focuses on studying specific aspects of integrated STEM, such as teaching strategies and challenges in implementing STEM-based projects (McLure et al., 2022). Roehrig et al. (2021) had clarified seven key characteristics of effective STEM-based projects. When integrating “A” into STEM, Ohtani (2021) suggested that the Design in the field of engineering (Engineering Design) forms and overlaps with Design in the field of art, thus forming and overlapping connections between STEM and STEAM education. In addition, the convergent thinking involved in STEM, when combined with the divergent thinking processes in art, allows innovation to prosper (Ohtani, 2021).

Based on the literature reviews conducted in this study, the characteristics of effective integrated STEM-based projects proposed by Roehrig et al. (2021) are adopted for the analysis of case studies. But to better include the perspective of Design which includes the field of art, the “Engineering Design” stated as part of the characteristics of effective STEM-based projects is considered as “Design” to reflect the inclusion of artistic and creative elements in STEAM. As the Japanese high school curriculum consists of career education, how STEM/STEAM-based learning explicitly links learning to STEM careers will not be considered as a required characteristic of effective STEM/STEAM-based learning, as it is out of the scope of this study to look into career education in Japanese high school education.

The characteristics of effective STEM/STEAM programs can be consolidated in Table 1 by adopting the considerations based on the literature reviews above. The considerations in Table 1 will be used when clarifying the characteristics of STEM/STEAM curriculum design in the case studies presented in this research.

Table 1
Characteristics displayed by effective STEM/STEAM programs

Considerations of Effective STEM/STEAM Programs
a. Engaging students in solving real world problems
b. Engaging students in engineering design to allow students to experience a full design process that allow students test their design solutions and improve their solutions through re-designing
c. Context for real-world problems needs to allow integration of STEM content by providing explicit connections between them
d. Making explicit connections between the content in targeted disciplines, which may involve multidisciplinary, interdisciplinary, or transdisciplinary approaches
e. Engaging students in an open-ended complex problem solving process where they make justified decisions in their design processes based on evidence
f. Developing students with 21st century competencies

2.4. Overview of STEM/STEAM Education in Japan

Around 2010, STEM education began gaining attention in Japan (Matsuura & Nakamura, 2021). The rapid advancement of technology led to the vision of Society 5.0, where science, technology, and innovations are seen as one of the important parts to contribute to a sustainable society locally and globally (MEXT, 2018b). Consequently, STEAM education is crucial to nurture students with the capabilities for problem-solving, discovery, and creation of new knowledge that contribute to the vision of Society 5.0 (MEXT, 2018b). To develop STEM/STEAM education, Japan has implemented various measures. In 2018, the Japanese Ministry of Economy, Trade, and Industry (METI) introduced the *Future Classroom* initiative (METI, 2020). The "*Vision for Future Classroom*," published in 2019, proposed the concept of *STEAM-based study,* which focuses on awakening the excitement of students and engaging them in the cyclical learning process that focuses on *knowing* and *creating* (METI, 2020).

In addition, problem inquiry and problem-solving learning activities are strengthened in the school curriculum. Examples to achieve such means are through subjects such as the *Period for Inquiry-Based Cross-Disciplinary Study* and the *Inquiry-Based Study of Science and Mathematics* (Central Council for Education, 2021). Based on this proposal, it was also emphasized that Super Science High Schools (SSH schools) should enhance problem discovery and problem-solving learning, such as project-based research, to further develop STEAM education (MEXT, 2020). SSH schools in Japan are designated by MEXT to provide advanced science and technology education, aiming to foster future scientists and engineers through specialized lessons and research opportunities. As of recently, 250 schools in Japan have been designated as Super Science High Schools (Japan Science and Technology Agency, 2026).

Although Japan has made progress in promoting STEM/STEAM education, challenges remain in its implementation. While STEM/STEAM education emphasizes interdisciplinary integration, effectively integrating different fields into a cohesive curriculum remains difficult (Sakaguchi & Fukuda, 2023). Moreover, influenced by traditional curriculum approaches, Japan's STEM/STEAM curricula may overemphasize theoretical knowledge while neglecting practical skills and problem-solving (Ohtani, 2021). This disconnection makes it challenging for students to apply knowledge in real-world contexts. Another significant challenge is incorporating new STEM/STEAM-related content into the existing curriculum without extending overall class hours, posing issues of time management (Ohtani, 2021). Additionally, while STEM/STEAM education requires highly skilled teachers, there remains a gap in professional development and teacher training in Japan (Arai, 2018).

2.5. Developments of STEM/STEAM education in Oita Prefecture in Japan

Some Japanese local governments are taking the initiative to promote STEM/STEAM education (Takenaka & Kugiyama, 2023). One prominent example is STEM/STEAM education in Oita Prefecture. Since 2021, the Oita Prefectural Board of Education has led the Oita Prefecture STEAM Education (*Next-Generation Talent Development*) promotion project, in collaboration with industry, academia, and government (Takenaka & Kugiyama, 2023). The initiative aims to develop next-generation talent for fields like the space industry and advanced technologies. This project offers STEM/STEAM-based learning for high school students, consisting of various extracurricular activities and lectures for teachers, known as the *Oita STEAM Platform*. It also supports schools in developing their original STEM/STEAM education programs. Within the *Oita STEAM Platform* initiative, local governments, schools, universities, and private companies cooperate to create a regional ecosystem for STEM/STEAM education. Based on the developments of STEM/STEAM education in Oita Prefecture, the high schools in Oita Prefecture are a good source to identify the case studies for this study.

2.6. The Period for Inquiry-Based Cross-Disciplinary in Japanese High School Education and STEM/STEAM-based learning

In Japanese high school education, the *Period for Inquiry-Based Cross-Disciplinary Study* subject engages students significantly in interdisciplinary and inquiry-based learning. The *Period for Inquiry-Based Cross-Disciplinary Study* is a subject in the high school curriculum where students utilize the perspectives and methods of inquiry and engage in interdisciplinary and comprehensive learning while reflecting on their own way of being and living (MEXT, 2018a). The goal is to cultivate qualities and abilities to better identify and solve problems. In Japanese high schools, students are required to complete a total of at least 74 credits over three years in subject studies. One credit is calculated based on 35 class periods, with each class period being 50 minutes. The *Period for Inquiry-Based Cross-Disciplinary Study* typically accounts for a minimum of 3 to a maximum of 6 credits over three years (MEXT, 2018a).

While there are similarities in the cross-disciplinary nature of STEM/STEAM education and the *Period for Inquiry-Based Cross-Disciplinary Study*, implementing STEM/STEAM-based learning may still face certain challenges. Ohtani (2021) explained that both the *Period for Inquiry-Based Cross-Disciplinary Study* and STEM/STEAM education share similarities in integrating learning objectives across disciplines and addressing real-world issues. However, they differ in their approach to engaging with complex problems. The *Period for Inquiry-Based Cross-Disciplinary Study* emphasizes the inquiry process, while STEM/STEAM education highlights trial-and-error through the process of design and creating. In addition, problem-solving activities in the *Period for Inquiry-Based Cross-Disciplinary Study* may emphasize more knowledge-centered inquiry rather than the creative approach to problem-solving in STEM/STEAM education (Ohtani, 2021). In addition, cross-disciplinary learning may still be challenged by traditional educational approaches in Japanese education (Ohtani, 2021).

3. Research Methodology

3.1. Research questions

To achieve the research purpose stated earlier, two research questions (RQ) are framed.
RQ1) What kind of integrated curriculum do Japanese public high schools adopt to implement STEM/STEAM-based learning in the *Period for Inquiry-Based Cross-Disciplinary Study*?

RQ2) How do Japanese public high schools design the curriculum to integrate different STEAM/STEM fields in STEM/STEAM-based learning in the *Period for Inquiry-Based Cross-Disciplinary Study*?

An integrated curriculum can be designed in different ways (Drake & Burns, 2004). Firstly, a *multidisciplinary* approach means that knowledge and skills from different disciplines can be taught individually but connected by common themes. An *interdisciplinary* approach means the curriculum is organized in such a way that specific subject knowledge and skills are learned through common themes that cut across disciplines. Thirdly, a *transdisciplinary* approach means that different subject knowledge and skills are learned based on students' questions and interests through complex problem-solving. "Disciplinary" refers to the teaching of specific content knowledge and skills individually (Vasquez et al., 2013). As learning moves from disciplinary to multidisciplinary, interdisciplinary, and transdisciplinary approaches, there is a noticeable shift from a focus on specific academic disciplines to a greater emphasis on real-world applications (Munegumi, 2019). It can be inferred that the degree of integration increases as the emphasis on solving real-world problems becomes more prominent.

3.2. Research method

The current study employed a qualitative research approach to develop a collective case study on high schools that have developed a comprehensive curriculum for implementing STEM/STEAM-based learning in the *Period for Inquiry-Based Cross-Disciplinary Study*. A collective case study involves more than one case study to examine the same research questions in a number of contexts (Goddard, 2010, Stake, 1995). The collective case study focuses on studying each case as part of a collection of cases that are linked by common issues or similarities. Collective case study may also be referred to multiple-case study (Chmiliar, 2010, Crowe et. al., 2011). There are different forms of designing the study of multiple case studies. The first form is where all case studies are selected in advance and studied at the same time (Chmiliar, 2010). The second form is a sequential design where case studies are selected based on the outcome of the previous case studies (Chmiliar, 2010). According to Yin (2018), multiple case studies can be selecting case studies that are replicates. Yin (2018) explained that case studies are selected so that individual cases may predict similar or contrasting results. Although this study focuses on studying the STEM/STEAM curriculum implemented in the *Period for Inquiry-Based Cross-Disciplinary Study* at high school, it is expected that each high school will design and implement the STEM/STEAM curriculum based on the needs of the students within the school. Rather than considering each select case study as replicates, this study takes an approach where each case shares a common link and are treated as a single entity (Stake, 1995). Using the collective case study approach, the STEM/STEAM curriculum of each high school selected will be studied to a certain depth, and through cross-case comparisons, the similarities and differences in curriculum design may be illuminated.

The objects of study for each high school case in this research are based on qualitative data collected through relevant school documents, interviews with program coordinators, and field notes taken during school visits. Through these three forms of qualitative data, the characteristics of the curriculum for STEM/STEAM-based learning in each high school case will be triangulated with reference to Table 1. As the design and implementation of the STEM/STEAM in each high school case is complex, this study adopted data and method triangulation to determine the breadth and ensure accuracy to the qualitative interpretations of the data. When collecting and analyzing the data, the authors collected the data together and analyzed the data collaboratively.

The school documents and interview transcripts in each high school case will be analyzed using the content analysis approach to identify and organize relevant data that exhibits the considerations mentioned in Table 1. In addition, the inductive analysis approach is used to analyze the data to clarify the characteristics of the STEM/STEAM curriculum in each high school case. The field notes taken during the school visits will be used to further support the understanding of the data analysis of the school documents and interview transcripts. After the analysis of each high school case, similar and different characteristics of STEM/STEAM curriculum design between the cases are then clarified (Patton, 2015).

3.2.1. Considerations for selecting case studies for purposeful sampling

The *Oita STEAM Platform* websites and the official high school websites are used to conduct an initial scan of the STEM/STEAM programs implemented, three public high schools in Oita Prefecture that are considered to have comprehensively designed STEM/STEAM-based learning in the *Period for Inquiry-Based Cross-Disciplinary Study* are selected. In addition, Table 1 was also used as a form of consideration when selecting high schools as case studies. The three high school cases selected for this study are School M, School K and School U, Table 2. The STEM/STEAM-based learning in these three schools will also be labeled as Project M, K, and U.

Table 2
Basic information about the school and the year STEM/STEAM-based learning was introduced

High Schools selected	School M	School K	School U
Location	Oita Prefecture, Oita City	Oita Prefecture, Kunisaki City	Oita Prefecture, Usa City
Student Population (based on 2024	958 students	450 students	403 students
Number of classes in Year 1	8	7	4
Number of classes in Year 2	8	7	4
Number of classes in Year 3	9	7	4
Project name for STEM/STEAM-based learning	Project M	Project K	Project U
Year when STEM/STEAM-based learning was introduced	from 2020	from 2023	from 2021
School type	Prefectural Public High School *The school is a Super Science High School (SSH)	Prefectural Public High School	Prefectural Public High School

3.3. Research design and implementation

The collection of relevant documents, interviews, and school visits were all completed in 2023. In the considerations for research ethics and privacy, permission for collection of data, school visits and information usage for research has been approved by each school.

3.3.1. Relevant School Documents

The relevant school documents provided by each school for study are shown in Table 3. Any information that may disclose the identity of the school, teaching staff, and students was censored or kept anonymous.

Table 3
Relevant documents collected from each school for data analysis

	Information for Project M	Information for Project K	Information about Project U
Relevant documents and resources collected for study	1. School guide book in 2023 2. The research reports of the SSH curricula in 2023 that include the following information: a. the developing plan of Project M b. time table of curriculum in Project M c. curriculum contents of Project M d. teacher-students ratio 3. A video that introduce Project M and its content	1. School guide book in 2023 2. School-wide curriculum time table of 2024 3. The time table of the Period for Inquiry-Based Cross-Disciplinary Study of 2024 4. The curriculum plan of Project K 5. The curriculum plan of Space-based STEAM project in 2023 6. The curriculum plan of Space-based STEAM project in 2024 7. Student learning outcomes of Space-based STEAM project in Year 1 of study 8. External support system plan for curriculum implementation 9. The staff allocation chart of Project K (teacher-students allocation)	1. School guide book in 2022 2. Time table of the Period for Inquiry-Based Cross-Disciplinary Study of 2022 3. Introduction of all projects developed in the Period for Inquiry-Based Cross-Disciplinary Study 4. The curriculum plan of Project U 5. The textbooks of Playful Coding in 2023 6. Introduction of the 6s' PROJECT 7. Presentation implementation guidelines of student learning outcomes in Year 2 in 2023 8. Chart for competencies and skills learning of Project U

3.3.2. Interviews with Project Coordinators

The offline/online interviews with teachers were semi-structured and unstructured. The interviewed teachers in Schools M, K, and U are responsible for the development, coordination, and implementation of the STEM/STEAM-based learning in each school. The main questions involved in the interviews are shown in Table 4. In Schools M and K, the interviews were audio-recorded using an IC recorder. The second author then transcribed the recorded interviews as research data. For School U, notes that were taken during the interview were primarily used as data, as no audio recordings were made during the interview. Informed consent was obtained, and all interviewed teachers were informed that their participation was voluntary, that their right to anonymity would be respected, and that they could decline further participation at any time. The data obtained through the interview were coded based on the questions in Table 4 while reading the interview transcripts. Before comparing with the document data and field notes, the interview transcripts were coded through an inductive approach to categorize the codes into immerging themes grounded from the data (Glaser & Strauss,1967; Lapadat, 2010).

Table 4
Content of the questions asked during the interviews and their objectives

The content of the questions asked during the interviews		Objectives
1	The educational objectives and student outcomes of STEM/STEAM-based projects	To clarify the characteristics of school curriculum design to implement STEM/STEAM-based learning through the *Period for Inquiry-Based Cross-Disciplinary Study*
2	The school curriculum schedule of STEM/STEAM-based projects during 3 years	
3	The teacher-student arrangement in STEM/STEAM-based projects	
4	The teacher training and external assistance	
5	The integration between STEM/STEAM-based projects with other disciplines	To clarify the characteristics of curricula design to integrate different STEM/STEAM fields into STEM/STEAM-based learning
6	The teaching and learning contents of STEM/ STEAM-based projects	
7	The pedagogies and teaching strategies used in STEM/STEAM-based projects	To clarify pedagogies used to integrate different STEM/STEAM fields into STEM/STEAM-based learning
8	The teacher-students relationship in STEM/STEAM-based projects	

3.3.3. School visits

School visits were made in each school to observe the lessons of STEM/STEAM-based learning. When conducting field visits, the authors would go into the classes to observe the lessons to understand the pedagogical approaches used by teachers. At the same time, field notes and photographs as a form of records. The authors also observed students' work to identify what kind of outputs students produce so as to relate the curriculum contents and student outcomes.

4. Findings

This section presents the key findings and interpretations based on the data collected.

4.1. Educational objectives and themes used to anchor Project M, K, and U

Educational objectives are an important part of the curriculum, as they will influence how students' learning experience is designed within the curriculum. The overarching educational objectives for Projects M, K, and U are consolidated in Table 5.

Table 5
Overarching STEM/STEAM educational objectives of Project M, K and U

	Project M	Project K	Project U
Through each project, these competencies wll be developed in the respective STEM/STEAM programs:	1. Scientific inquisitiveness: Interest in science and solving problems using scientific methods and thinking skills. 2. Logical thinking: Using the knowledge have learned and data have acquired logically. 3. Internationality: Understand society and the world from an international perspective, and develop communication and cultural thinking skills. 4. Design thinking: Use empathy and the five senses to solve problems creatively. 5. Integration of knowledge and skills in various fields: Solve problems by integrating knowledge and skills in various fields and global thinking skills.	1. The ability to analyze and solve the current issues on Earth from the perspective of the universe 2. Be able to understand and practice the process from problem findings, data collection and analysis to problem solving 3. The ability to think widely and deal flexibly with unknown problems 4. The international communication skills 5. A proper sense of patriotism and professionalism.	1. To learn how to identify problems while discovering the attractions and issues of Usa City and exploring ways to solve these problems. 2. To collect and analyze information, and work with peers to effectively present. 3. To cultivate the attitude to consider one's role and lifestyle in solving community and social problems and reflecting on one's career path in connection with the community and society.

All three projects focus on the development of problem-solving skills, logical thinking skills, and the ability to integrate knowledge and skills from various fields to solve problems. Development of design thinking is explicitly stated in the objectives of Project M and U. While the projects in the three schools can be different, common objectives to be achieved through STEM/STEAM-based learning can be observed.

In Project M, students engaged in problems related to society and science. Project M is divided into two tracks. Students in the science & mathematics stream will work on *Science/Math Track*, which focuses on solving problems related to the science and mathematics fields. Students in the general studies stream are in *Normal Track*, which addresses complex problems related to Sustainable Development Goals (SDGs), particularly touching on topics related to economy, society, and nature. In Project K, *SPACE* (宇宙) is used as a theme. Students focus on space-related topics in STEM/STEAM-based learning. This is due to the school's dedication to cultivating talents for the space industry and also considering the development of the spaceport in Kunisaki City, where the school is situated. Project U anchored STEM/STEAM-based learning around issues related to the local community and students' personal development and career aspirations. The implementation of the overarching educational objectives of Project M, K, and U can be viewed from the yearly objectives that are consolidated in Table 6.

Table 6
Overarching STEM/STEAM educational objectives of Project M, K and U

Year \ Project	Project M		Project K	Project U
	Science/Math Track	Normal Track		
Year 1	1. Cultivate the interest in science and improve the problem-slving skills and logical thinking skills through mini projects and nature survey 2. Learn design thinking skills and knowledge intergation skills for doing problem-solving projects 3. Learn the ability of data collection and analyzation through ICT for doing problem-solving projects	1. Learn the issues related to SDGs to cultivate the interest in science and problem-solving. 2. Learn design thinking skills and knowledge intergation skills for doing problem-solving projects 3. Learn the ability of data collection and analyzation through ICT for doing problem-solving projects	1. Understand the basic knowledge and issues about SPACE through lectures 2. Improve the basic ability of inquiry through workshop 3. Using the knowledge and skills learned from lecture and workshop to solve the space-related projects, for example space food	1. Learn the basic ability of inquiry through lectures and interviews 2. Learn design thinking skills and creative thinking skills to show the charm of School U 3. Set up the research topic about the issues related to Usa City for problem-solving projects in Year 2 through group work 4. Improve the writing and expressive skills through presentation
Year 2	1. Use the knowledge and skills learned in Year 1 to do group and individual problem-solving projects to improve the interest in science, problem-solving skills, collaborative skills, logical thinking skills, and individual inquiry skills 2. Improve English communication and presentation skills	1. Use the knowledge and skills learned in Year 1 to do group inquiry projects to improve the inquiry skills and logical thinking skills, and collaboration skills 2. Improve the ability of data analyzation and international communication skills	1. Learn deeper and more professional knowledge and issues about SPACE 2. Solve more complex SPACE-related issues	1. Solve the problems chose in Year 1 through the process of "research, ideation, prototype, test, and presentation" to improve problem solving skills and improve the understanding of community's issues and charm 2. Based on the research have done, set up a new research topic to more deeply think about the issues related to USA City. 3. Improve the writing and expressive skills through presentation
Year 3	1. Review the projects have done before, writing research paper for future work and study 2. Improve communication skills through presentation	1. Review the projects have done in Year 2, writing research paper for future work and study 2. Improve logical thinking skills and scientific thinking skills through lectures from experts	1. Learn deeper and more professional knowledge and issues about SPACE 2. Solve more complex SPACE-related issues	1. Continue the projects from Year 2. Think about the career aspirations using the research skills and knowledge have learned. 3. Write research paper for future study and work

4.2. Approaches to design STEM/STEAM-based curricula around the *Period for Inquiry-Based Cross-Disciplinary Study*

The three projects displayed different characteristics in designing STEM/STEAM-based learning around the *Period for Inquiry-Based Cross-Disciplinary Study*. In the following sub-sections, the curriculum for each project is dissected and highlights the key approaches adopted by each school to implement STEM/STEAM-based learning.

4.2.1. Tweaking the high school curriculum for Project M

Project M is divided into two main tracks, *Science/Math Track* and *Normal Track*, as mentioned in the previous section. Students in the *Science/Math Track* will go through *Science Inquiry Projects* and the *Mai Project*. Students in the *Normal Track* will engage in the *SSH Inquiry Projects*. To enable students to engage in complex problem-solving in these two tracks, common foundational subjects are created outside the *Period for Inquiry-Based Cross-Disciplinary Study* to allow students to acquire some STEM/STEAM-based knowledge and skills that may be applied to projects in the two tracks. The curriculum layout for Project M for the two different tracks can be illustrated through Figures 1 and 2.

The common foundational subjects created are *Mai STEAMs (舞 STEAMs)*, *Data Science* and *SSH Information Study*. *Mai STEAMs* is a new subject created by School M to specifically support STEM/STEAM-based learning. *Data Science* and *SSH Information Study* are subjects created by modifying the *Information Study* (情報) subjects that are originally available in the high school curriculum.

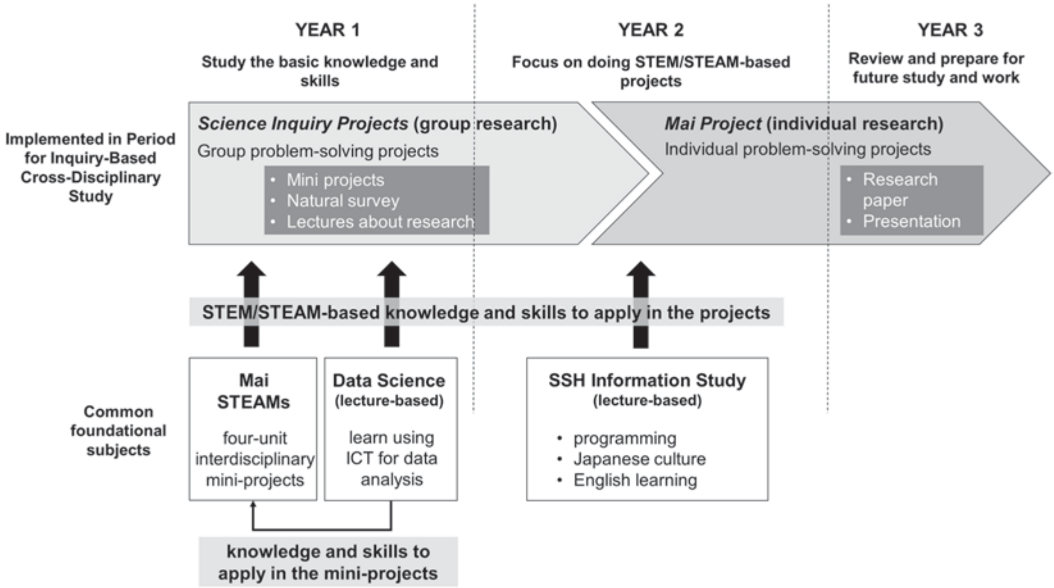

Figure 1 Curriculum plan for the *Science/Math Track* in Project M

Figure 2 Curriculum plan for the *Normal Track* in Project M

Mai STEAMs consist of four interdisciplinary mini projects, each focusing on different topics. Each unit includes approximately seven to nine lessons, with one lesson per week. Figure 3 provides a brief outline of Mai STEAMs. In Units 1 and 2, students will acquire the basic research skills. This process includes determining the theme and topic, formulating research questions and plans, conducting research and data analysis, writing a report, and presenting their findings. In Unit 3, students will learn the design thinking process, which includes empathy, problem identification, idea generation, prototyping, testing, and evaluation. Through this process, students will learn how to create prototypes. The project topic involves designing a lever crank mechanism using cardboard and Lego blocks, Figure 4. In Unit 4, students will be learning about programming by using sports as the topic.

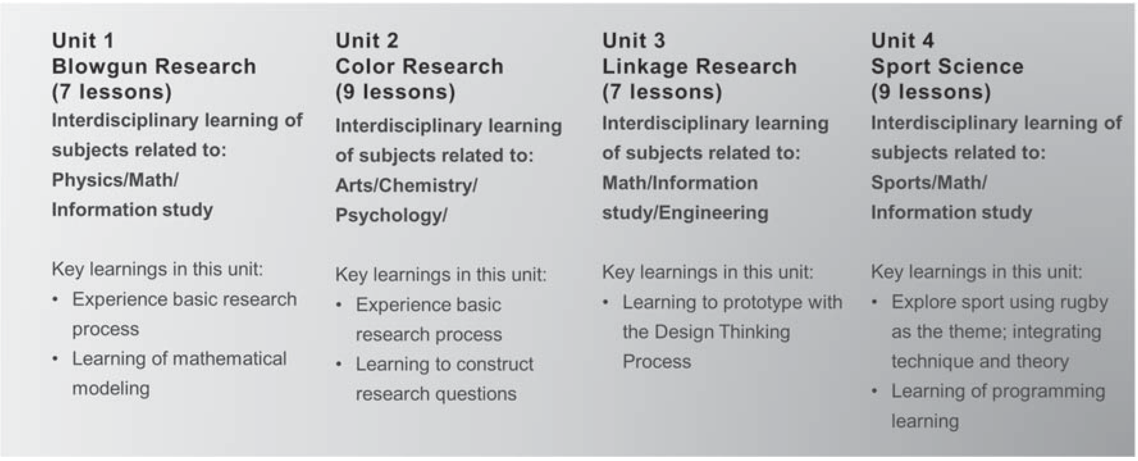

Figure 3 Brief outline of Mai STEAMs and learning outcomes

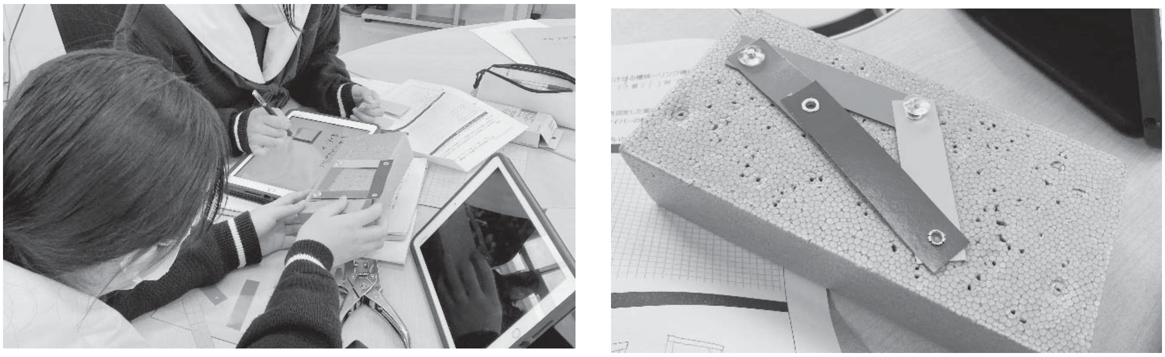

Figure 4 Activities during Unit 3 in Mai STEAMs project

In *Data Science*, students will learn how to use information communication technology (ICT) to search for and analyze information. They will also be taught programming skills. The knowledge acquired in *Data Science* can be applied in *Mai STEAMs* and in data analysis when engaging in complex problem-solving in the *Science Inquiry Projects, Mai Project* and *SSH Inquiry Projects*. In the *SSH Information Study*, students will focus on improving their English presentation and communication skills. In the context of *Science Project*, the *SSH Information Study* covers three main competencies: programming, data analysis, and academic writing. Students will learn to use more advanced and professional methods for programming and data analysis to improve their logical and critical thinking skills for inquiry projects. Additionally, students will enhance their English writing skills to prepare for English poster presentations. For students in *Normal Project* track, *the SSH Information Study* for these students will focus more on programming, English learning, and Japanese culture. The difficulty level of the subject content in the *SSH Information Study* for this track is lower as compared to the content for students in the *Science Project*.

Table 7
Program overview for *Science/Math Track*

Year	Month	Science/Math Track	Key activities	Brief outline of learning content	Objectives
Year 1	Apr ~ May	*Science Inquiry Projects*	orientation for mini projects	(1) Presumed length of unused toilet paper (2) Exploring how to get an egg to fall from the 2nd floor without breaking (3) Improve (2) based on the research result and group discussion	Improve students' interest in science research
	Jun		lecture on related Chemical subject	(1) Learn the composition and precautions of gas burner (2) Work glass	Learn the basic research knowledge and skills in the Chemical subject for future problem-solving projects
	Jul ~ Nov		conduct nature survey	(1) Conduct nature survey in Yaku-shima (2) Analyze the results of the survey and produce a report for presentation	Learn how to do research, data analysis, produce reports and presentation
	Dec		engage in mini projects	Using equipment from different labs to do mini projects	Repeatedly experience inquiry activities to learn the basic research knowledge and skills
	Jan ~ Mar		lectures for conducting research	(1) Methods for setting research topics (2) Creating research plan (3) Methods for searching previous reviews and so on	Teach students how to do research
Year 2	Apr		set the research topic	Think about the research topic	Develop ability to start the research and set research topic
	May		conduct research activities	Think about how to do the research (Experimental preparation, literature search and so on)	
	Jun		conduct research and mid-term presentation	Make the poster to do presentation The 3rd year science students will provide advice	Review and discussion with the senior to improve the research
	Jul ~ Sept		research review and poster presnetation	Review the research did before and improve the research contents, prepare the poster presentation	
	Oct		research activities	Three hours of continuous inquiry time (3 rounds)	Conduct research and improving problem-solving skills
	Nov	*Mai Project*	survey the research fields	Based on experiece of group research, think about the future individual research topic	Ability to start a research, engage in deeper research topic, improve the individual thinking skills
	Dec		set the research topic and start research	Talking with science and math teachers to set the research topic	
	Jan ~ Feb		conduct research and translate English papers	Doing research and traslate the English papers as the previous reviews	Practice English reading and writing skills
	Mar		English poster presentation	Review and presentation with the foreign student	Practice the English communication skills
Year 3	Apr		writing Research Papaer	Summary the research process of Mai Projects and write the research papaer	Practice research paper writing skills and individual research skill
	May~Jun		Final Presentation	Making research paper and research presentation	Improve the logical thinking skills and expressive skills

Table 8
Program overview for *Normal Track*

Year	Month	Normal Track	Key activities	Brief outline of learning content	Objectives
Year 1	Apr	SSH Projects	orientation	An Explanation of SSH Projects	Explain what is SSH Projects, and what is SDGs, helping students have an understanding of SDGs
	May~Jul		lectures about SDGs	Lectures on different subject areas are organized to explain real-life issues related to each subject area, and students can choose the lectures they are interested in	Learn the basic research knowledge and skills in chemical field for future problem-solving projects
	Jul ~ Nov		Conduct debate on select topics	Students are categorized into the affirmative team and the negative team based on each field to do a two-hour debate competition	Improve students logical thinking skills, critical thinking skills through information collection, analyzation, and expression
	Dec~ Mar		conduct research acitvities that lead to the 2nd Year of study	Selecting the interested topic, and make Image Map, to think about the following questions: 1. What kind of existence is the unknown problem; 2. What kind of problem exists now	Help students to decide their research topic and have a better understanding of SDGs
Year 2	Apr ~ May		set the research topic	Setting the research topic, research question and hypothesis	start the research and set research topic
	May ~ Jul		conduct research activity part 1	Doing the first part of research project	Practice the problem-solving process, improve cooperative skills
	Aug ~ Nov		preparation of mid-term presentation	Making poster and practicing presentation	Assessment, and improve the expressive skills
	Oct		mid-term presentation	Sharing the research contents and improve the research based on advice	
	Oct ~ Dec		conduct research activity part 2	Doing the second part of research project	Improve research and practice the problem-solving process, improve cooperative skills
	Dec ~ Jan		preparation of final presentation	making poster and practicing presentation	Conduct assessment and improve the presentation skills
	Feb		final presentation	poster presentation	
Year 3	Apr ~ Jun		writing research paper	Students need to review their research and write research paper, presentation	Review the research ad summary the ideas related to SDGs, to have a better understand of SDGs and problem-solving
	Jul~Dec		lectures on varied topics	Review and presentation with the foreign student	Have a better understand of SDGs and issues from different fields. Learn to find the new research topic for future work and study

Science/Math Track is divided into two parts, Table 7. The first part is called *Science Inquiry Projects*, which stretches from Year 1 to the first half of Year 2, with a focus on group research. The second part is called the *Mai Project*. *Mai Projects* focus on individual research and are conducted from the latter half of Year 2 to Year 3. Refer to Table 4. In *Science Inquiry Projects*, students will learn basic knowledge and skills related to inquiry methods and enhance their interest in research through mini projects, conducting surveys, and lectures in Year 1. In Year 2, students will apply the knowledge and skills they learned in Year 1 to conduct problem-solving projects that involve determining a research topic, conducting research, ideation, prototyping, testing, and presentation. Students select a research topic based on their interests and are divided into groups to carry out group problem-solving projects. After completing the *Science Inquiry Projects*, students will transition to *Mai Projects*. *Mai Projects* focuses on individual research to improve students' research skills. In *Mai Projects*, students will choose a new research topic based on their experience in *Science Inquiry Projects*. They determine their research topics through consultation with science and mathematics subject teachers. In Year 3, students will focus on preparing a research report and poster presentation in the first semester. *Mai Projects* aim to stimulate students' initiative and better prepare them to face future challenges in university and society.

The *SSH Inquiry Projects* in *Normal Track* is a three-year program, Table 8. The curriculum in Year 1 focuses on lectures to help students understand the SDGs and the topics that may be related to different disciplines. The project consists of three parts: basic lectures related to SDGs, debates, and research. For basic lectures, students can select topics of interest from ten different subjects. For example, in the subject of National Language, the topic for discussion can be *Exploring "Equality" from the Perspective of "Inequality."* In another example, in the subject of biology, students may select the topic of *SDGs from an* agricultural perspective. After the selection of a topic, for each topic, students are divided into affirmative and negative teams to defend their arguments in a two-hour debate competition. Students will collect and analyze data to express their arguments accurately and logically. As a result, students can improve their logical thinking and communication skills. After students understand the information related to the SDGs, they will choose the research group and the research topic for Year 2. In Year 3, students mainly focused on writing a research paper and creating a poster based on the research done in Year 2.

4.2.2. Reconfiguring the high school curriculum to a specific theme and collaborating with experts to bring in specialized content for Project K

The STEM/STEAM-based program in High School K leverages the ambitions of the development of a spaceport in Kunisaki City and collaboration with external experts as collaborators. Figure 5 illustrates the structure of Project K. At the start of the program, all Year 1 students will engage in the *Space STEAM Inquiry Projects*. The *Space STEAM Inquiry Projects* consists of two parts. The first part of the program is called the *Think Space, Think Kunisaki Program*, and the second part is called the *Think Moon Program*. The *first semester comprises seven sessions for the Think Space, Think Kunisaki program*. Each session is made up of a one-hour lecture followed by a one-hour workshop that focuses on problem-solving. Students will learn about space and relate it to the local context. An outline of the sessions is presented in Table 9. Experts from external organizations who specialize in space and fields relevant to the project will be invited to conduct the lectures and workshops. In the second semester, the *Think Moon Program* focuses on engaging students in complex problem-solving. For instance, students must compare living on the moon to living on Earth and identify potential challenges. Afterward, students will apply the problem-solving processes they learned earlier to propose solutions.

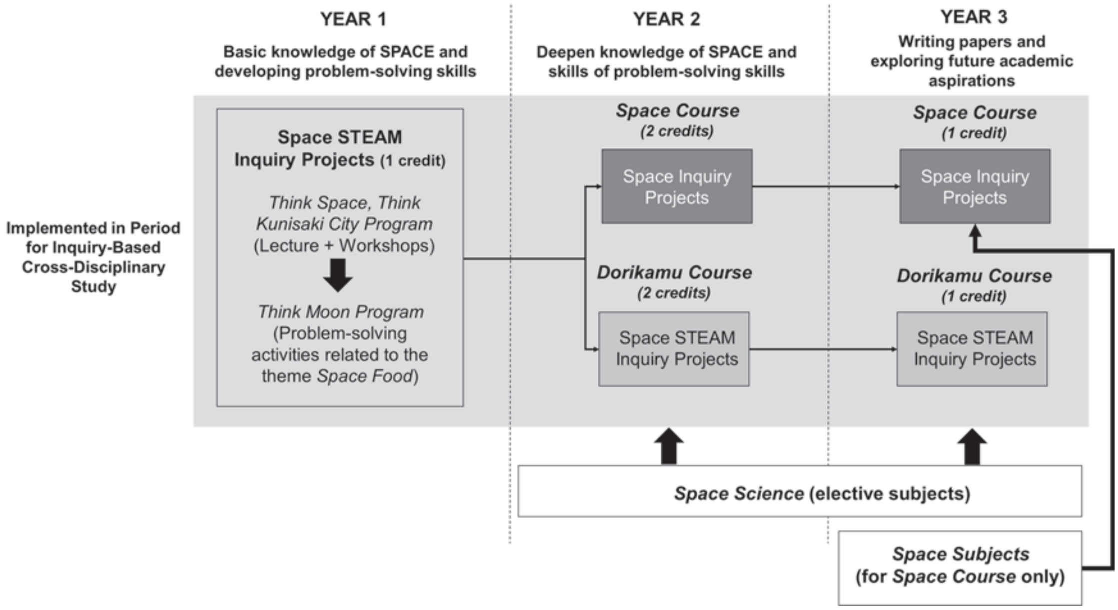

Figure 5 Curriculum plan for Project K

In the second year of study, Year 2 students will be divided into two tracks while the theme *Space* continues to anchor Project K. Part of the students are enrolled in the *Space Course.* Students in this track are those who choose to study more specifically on the subject of *space* and also consider applying for university entry through examinations by specific recommendations. such as the *Sougo Kata Suisen* (綜合型推薦) examinations, rather than the usual university entrance examinations. The *Space Course* is designed in such a way that students in the arts and science stream will be able to study. The majority of the students, other than those in the *Space Course,* will be enrolled in the *Dorikamu Course* (ドリカムコース). Students on the *Space Course* will engage in the *Space Inquiry Projects*. On the other hand, students in the *Dorikamu Course* will continue to engage in the *Space STEAM Inquiry Projects*, Table 10.

During data collection for this study, the *Space Inquiry Projects* in the *Space Course* were yet to be fully implemented; thus, detailed information about the *Space Course* is unable to be presented.

But a brief description of the *Space Course* based on available documents and interview data is consolidated as follows. In the first semester, the Year 2 students in *the Space Course* will learn topics related to satellites, debris, exploration, and daily life through lectures and inquiry-based activities. In the second and third semesters, students will then explore topics related to four major themes, such as *Life in Space*, *Space Environment*, *Space Technology*, and *Space Education,* through a *Space STEAM Map*. The *Space STEAM Map* is a unique study framework that connects various topics to the four major themes, allowing students to choose a topic that interests them. After choosing the topic of interest, students will then form groups to engage in six months of research activities on the topic of interest. The school also tries to connect key learnings in other parts of the school curriculum to the four major themes. In the *Dorikamu Course*, in the first semester, students will engage in mini projects that aim to develop students' basic knowledge of space, space exploration, law related to space, system thinking, research skills, and presentation skills. Then after, they will engage in the *Space STEAM Inquiry Projects,* where the theme *Space x Kunisaki City* was used to get students used to the concepts of STEM/STEAM to explore solutions to tackle earth and regional issues from the perspective of space. For example, getting students to explore the tasks of moving from Kunisaki City to living on the moon. Thus, for Year 2 students, they engaged in different forms of inquiry-based activities structured around the topic of space. It should also be noted that School K specifically increased the number of credits of *the Period for Inquiry-Based Cross-Disciplinary Study* to 2 credits (minimum was 1 credit) so that students in both the *SPACE Course* and *Dorikamu Course* are given more time to conduct research, prototyping, and testing. This allowed students to develop critical thinking skills and allowed them to develop their own personal interest in depth. In the third year of study, students in both the *SPACE Course* and *Dorikamu Course* focus on writing research essays and considering their future academic and career paths based on their studies in Project K.

To further support the STEM/STEAM-based learning through the topic of space, a set of elective subjects, *Space Science*, is created to connect specific subject content to the theme of *space.* For example, the elective *Space Tourism Commercialization* (宇宙観光商品化) is offered by the Business IT Course. As an additional example, the Horticulture Business Department offers the Space Cultivation of Plants (宇宙栽培植物). All students can choose the electives they are interested in to broaden their knowledge about space, which may contribute to their creative problem-solving. *Space Science* electives also allow students to study beyond their traditional subject boundaries, based on their interests, passions, and career paths.

To strengthen the connections between specific disciplines, High School K also introduced a series of *Space Subjects* for students enrolled in the *Space Course*. These subjects include *SPACE Math*, *SPACE English*, *SPACE English Application*, *SPACE Physics*, *SPACE Biology*, *SPACE Basic Biology*, and *SPACE Chemistry*. The content of *Space Subjects* is linked to *Space Science* electives and *Space Projects*; this further allows students to link the theme of space across various subject studies.

Table 9
Program overview of *Think Space, Think Kunisaki Program*

Timeframe	**Project content and objectives**		
April. 12	**Lecture**	**Lecture Content**	**Objective**
	What is Space and Local Spaceport	Talk about what Kunisaki City doing now	Students will have a basic understanding of space and the relationship between Kunisaki City to Space
	Workshop	**Workshop Content**	**Objective**
	Make the futuremap of Kunisaki City	Groups of four to five students to make the futuremap in one paper	understand what is Space and the relationshop of Space and the local city
April. 28	**Lecture**	**Lecture Content**	**Objective**
	Why choosing Space as the theme (Online)	Talk about the basic knowledge about Space, Space and work, space food, the issues about life in Space, etc.	Learn the issues about Space
	Workshop	**Workshop Content**	**Objective**
	Doraemon props can be used for students in School K in 2043	Groups of four students (Mixed seven classes of students) to generate ideas about future props for school life and poster presentation	practice idea generation
May. 12	**Lecture**	**Lecture Content**	**Objective**
	What is inquiry activitites (Orientation)	Explain the enquiry activities students will do in the first semester	Have a brief understanding of what students will do in the first semester
	Workshop	**Workshop Content**	**Objective**
	Marshmallow Challenge	team work for the Marshmallow Challenge Competition	understand the problem-solving process and team work
May. 26	**Lecture**	**Lecture Content**	**Objective**
	The Incredulity of the Universe and the Role of the Technicians	Introduce some Space projects, some special knowledge bout the age and mystery of the universe	Learn more professinal knowledge of Space
	Workshop	**Workshop Content**	**Objective**
	What would you like to do if travelled to Space	Imagine and model what you want to do and see while travelling in the universe	Prototyping
June. 9	**Lecture**	**Lecture Content**	**Objective**
	Information literacy	learn how to search and filter information from Internet	Learn the basic inquriy methods of information collection
	Workshop*	**Workshop Content**	**Objective**
	Create the tourism promotion for different country as a tourist office staff	Search for the information about "environment" "food" "culture" and "fashion" from SNS or other media to make tourism promotion for different country	Practice information search and analysis
June. 23	**Lecture**	**Lecture Content**	**Objective**
	Move to another planet	Using game to help students to understand what is the important things should be thought about when move to another planet	Learn to think about the issues in space and think about ho to solve it
	Workshop	**Workshop Content**	**Objective**
	Create the tourism PR for different country as a tourist office staff	idea generation to make poster for presentation	Idea generation and development, team work
June. 9	**Lecture**	**Lecture Content**	**Objective**
	Information literacy	learn how to search and filter information from Internet	Improve the ability of information collection and analyzation
	Workshop	**Workshop Content**	**Objective**
	Create the tourism PR for different country as a tourist office staff	make poster and presentation based on the workshop (*) in June 23	evaluation and prepare presentation
July. 7	**Presentation**		
	Presentation about tourism promotion made by students in each class		

Table 10
Program overview of *Space STEAM Inquiry Projects*

Year	Month	For students not taking the *Space Course*	Key activities	Brief outline of learning content	Objectives
Year 1	Apr~Jul	*Space STEAM Inquiry Projects*	Think Space, Think Kunisaki City Program	(1) Seven weekly two-hours a lecture (1 hour) for learning SPACE, and a workshop for learning problem-solving methods(1 hour)	Teach students the basic knwoledge related to SPACE and the problem-solving methods
	Sept		Think Moon Program	(1) Lecture: Thinking about living on the Moon (2) Workshop: Think about the life on the moon (3) Divide groups. Students will choose the topic they are interested in: menu development, food production, and general diet	Prepare for the space-food-related problem-solving activities
	Oct			(1) Lecture about the eating habits on the moon (menu development group) and the space nutritional science (food production, and general diet group) (2) Worksheet: Idea generation (What should be achieved for life on the moon)	Learning of idea generation and prototyping
	Nov			(1) Worksheet: Idea generation (What should be achieved for life on the moon) (2) The lesson about how to do prototype	
	Dec			(1) Summary the idea generated (2) Organize the information used for prototyping (3) Mid-presentation	Practice the presentation skills
	Jan			Make prototypes and test	Practice the problem-solving skills, especially the design thinking skills
	Feb			Make slide and prepare the final presentation	Practice the expressation skills and presentation skills
	Jun			Final presentation	
Year 2	Apr	*Space STEAM Inquiry Projects: Think Space, Act for Earth Program*	Mini Project Themes: *Space x My Vision*; *Space x Social Systems*	Lecture about foundational knowledge of space and exploration of space	Kick off, improve data collection skills and cooperative skills
	May			(1) Use TIMELINE activitiy (created by the school) to think about own story (2) Lecture about Space Law (3) Debate (4) Presentation	Improve data collection skills, inquiry skills and presentation skills
	Jun ~ Jul			(1) Lecture about Systems thinking (2) Workshop to focus on application of systems thinking	Practice systems thinking, to improve creativity, communication skills, cooperative skills and so on
	Jul ~ Aug			Summary the finding of my story and decide the group research topic	Presentation and prepare for next semester
	Sept		Space x Kunisaki City (Group Research: Space-related learning, STEAM inquiry activities, and presentations)	(1) Lecture about Satellite Utilization (2) Search for the information about joint plans of Kunisaki City (3) Think about the problem between space and earth	Deepen the knowledge about space; problem identification
	Oct			(1) Lecture about future agriculture and space technology (2) Think about the life in space and decide the research topic	Deepen knowledege about space, decide research topic
	Nov			Research (Problem finding and information collection)	Problem solving process, Information collection, problem finding (ideation)
	Dec			(1) Problem solving (think about how to do prototype) (2) Mid-presentation	Improve problem solving skills and presentation skills
	Jan			(1) Prototyping (2) Final-presentation preparation	Improve inquiry skills, information collection skills and presentation skill
	Feb			(2) Final-presentation	Improve presentation skill
Year 3	Apr ~ Jul	Future academic and career developmets	Individual Research	Individual research about space	Improve the individual research skill
	Seb ~ Nov		Future Course Selection	Think about the future development	Help students to better decide the future development
	Feb ~ Jan		Writing graduation paper	Based on the individual research to write essay	Improve paper writing skills and prepare for future study and work

4.2.3. Tapping on existing outside programs to support STEM/STEAM-based learning in Project U

Project U is mainly implemented within the *Period for Inquiry-Based Cross-Disciplinary Study* for all students in School U, Figure 6 and Table 11. Some projects introduced in Project U mainly focus on inculcating students with the design thinking process and interdisciplinary learning. Project U consists of three key features. Firstly, the *6s' Project* is introduced to the school by the Oita Prefectural Board of Education, where Year 1 students will learn the design thinking process. The *6s' Project* consists of seven lessons and is conducted in collaboration with instructors who are from external organizations. Using design thinking, students will create a six-second animation that showcases the charms of Usa City (宇佐市) in Oita Prefecture. Through this project, students go through the process of developing empathy, determining topics to focus on, ideation, testing their ideas, and presenting them. The design thinking process learned from the *6s' Project* will be applied in subsequent projects in Project U. In addition, students will begin to identify their research topics for *Project 1* in the second year of study.

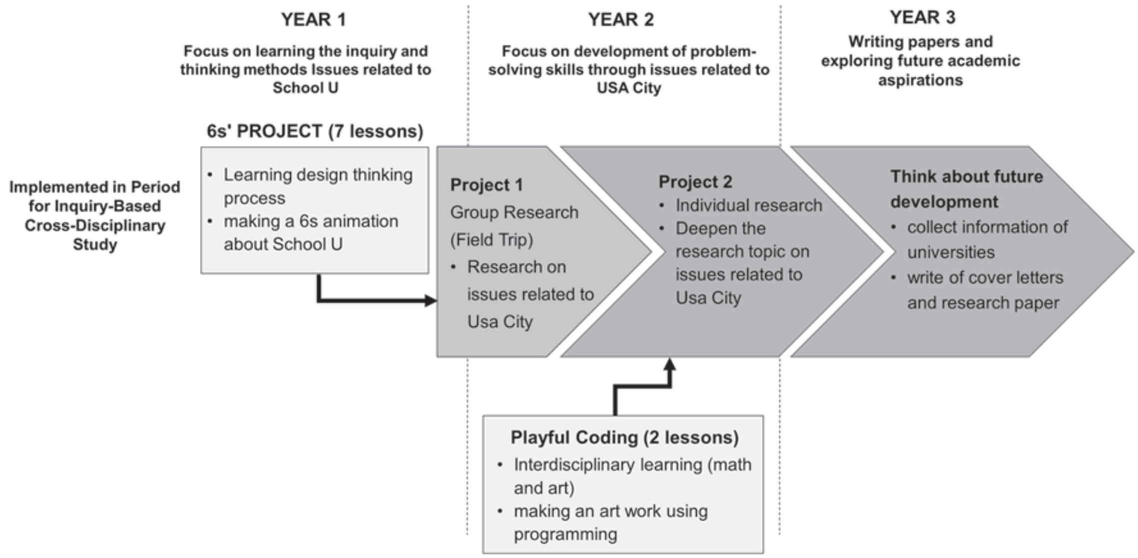

Figure 6 Curriculum plan for Project U

As a key second feature in the program, students will move on to complete two key projects, *Project 1* and *Project 2*, in the second year of study. The key projects mainly focus on using design thinking to identify the charms and issues of Usa City. This part of the program engages students in solving community issues around them through fieldwork, analyzing data, and doing presentations. *Project 1* allows students to work in groups. In *Project 2*, students will work individually to look deeper into the issue of Usa City. *Project 2* will stretch into the third year of study and end with a presentation. Using the skills learned in the STEM/STEAM-based program, students will then attempt to consider the next step of their academic career by identifying relevant universities of their interest and writing out their future academic aspirations.

As an additional layer of learning for students to apply STEAM skills to the projects in Project U, High School U adopted a mini-interdisciplinary project called *Playful Coding*. *Playful Coding* is a program developed through the *Future Classroom* (未来の教室) initiative advocated by the Japanese Ministry of Economy, Trade, and Industry (METI). This project integrates math and art, allowing students to create digital artwork through programming, fostering their creativity and expressiveness. The objective of this project is to give students the opportunity to further engage in interdisciplinary learning and STEAM education.

Table 11
Program overview of Project U

Year	Month	Key activities	Lesson time allocated	Brief outline of learning content	Objectives
Year 1	Aug~Dec	6s' PROJECT	7	(1) Set up the topic of animation (the charm of Usa City) (2) Understand the charm of photography and editing through storyboard case studies (3) Ideation and making storyboard (4) Photography,editing and so on, making animation (5) Mid-term presentation and final presentation	Learn the design thinking process (empathy, setting topic, ideation, test, and presentation)
	Jan~Mar	Project 1 (Group Research)	8	(1) Grouped according to the research interest (the charm of Usa City) (2) Collect the data and set up the research topics (3) Listen to the third grade presentation (4) Review the study in Year 1	set the research topic and collect information for Project 1 in Year 2
Year 2	Apr~Jun	Project 1	10	(1) Summary and analyze information got in Year 1 (April) (2) Find the field place and prepare for field trip (May) (3) Field trip and analyze data got from field trip (June)	developing inquiry skills (research, collect and analyze information, cooperative skills)
	July	Playful Coding Program	2	Making an artwork through programming	Try the interdisciplinary STEAM education
	Sept~Oct	Presentation of Project 1	10	(1) Prepare for presentation (Sept) (2) Presenation (Oct)	Practice the expressive ability
	Nov~Mar	Project 2 (Individual Research)	14	(1) Deepen the research, set the research topic (Nov) (the charm of Usa City) (2) Field trip (Dec~Feb) (3) Summary and analyze the information got from field trip (Feb) (4) Listen to the presentation by 3rd grade students (Mar) (5) Review the study in Year 2	Improve the individual inquiry ability and learn from three grade students
Year 3	Apr~May	Project 2	9	(1) Summary and analyze data got in Year 2 (2) Presentation	Practice the inquiry process (analyze information, presentation, expressive skills)
	Jun~Nov	Research about univisity for academic progression (cover letter)	15	(1) Determine the desire university (2) Collect and analyze the information of university for academic progression (3) Collect high-level information through lectures on local and social contemporary issue (Hire an external lecturer) (4) Write the cover letter	Using the inquiry process have learned to find a desire university and write cover letter for future study
	Dec~Mar	Review three years of learning activities (Graduation research)	11	(1) set up topic: select topics of most interest in the career paths and use them as topics of graduation research (2) Collect and analyze information (3) Presentation	Practice the inquiry process repeatedly, help students to think about their future development about career

5. Discussions

5.1. Can the STEM/STEAM-based programs offered in the three high school cases be considered as effective STEM/STEAM-based programs?

Table 1 in the earlier section presented the key considerations for implementing effective STEM/STEAM-based programs. Based on the findings, Table 12 consolidated the key observations in the implementation of STEM/STEAM-based curricula in the three high school cases that may be considered effective STEM/STEAM-based programs.

Based on the data collected, all three schools adopted a transdisciplinary approach towards engaging students in solving real-world problems in the *Period for Inquiry-Based Cross-Disciplinary Study*. The interdisciplinary approach is mainly used as a means for students to develop necessary knowledge and skills in different STEM/STEAM fields so as to apply them to projects for solving real-world problems. School M and School K redesigned part of the school curriculum to either create new subjects or modify the existing subjects to support the study of STEM/STEAM-based learning in the *Period for Inquiry-Based Cross-Disciplinary Study*.

While all high school cases adopted design thinking as the approach to teach students to engage in real-world problems, the extent of using design thinking was not clearly observed through the findings. Especially in the aspect of testing prototypes, it was not clear if all students were required to develop prototypes to test against the problems.

Based on Table 12, it can be observed that all three high school cases fulfilled most of the key considerations for effective STEM/STEAM-based programs.

Table 12
Characteristics of the three STEM/STEAM programs against the key considerations of STEM/STEAM Programs

			Characteristics STEM/STEAM-based learning implemented through the *Period for Inquiry-Based Cross-Discinplinary Study* in each of the high school case		
			School M	**School K**	**School U**
Key considerations for implementing effective STEM/STEAM programs based on Table 1.	**Making explicit connections between the content in targeted disciplines which may involve multidiscipline, interdiscipline, transdiscipline**	**Transdiscipline Approach**	Implemented within the *Period for Inquiry-Based Cross-Disciplinary Study* as research projects in the Science Inquiry projects and Mai Project for students in the Science/Math Track in Year 2 and 3; and as research projects in the SSH projects for students in the Normal Track in Year 2.	Implemented within the *Period for Inquiry-Based Cross-Disciplinary Study* as projects in the Think Moon Program for Year 1 students. In addition, in the Space Inquiry Projects for the Space Course and the Space STEAM Inquiry Projects for the Dorikamu Course for Year 2 students in the respective courses.	Implemented within the *Period for Inquiry-Based Cross-Disciplinary Study* as complex problem-solving projects that engage in issues related to Usa City.
		Interdiscipline Approach	Implemented as outside the *Period for Inquiry-Based Cross-Disciplinary Study* subject through the mini project Mai STEAMs.	Implemented within the *Period for Inquiry-Based Cross-Disciplinary Study* as projects in the Think Space, Think Kunisaki City Program (Lecture+Workshop).	Implemented within the *Period for Inquiry-Based Cross-Disciplinary Study* as the 6S' Project where students are given a specific task to utilise specific knowledge and skills realted to the different STEAM fields. While Playful Coding project is an interdisciplinary STEAM project that is offered outside the *Period for Inquiry-Based Cross-Disciplinary Study*. The Playful Coding poject merry math and art to create art works through programming.
		Multidiscipline Approach	Specifically created to support STEM/STEAM-based learning, subjects like SSH Study, Data Science and the lectures provided within the *Period for Inquiry-Based Cross-Discinplinary Study* are mainly studied individually as knowledge to be applied into the research projects.	The Space Science elective subjects and the Space Subjects outside the *Period for Inquiry-Based Cross-Discinplinary Study* are designed to be studied individiually as knowledge to be applied in the inquiry projects in the Space Course and Dorikamu Course.	Not observed through the curriculum design.
	Engaging students into real world problems that are considered to be open-ended		The research projects in the Science Inquiry projects and Mai Project for students in the Science/Math Track in Year 2 and 3; and the research projects in the SSH projects for students in the Normal Track in Year 2 can be considered to engage students in real world problems that are open-ended. One of the main objectives of the projects is to allow students to apply the different STEM/STEAM fields when engaging the projects.	The Think Moon Program for Year 1 students, and the Space Inquiry Projects for the Space Course and the Space STEAM Inquiry Projects for the Dorikamu Course for Year 2 students used Space as the theme to allow students engage in complex problem-solving. Through projects, students are expected to integrate knowledge learned from the Space Science elective and Space Subjects.	The complex problem-solving projects in the *Period for Inquiry-Based Cross-Disciplinary Study* present the main opportunity for students to be engaged in real-world problems that set the context in Usa City. While it is expected that students apply the knowledge and skills learned from the 6S' Project and the Playful Coding Project. As compared to School M and School K, the study of different STEM/STEAM fields outside the *Period for Inquiry-Based Cross-Disciplinary Study* that can be applied to the complex problem-solving projects are not as varied and broad.
	Context of real world problems allow integraton of STEM/STEAM content				
	Engaging students in full design process and allow for testing prototypes		All three STEM/STEAM programs engaged students in applying the design thinking process to engage in solving real-world problems. But the data collected from all three schools did not present clear indication to what extend the design process was strictly implemented. While students in all three schools were required to present solutions to the complex problems that they were engaging, there were not enough evidence to show that all students were required to produce a prototype for testing against the problem.		
	Developing students with 21st CC		It was evident that all three schools develop students with 21CC through the respective STEM/STEAM programs as a whole.		

5.2. Creating STEM/STEAM-based learning around a dedicated school subject such as the *Period for Inquiry-Based Cross-Disciplinary Study*

While many countries are challenged by not having formal curriculum time to implement integrated STEM/STEAM-based learning (Lee & Lee, 2022), Japanese high school education is empowered by having the *Period for Inquiry-Based Cross-Disciplinary Study* that supports such cross-disciplinary learning. From the cases presented, it is possible to design and implement integrated STEM/STEAM-based learning in the *Period for Inquiry-Based Cross-Disciplinary Study*. In the three high school cases, several key characteristics were observed in the curriculum designed for STEM/STEAM-based learning through the *Period for Inquiry-Based Cross-Disciplinary Study*.

Firstly, Japanese high schools are given the autonomy and flexibility to achieve the learning outcomes of the *Period for Inquiry-Based Cross-Disciplinary Study*. This flexibility allowed Schools M, K, and U to design STEM/STEAM-based learning according to the strengths and needs of the schools. Drawing from their respective locality and strengths, Schools M, K, and U each adopted relevant themes that helped the schools to anchor their respective STEM/STEAM-based projects. In addition, School M and School K not only managed to create new subjects but also modified some of their existing subjects in the schools to support STEM/STEAM-based learning. School K even increased the number of lessons by increasing the number of study credits for Project K. Not only are High School M and School K using the *Period for Inquiry-Based Cross-Disciplinary Study*, but they are also restructuring part of their school curriculum to support STEM/STEAM-based learning. This flexibility in calibrating their school curriculum to support STEM/STEAM-based learning may be a consideration for other high schools when considering incorporating formal curriculum time for STEM/STEAM education.

Secondly, additional STEM/STEAM related subject content is inserted to provide students with the depth and breadth of knowledge and skills to engage in complex problem-solving in the STEM/STEAM-based projects. STEM/STEAM related subject content can be provided by creating new subjects or modifying existing subjects as observed in School M and School K. But it can also be provided via additional small projects inserted in between the main STEM/STEAM-based project, as in School U. This suggests that learning STEM/STEAM content may not be sufficient if it is only done through STEM/STEAM-based projects. While the learning of content in the different STEM/STEAM fields can be achieved through the main projects, certain subject content that may be considered foundational or may provide a deeper understanding of specific STEM/STEAM fields can be taught outside the main projects. This suggests that schools should be ready to invest additional time and resources in implementing a STEM/STEAM curriculum that consists of depth and breadth.

In the respective STEM/STEAM-based curriculum of the three cases, scaffolds are created to allow students to learn prerequisite knowledge and skills to be applied in the main projects. In addition, the complex problem-solving projects in the curriculum are not one-off. The difficult level of the projects is also calibrated in such a way that students go through a less intensive project before they go deeper into their topics of interest in the subsequent projects. In a way, students would have gone through at least two rounds of complex problem-solving activities before they finish off the STEM/STEAM-based learning during the third year of study. In the case of these three schools, curriculum flexibility in time allocation for STEM/STEAM-based learning may have provided them with the advantage of developing necessary learning scaffolds.

5.3. Other possible considerations when designing STEM/STEAM curriculum similar to the three case studies

Through the analysis of three case studies, it is clear that the issue of lacking curriculum time for integrating STEM/STEAM education can be addressed by utilizing subjects such as the *Period for Inquiry-Based Cross-Disciplinary Study*. However, if other Japanese high schools are to implement STEM/STEAM-based learning through the *Period for Inquiry-Based Cross-Disciplinary Study*, some other considerations need to be considered.

All three cases incorporated authentic project themes by leveraging unique characteristics and regional contexts. By using authentic themes that connect students with the regional context, students get to understand and know more about their community or the specific region that they are tasked to work on for their projects. For example, students who are in the *Science Inquiry Projects* in School M conducted their projects by using Yakushima Island, just off the coast of Kagoshima Prefecture in the Kyushu region, to develop their inquiry skills. Another example is in School K, where the local development of a spaceport is used to set the theme "*Space*" to anchor the STEM/STEAM-based learning. Thus, when planning the curriculum for STEM/STEAM-based learning, it is suggested that schools consider incorporating local and regional characteristics and utilize them as authentic themes and learning experiences.

In addition, working with external experts may be necessary to bridge the lack of specific expertise for implementing certain specialized learning content in STEM/STEAM-based learning. In School K and School U, experts from external organizations supported the implementation of certain aspects of STEM/STEAM-based learning in their projects. While it is not obvious in the current findings that presented Project M, teachers in School M did consult experts in external organizations, specifically in projects such as the dyeing experiments in *Mai STEAMs*. Thus, it is necessary for schools to establish external collaborations to implement STEM/STEAM-based learning.

From the three case studies, it is clear that teachers will play the role of facilitator in STEM/STEAM-based learning. However, the teachers' understanding of STEM/STEAM education and their grasp of complex problem-solving processes can significantly impact the depth and breadth of the knowledge students acquire. For instance, in School M, science teachers were deployed to assist students in setting themes for the Science Inquiry Projects, offering their expertise and guidance. This suggests that appropriate teacher training will be necessary in schools where teachers may lack sufficient expertise. This not only enhances teachers' teaching abilities and promotes the deeper development of STEM/STEAM education but also helps alleviate the pressure teachers might feel when delivering STEM/STEAM-related curricula.

6. Limitations

The limitations of this study primarily involve the following aspects, along with corresponding suggestions for this study to further develop. Firstly, this study focuses on only three cases in Oita Prefecture, resulting in a small sample size. The development of STEM/STEAM education in other regions of Japan has not yet been explored. Therefore, the scope of this study could be extended to include cases of STEM/STEAM education development in other regions of Japan to identify similarities and differences in designing and implementing STEM/STEAM-based curriculum *Period for Inquiry-Based Cross-Disciplinary Study*.

Secondly, this study primarily focuses on the qualitative analysis of documents and perspectives provided by the teachers and the proposed suggestions for STEM/STEAM curriculum design. But other components related to curriculum, such as assessment methods, pedagogical approaches, learning environment, learning content, and the collaborative dynamics between external experts and the schools, have yet to be studied. Thus, to fully understand the case studies mentioned in this paper, the other components related to the curriculum need to be studied in order to gain a holistic view of STEM/STEAM education in Japanese high schools.

7. Conclusion

This paper set out to identify the characteristics of STEM/STEAM curriculum that is designed to be implemented in the *Period for Inquiry-Based Cross-Disciplinary Study* in the Japanese high school. Using a qualitative approach to conduct a collective case study that compares three cases, the following key characteristics can be suggested. Firstly, the *Period for Inquiry-Based Cross-Disciplinary Study* in the high school curriculum provided an autonomous and flexible means for Japanese high schools to implement STEM/STEAM-based learning through multidisciplinary, interdisciplinary, and transdisciplinary approaches in different parts of the curriculum to engage students. This is achieved by developing the STEM/STEAM curriculum as a three-year program and fully using the curriculum available to the *Period for Inquiry-Based Cross-Disciplinary Study*. While all three high school cases adopted design thinking as an approach for students to engage in real-world problems in STEM/STEAM-based projects, it is still uncertain to what extent design thinking was used in the curriculum. In addition, it can be observed that all three schools designed necessary scaffolds to engage students in learning and, at the same time, provide the depth and breadth in subject areas to further interest students in STEM/STEAM. Finally, when designing STEM/STEAM-based programs, it can be suggested that high schools should consider utilizing local resources to support the STEM/STEAM programs. At the same time, local issues may also be used as the themes for students to engage in solving real-world problems through STEM/STEAM approaches.

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