Early STEAM Education Project Mathematics Course at NIT, Matsue College -Part Ⅱ: Bridge Learning for introduction to technical college mathematics-

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As part of the early STEAM (Science, Technology, Engineering, Art, and Mathematics) education, National Institute of Technology (KOSEN, NIT), Matsue College has been offering a total of six mathematics courses to third-year junior high school students who are interested in the school or mathematics and prospective students of the school since 2024. This is an educational program conducted under a project of NIT, which aims to provide a Bridge Learning education to smoothly connect the study of mathematics in primary schools, junior high schools, and technical colleges. The purpose of this paper is to propose the teaching materials used in the early STEAM Education Project Mathematics Course at NIT, Matsue College.
The course for third-year junior high school students was held four times in a hybrid face-to-face and online format, focusing on ' functions', 'congruence and similarity', 'the theorem of the angle of circumference', and 'the Pythagorean theorem', as well as applications in mathematics and engineering studied at the technical college. The course attracted a much larger number of applicants than expected, which suggests that there is a high demand for early STEAM education mathematics courses. Furthermore, the course received a positive response from the participants, which has already been reported by the authors in other journal papers, as it could be used in different technical colleges.
The course for prospective students of the school was held twice in an online format and included lectures on 'equations and complex numbers', 'trigonometric ratios and trigonometric functions (including the sine and cosine theorems)', which are studied in the first year of a technical college. In these lectures, teaching materials were prepared based on the matters learned in junior high school, with a greater awareness of the 'bridge' between the mathematics studied at the technical college. The aim is to familiarise students with the mathematics taught at technical colleges before they enrol, so that they can become accustomed to the mathematics and atmosphere at technical colleges, and to make them aware that middle school mathematics serves as the foundation for technical colleges. Details of the contents, the effect of these courses, and the participants' responses will be reported in the presentation.

Keywords: *Early STEAM Education, Bridge Learning, Mathematics in Engineering, Mathematical Education*

Introduction

In recent years, 'early STEAM' (Science, Technology, Engineering, Art, Mathematics) education has attracted attention at universities and technical colleges in Japan (Sakai, M. & Tanaka, T. (2024)). In Shimane Prefecture, where National Institute of Technology (KOSEN, NIT), Matsue College is located, few institutions provide early STEAM education and cram schools that support learning, which is thought to be one of the reasons why elementary and junior high school students are turning away from science, engineering, and mathematics. Furthermore, in recent years, there have been many cases in which students with low basic academic skills have been unable to adapt to study at technical colleges. Such a phenomenon could also occur at other technical colleges.

Against this background, it was considered necessary to increase STEA education opportunities for elementary and junior high school students and to strengthen the mathematics (M) skills of junior high school students before entering a technical college to increase the effectiveness of learning at a technical college. To bridge the learning gap between elementary, junior high, and technical colleges, we developed the Early STEAM Education Program, which combines a craft and science course (STEA) and a mathematics course (M) for elementary and junior high school students, under the project named ‘STEAM Education Programme to realize bridge learning between elementary, junior high, and technical colleges’. This education program was planned to build on what students learn in elementary and junior high school and bridge learning with an awareness of how this will lead to engineering and mathematics studies at the technical college.

The content of the mathematics courses focused mainly on functions and elementary geometry (ZUKEI in Japanese), which are the foundations of mathematics. This is because a deep understanding of functions and elementary geometry is beneficial for learning mathematics at technical colleges and its applications in engineering. In addition, In the National Assessment of Academic Ability in 2024 (an annual survey of third-year junior high school students by the Ministry of Education, Culture, Sports, Science and Technology in Japan), two issues were identified: being able to think logically and prove things (in the field of elementary geometry) and being able to interpret events mathematically and explain how to solve problems mathematically (in the field of functions). In other words, these issues can be said to be the qualities and abilities needed to become practical and creative engineers not only in mathematics but also in technical colleges. To cultivate these qualities, it is meaningful to expose students to the mathematics they will learn at a technical college through early STEAM education while making them aware of the relationship with junior high school mathematics. As for the lectures for third-year junior high school students, we received more applications than expected and the response was so great that we have already presented an outline of the mathematics lectures for third-year junior high school students, to share information with other technical colleges (Matsuo, K., Koide, S., Katayama,M., Homma,H. & Suzuki, J. Submitted).

This paper presents a comprehensive overview of the mathematics courses offered to new students entering NIT, Matsue College in April 2025, as well as the courses for junior high school students, including the teaching materials and approaches used.

Materials and Methods or Pedagogy

This section describes the content of the mathematics course we have developed, including details on the teaching materials and implementation methods. The course consists of two main parts.

1. Mathematics course for engineering
2. Preparatory course for entering KOSEN.

In common with both courses, we prepared teaching materials and conducted lectures based on the following principles(i)-(iii).

(i)To enable students to realize the importance of basic knowledge of junior high school mathematics (seamless learning between junior high school and technical college).

(ii)Deepen their understanding of related units (seamless learning within mathematics).

(iii)To increase interest in mathematics and engineering in technical colleges (seamless learning within mathematics and engineering).

As with all studies, mathematics is based on the content learned in primary and secondary school, and mathematics itself is connected to each of these fields. By studying functions in depth, students gain a deeper understanding of figures and equations. Studying figures in depth provides a deeper understanding of functions and equations. This can be understood from the fact that in modern mathematics, algebra, analysis, and geometry have been developed while connected. Furthermore, the development of science, not just mathematics, cannot be separated from the progress of technology. An overview of the relationship between mathematics and engineering may be useful in motivating students to study mathematics and in raising their motivation for engineering. The achievement of the three principles (i) to (iii) listed above is assessed by the following items in the participant questionnaire.

Table 1. Most important evaluation items.

(i)	Would it be useful for your future study of mathematics?
(ii)	Did you gain a deeper understanding of the relevant units?
(iii)	Did you become interested in the mathematics studied at the technical college?

An overview of each of these courses is as follows.

1. Mathematics course for engineering

Preparation began in September 2024, and the course itself was held four times between November and December in a hybrid face-to-face and online format. The reason for the face-to-face and online hybrid format was to enable junior high school students from distant locations to participate through the online format.

There were 109 applicants for each session, for a total of 436. In the face-to-face course with a maximum of 40 participants, students from the technical college acted as Teaching Assistants and patrolled the desks during the exercises (see Figure 1). In the online format, after the face-to-face format, a slide video was created separately using the recording function of PowerPoint (Figure 2), and the video link was shared with all participants.

Figure 1. TA in the lecture

Figure2. Slide video

Session 1: Functions.

Functions are formulated as one of the mappings in modern mathematics. That is, for any number x in the domain X, if there exists just one corresponding number $y \in Y$, that correspondence is called a function. According to this definition, even something that cannot be expressed or is difficult to express, by a mathematical formula, e.g., Figure 3 is a function.

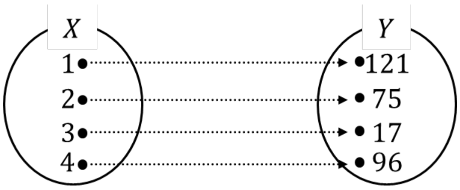

Figure 3. One example for a function

So, starting with the question 'What is a function?', and gave an overview of the functions studied at technical colleges and how functions are used in engineering.

Session 2: Congruence and similarity

The unit on congruence is an introduction to the mathematical method of 'proof' for Japanese junior high school students. Similarity is also an important concept linked to trigonometric ratios. When focusing on triangles, many junior high school students confuse the definition of congruence with the congruence condition. Therefore, I started by explaining the definition of congruence, had the students practice selected exercises, and finally gave an introductory explanation of trigonometric ratios as an application of similarity (Figure 4).

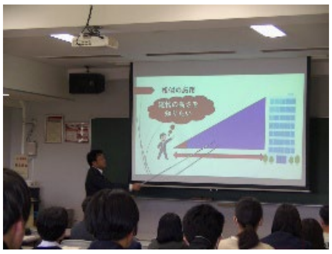
Figure 4. Face-to-face lecture 'congruence and similarity'

Session 3: Circles (including the circumferential angle theorem)

The circle is one of the quadratic curves (conic curves), and students learn the basics, such as pi and area, in primary school. In junior high school, students also learn the theorem of the angle of the circumference. Based on these foundations, the Matsue National College of Technology redefines the circle in the framework of coordinate geometry. In other words, they study the equation of a circle and the tangent lines of a circle. Therefore, after reviewing the definition of the pi angle, quadratic curves, and the Maclaurin expansion of pi were introduced, etc.

Session 4: Pythagorean Theorem

The Pythagorean Theorem is the basis for proving various properties of trigonometric ratios and various facts about coordinate geometry. Furthermore, by using the concept of trigonometric ratios, it is extended to general triangles, as the cosine theorem. In this session, as many students had not yet learned the Pythagorean Theorem at school at the time of the face-to-face session, explanations were given starting with the basics, and entrance exam-level questions were dealt with in an online format. In addition, the integral formula for the length of a curve was covered as a link to the mathematics of technical colleges.

2. Preparatory course for entering KOSEN

The course was conducted in February and March 2025 online for 198 students who intend to enter NIT, Matsue College in April 2025. In this course, we provided them with an advanced study of the content they will learn in their first year at the technical college. To motivate the learners, we made it interactive by sharing the answers to questions received after the course, before the students entered the school. To motivate the learners, the course was designed to be interactive by sharing answers to questions received after the course before enrolment. Furthermore, a confirmation quiz (one-choice type) was conducted to quantify the students' level of understanding. It should be noted that the results of this quiz are not related to admission itself or post-entry grades.

Session 5: Equations and complex numbers

Complex numbers appear together with trigonometric functions in the solution of the equations of motion for single oscillations in physics. Complex numbers have many applications in engineering, including the deformation of beams, analysis of structures, analysis of electrical circuits, and signal processing. In our school, the curriculum includes studying complex numbers in the first grade (content consists of an introduction to complex numbers, properties of complex numbers, and basic matters in the complex plane), Fourier transformations in the fourth grade, and rudiments of complex function theory in the fifth grade. On the other hand, because students learn so much in the first year, it is difficult to explain the mathematical background of complex numbers, especially why imaginary numbers were introduced, in class time. Therefore, an attempt was made to explain the historical background of the introduction of imaginary numbers. This originated in the discussion of solutions to cubic equations by Cardano, Bombelli, et al. According to Rotman (2016), we will describe below an overview. According to the formula for the solution of the cubic equation by Cardano, one of the solutions for the cubic equation $x^3 - 7x + 6 = 0$ is expressed as

$$x = \sqrt[3]{\frac{1}{2}\left(-6 + \sqrt{\frac{-400}{27}}\right)} + \sqrt[3]{\frac{1}{2}\left(-6 - \sqrt{\frac{-400}{27}}\right)}$$

On the other hand, the left-hand side of this equation can be factorized as $(x-1)(x-2)(x+3)$, so the solutions are all real numbers. To solve this certain irrationality, it is said that 'the number that is squared to -1', i.e., the imaginary unit i, was born; Bombelli introduced the four arithmetic operations on the imaginary numbers, and other studies showed that the above equation is a real number 2.

By telling the audience about the confusion of the people at that time when imaginary numbers appeared and how they dealt with the concept, I tried to make them familiarize themselves with the concept of imaginary numbers and understand the inevitability of their appearance. Furthermore, the following exercises were frequently incorporated between lectures (Figure 5).

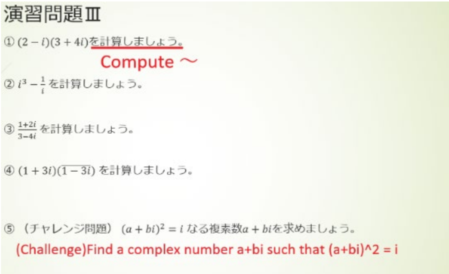

Figure 5. One of the exercises in Session 1

Session 6: Trigonometric ratios (including sine and cosine theorems)

Trigonometric functions are an essential part of engineering. The idea of the Fourier series, which is applied in signal processing and other areas, is, very crudely stated, to express a function as a superposition of sinusoids (sin) and cosines (cos), and the Fourier series is applied in various areas of engineering. Therefore, students need to be familiar with the handling of trigonometric functions, including derivatives, integrals, and matrix calculations. In our school, students learn the basics of trigonometric ratios and trigonometric functions in the first year and learn applied calculations of trigonometric functions from the second year onwards during lectures on differential and integral calculus and linear algebra. Despite being important concepts in mathematics and applications, the concepts of trigonometric ratios and trigonometric functions are difficult for beginning students to understand and are considered to be one of the hardest units for beginning students, as there are many important formulae such as interrelationships ($\sin^2 x + \cos^2 x = 1$, etc.), cosine theorem, additive theorem, and double angle formula. Therefore, the lecture introduces trigonometric ratios, trigonometric ratios of obtuse angles, interrelationships, the sine theorem, and the cosine theorem, and sets up simple exercises. These contents are equivalent to three lectures (270 minutes) in an actual technical college class (90 minutes), but the lecture video is compressed to about 26 minutes. The aim is to lower the hurdle for students to watch the videos, to get an overview of trigonometric ratios, to familiarize them with the concept of trigonometric ratios, and to make them think that they have 'heard of it before' in actual classes by combining the videos and teaching materials (Figure 6). The aim is to make the students feel that they have heard of the concept before. At the end of the lecture, the area formula for triangles using trigonometric ratios and Heron's formula for finding the area from the lengths of three sides were introduced, and through exercises, the students were able to experience the usefulness of trigonometric ratios. In addition, as Greek letters are often used in mathematics at technical colleges, a list of Greek letters is included in the teaching materials.

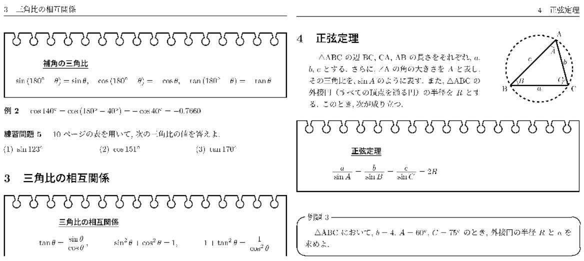

Figure 6. A part of original textbook of 'trigonometric ratios' (written in Japanese).

Results and Discussion

Here we present the results of the questionnaire survey for "Preparatory course for entering KOSEN (S5-6)" conducted after the students enrolled in the course. The questionnaire was conducted with the approval of the Ethics Review Committee at the author's institution. A written explanation is provided to all eligible participants that the survey responses will be used as research data for early STEAM education, that the data will be published in a form that anonymizes the eligible participants and does not identify them, and that participation in the survey will not affect their academic grades.

A questionnaire with the following questions was sent to 198 new students (first year) of NIT, Matsue College, regarding the course for entering a technical college.

Q1: Was it difficult?
Q2: Did you gain a deeper understanding of the relevant units?
Q3: Would it be useful for your future study of mathematics?
Q4: Did you become interested in the mathematics studied at the technical college?
Q5: Was it satisfactory?
Q6: Questions and impressions (free text)

Table 2. Average score for question items.

Question items	S1-4	S5-6
Q1 Was it difficult?	3.1	3.3
Q2 Did you gain a deeper understanding of the relevant units?	3.9	3.5
Q3 Would it be useful for your future study of mathematics?	3.8	3.7
Q4 Did you become interested in the mathematics studied at the technical college?	3.7	3.6
Q5 Was it satisfactory?	3.8	3.4

Of the 198 enrolled students, 78 had taken "Mathematics course for engineering (S1-4)". 78 of them were asked the same. For each question, excluding open-ended questions, the scores were quantified as follows: 4 for "agree", 3 for "somewhat agree", 2 for "somewhat disagree", and 1 for "disagree".

Some of the comments for Q6 are provided below.

Mathematics course for engineering (S1-4)
- Senior technical college students taught me and helped me understand what I didn't understand.
- It was difficult, but I could understand a lot, so I think it was a good class.

Preparatory course for entering KOSEN (S5-6)
- I thought it was good to be exposed to technical college mathematics from an early stage.
- I thought I would do a better job of reviewing the content after entering a technical college because it was very difficult.

Discussions

・The level of difficulty of both courses included advanced content such as mathematics studied at technical colleges and mathematics used in engineering, but it can be said that the setting was generally appropriate.

・Both the depth of understanding of related units (Q2) and interest in mathematics studied at technical colleges (Q4), which were used as indicators of achievement in Bridge Learning, showed high values.

・The results of the Preparatory course for entering KOSEN questionnaire showed that the results differed between students who had taken the Mathematics course for engineering (Group A) and those who had not, i.e. those who had taken only the Preparatory course for entering KOSEN course (Group B) were examined to see if there were any differences in the results. The results showed that Group B was slightly higher in difficulty level (Q1), but Group A was higher in Q2 to Q5. There was a difference of about 0.5 points in terms of satisfaction, which is a natural result given that Group A originally had students with an interest in mathematics as participants.

・To get an overall picture of the free descriptions in Q6, the co-occurrence networks created by KH Coder are shown in Figures 7 and 8 below. Figure 7 shows the co-occurrence network of free descriptions in the Mathematics course for engineering, and Figure 8 shows the co-occurrence network of free descriptions in the Preparatory course for entering KOSEN. The size of the circle indicates the occurrence rate of words, the line suggests the association between words, the thickness of the line indicates the strength of the association, and the color coding of the circle suggests groups of words that are highly related to each other. In the co-occurrence network for the Mathematics course for engineering (Figure 7), in addition to *mathematics*, *learn*, *know*, and *understand*ing, other words were mentioned that could be related to TA, such as *senior students* and *KOSEN*. In the co-occurrence network for the Preparatory course for entering KOSEN (Figure 8), words such as *difficult*, *understanding*, and *mathematics* were mentioned. Words like *complex numbers* and *triangles* related to the content were also mentioned.

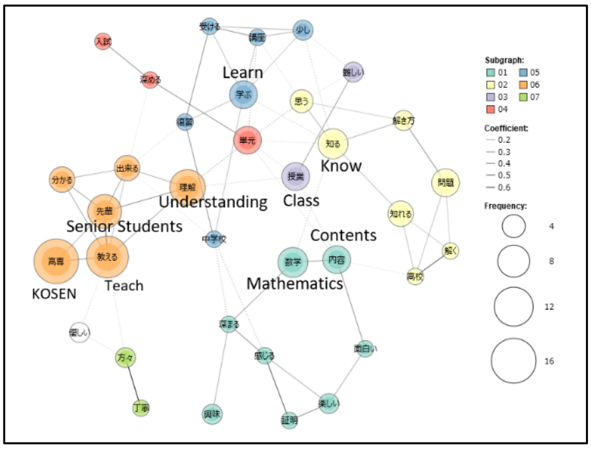

Figure 7. Co-occurrence networks for comments for Mathematics course for engineering (S1-4)

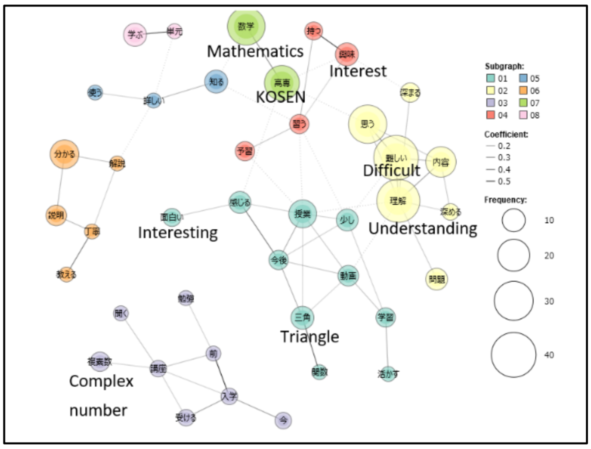

Figure 8. Co-occurrence networks for comments for Preparatory course for entering KOSEN (S5-6)

Conclusions

This paper introduces the mathematics course as part of the early STEAM education project at NIT, Matsue College, and shares the teaching materials. The results of the student questionnaire and the ratio of students who took the course to the total number of students enrolled in the course indicate that the initiative was generally successful. In addition, there are specialised subjects in which trigonometric functions are taught earlier than in mathematics classes. Early STEAM education is expected to have the advantage of facilitating the introduction to such specialised subjects. In mathematics classes at technical colleges, it is also important to provide classes that are conscious of the connection with specialised subjects, for example, by presenting examples of engineering applications. Future challenges include implementing the course in other subjects and expanding it to a broader geographical area. Furthermore, we would like to quantitatively verify the effectiveness of early STEAM education from a long-term perspective by conducting a follow-up survey of participants.

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