Enhancing Grade 11 students’ representation and connection in permutation and combination for their problem solving

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Abstract The purpose of this paper was to enhance Grade 11 Thai students’ concept of “Permutation and Combination.” The participants included 35 Grade 11 students in Khon Kaen University Demonstration Secondary School (Suksasart), Khon Kaen, Thailand in the academic year of 2018. The students were studying with adoption of Lesson Study Innovative mathematical learning activities to acquire knowledge of permutation and combination by using Open Approach. The methodology used in this study was in the interpretive paradigm. The students’ concept about permutation and combination was interpreted through students’ tasks and class observation. The interpretation considered on how and what teachers’ understanding on students’ learning on permutation and combination. The findings revealed that students held several ideas for their solving problem development in the lessons of permutation and combination. The study discussed and identified key students’ solving-problem learning, which further highlighted the implications to enhance students’ learning on mathematics performance based on lesson study and open approach in Thailand.

Keywords: Problem Solving, Permutation and Combination

1.Introduction

According to the instructional approach of Thailand, classroom activities are massively executed with teachers describing relevant knowledge, rules, and formulas. Then, students are given a large number of assignments to practice as a means to assess their knowledge obtained from the lessons that have been taught to them. Thus, it is important to understand how teachers’ mathematical tasks increase students’ learning when students have different background knowledge and out-of-classroom experience. The nature of students’ learning is determined by using various types of tasks and observe how the students adopt their critical thinking towards the tasks.

Generally, in mathematics class, teachers can apply several lesson structures and types of learning activities to stimulate students’ learning. Some teachers focus on developing skills by assigning exercises to students to complete as expected them to develop their conceptual understanding on solving challenging problems as practicing skills. In the previous study, it was found that a variety of solution methods encourage students to pose new tasks which lead them to improve their learning [1], [5], [8], [9].
Particularly in the lesson of ‘permutations and combinations,’ students are typically taught to remember formulae, problem categories, and solve each problem by using the appropriate formula. However, it was noticed that students who learn the lessons in this conventional teaching pattern could remember the principles of permutations and combinations for the short term aiming to pass the end-of-chapter tests. Although the lesson of permutations and combinations is likely to be practical knowledge that allows students to explore thinking of possibilities within the context of problem-based situations, students found themselves lack the conceptual understanding necessary to practically solve problems in the real world [2]. Hence, it is essential for teachers to adopt innovative mathematical teaching and learning methods to promote students’ deeper levels of understanding of permutations and combination in long term.

To design appropriate lessons and learning activities for students to perform process series of thinking abilities in solving problems can be assessed how they face challenges by adopting various perspectives. According to National Council of Teachers of Mathematics, teacher should therefore monitor the representation of students’ thinking processes in solving problems to determine how students’ thinking structures process [3].

The connective model of learning mathematics is widely used in secondary students, particularly in the early stages of their development: language, images, symbols and concrete experience. The model addresses the central importance of explicitly supporting students to link the different representations of mathematical conceptual ideas. Furthermore, this innovative model was found to fit in the national curriculum requirement of the United Kingdom as the government aims to lead students to ‘be able to move fluently between representations of mathematical ideas’ [4] [6] [7]. From the suggestions stated in previous studies and the limited number of exploratory studies in Thailand in the context of the 21st century learning, it is essential to investigate adoption of innovative learning of permutations and combinations to enhance students’ mathematical representation.

2. Research Methodology

In this qualitative study, a case study was used to draw conceptual understanding of students’ mathematical problem-solving process. Data were collected from classroom observation by recoding the students’ learning activities, taking notes of students’ worksheet and taking photographs of students’ mind map drawing. Data were then analyzed by the mathematical problem-solving process based on Haylock and Cockburn (2003)’s guidelines for teaching mathematics in primary level.

The study aims to study the mathematical problem-solving process of circular permutations of Grade 11 students and answer the research question:

‘What is the mathematical problem-solving process for Grade 11 students in class 5/1?’

2.1 Population

The population was a total of 29 students of Khon Kaen University Demonstration School. Secondary Department (Education) of Grade 11 in class 5/1, Semester 1, in the academic year 2019.

2.2 Research instruments

1. The tools used to collect data include a lesson management plan for the lesson unit of circular permutations, consisting of 5 plans, each of which consists of 1 learning activity which also used for collecting data in the learning and problem-solving stages.

2. Tools for data analysis are as follows:
   (1) Video recorder to record target students conduct activities in the class.
   (2) Assignment or worksheet for each learning activity.
   (3) Photos of mind map drawing reflecting conceptual understanding of target students.
   (4) Protocols obtained from recordings during mathematical activities protocols.
2.3 Data collection

Data were collected with the following steps:

1. The instructor, also the author, conducted teaching management and observed target students’ problem-solving process of circular permutations during the activities. In this step, video recording was used to record how students’ express their thinking. Taking photos of students’ work also used to capture detail of their work piece.

2. The research assistant was also responsible for observing target students’ problem-solving process of circular permutations during the activities. In this step, video recording was used to record how students’ express their thinking. Taking photos of students’ work was used to capture detail of their work piece as well.

3. The author gathered information from organizing teaching and learning activities in each class period.

4. Data obtained from class observations and research tools were summarized and further analyzed according the conceptual framework.

2.4 Data Analysis

Data obtained from class observations and research tools reflecting students’ representation of their mathematical understanding of circular permutations through problem-solving process based on Haylock & Cockburn (2003)’s teaching mathematical model for secondary school students that links the different representations of students’ mathematics understanding in the early stages of their development: language, images, symbols and concrete experience as explained below.

1. Analyze data from learning logs during the activities. The photos of students’ representations of their ideas were taken photos based on learning framework of Haylock and Cockburn (2003)’s connective model of learning mathematics.

2. Interpret data by considering the learning framework as shown in Figure 1.

![Figure 1](image_url)

**Figure 1** The connective model of learning mathematics of Haylock and Cockburn (2003)

From the model, the problem situations are directly linked to concrete experience in which the spoken language may be influenced. Also, there is a link between concrete experience and a picture or image in which the spoken or written language may be influenced. In addition, there is a link between the image and the mathematical symbol in which the language spoken, or written language may be influenced. On the other hand, there is a reverse link between concrete experience, pictures or images, language and mathematical symbols to explain the student’s understanding. The evidence of students’ representation of their mathematical ideas were then discussed in the next part.
3. Results and Discussion

From the analysis of students’ mathematical problem-solving process on circular permutations taught for Grade 11, the results showed that the target students had the mathematical problem-solving process as follows:

1) Students began to solve problems by connecting problem situations to their concrete experiences by turning the cube and bracelets made from ping pong balls or alternating magnetic buttons on a circular tray that they had experienced from the previous lessons.

2) Students used their language to communicate their own ideas among members in the group, or between groups then convey their ideas in written language, both formal and informal.

3) Students drew illustrations to clarify their path of problem-solving process and to give the presentation for the class.

4) Students applied mathematical symbols to use in the final problem-solving process that lead them to the answers and conclusions.

From classroom observation emphasizing on students’ mathematics learning, it was found that students developed a systematic problem-solving process and represented adequate reasoning skills in each step of problem solving as well as rechecking their answer in each step until they finalize the answer.

3.1 Solving problems from linking experiences

Learning questions: Teacher asked students to shuffle 4 numbers into a linear pattern as shown in Figure 2.

Teacher: How many possible ways to arrange this number into a linear pattern?

Students: 1234, 2341, 4123, 3412, 4321, 2143, 1432, 3214, 4231, 3142, 2314, 1423, 2134, 1342, 3421, 4213, 1243, 2431, 4312, 3124, 4132, 1324, 3241, 2413

According to figure 2, it is found that students solve problems by connecting the situations with their previous experiences based on what students have learned in the earlier lesson unit of linear permutation. Then, the instructor asked the students with the following dialogue.

Teacher: Is there any other way?
Student: I do not think so.
Teacher: How do you know that there are no other ways?
Students: Well, here are all possible ways as 4! = 24 ways.

The statement reflected that students could link the problems with their experience from the previous lesson.
3.2 Solving problems from linking images and languages

From Figure 2, the instructor designated the number for each type of circular permutation. Then, the instructor rearranged numbers into a circular order and asked students to reconsider them altogether.

![Figure 2: Example of students rearranged number in circular permutation from Figure 2](image)

From Figure 3, it was found that the students use illustrations to describe and presented in spoken language as the following dialogue.

Teacher: Students, consider which circles are alike.
Student 1: Circle number 5 and number 22.
Student 2: Circle number 9 and number 24.
Teacher: How do you know that they are the same?
Students 1 and 2: If you roll 1 to the top, you will get 5 and 22 the same. Likewise, number 9 and number 24 are the same.
Student 3: Circle numbers are 11, 19, 16, 14 are the same.
Student 4: No, not 14, but Number 3 instead.
Teacher: Why do you know that 14 it is not the correct one?
Student 4: Because if alternating the front numbers to the same back, it will be arranged as pattern 1, 3, 2, 4.

The statement reflected that students could selection answer by the problems with their experience from the previous lesson.

3.3 Solving problems from linking images, languages, Experience and symbols

According to figure 3, the instructor used questions to enable students to seek answers as follows:

Teacher: Do you think how many different types of circles would they have?
Student 5: \(3!\) ways.
Teacher: How did you come up with that ideas?

Then, the teacher asked the student representative to explain in front of the class as follows.

Student 5: Let's take it this way. If we take 1 out and then make other 3 numbers rotated, we can get them in the same way as \(3!\) ways. This means that we base one number and use the rest to rotate in linear permutations, so we will have \((4-1)\) ways as showed in Figure 4.
According to figure 4, it is found that the students used the illustration of the explanations which were presented in spoken language. Students used their previous experiences, such as linear permutations, to explain the concepts and were able to count the number of ways in mathematical symbols.

Then, the teacher expanded from arranging 4 numbers into 8 numbers and changing them into 10 different items into ordering \( n \) different items as the following dialogue.

**Teacher:** If I ask you to arrange 8 different numbers in circular pattern, how many ways can they be?

**Students:** \( (8-1)! \) ways based on the same reason.

**Teacher:** If I ask you to arrange 10 different numbers in circular pattern, how many ways can they be?

**Students:** \( (10-1)! \) ways based on the same reason.

**Teacher:** If I ask you to arrange \( n \) different numbers in circular pattern, how many ways can they be?

**Students:** \( (n-1)! \) ways based on the same reason.

From the dialogue, it was found that students solve the problems based on previous experiences and used the same reason as the original ones that helped them quickly count the number of all patterns by using mathematical symbols leading to general conclusions.

### 3.4 Linking images, experiences, languages, symbols, and concrete media

**Learning issues:** The teacher asked students to find number of ways that 6 different colors can be shown on cube page, one color each side.

**Teacher:** Find number of ways that 6 different colors can be shown on cube page, one color each side. You can paint the cube in colors if you want to.

Some students drew a cube with colors in a 3D cubic shape. Some groups drew a picture of cube unfolded and paint each side while some groups drew the flattened cube with colors and put number on each side as shown in Figure 5.
Figure 5 Students’ representation of cube drawing and the unfolding of the cube

From Figure 5, it was found that students used illustrations and use symbols as numbers to clarify their problem-solving process. After that, students counted the number of possible methods of painting.

The answers were different, for example, $6! = 720$, $5! = 120$, $540$, $\frac{720}{2} = 360$, $180$ and $30$, as shown below.

Figure 6 Students’ representation of calculating ‘how many possible ways to paint a cube?’
From Figure 6, the teacher further asked the student representative to present how they came up with the answers on the board. Then, the teacher used questions for students in the class to consider altogether again as the following dialogue.

**Teacher:** Do you think which group has correct answer, who has too little, too high or just right?

**Student 1:** For the group that answered $6! = 720$, I think it was because they think it in a linear pattern. But the cube is like a circular pattern, so I think 720 is too much.

**Student 2:** For the group that answered $5! = 120$, I think it was because they think it in a circular pattern. However, the cube is like a circular pattern from left to right and from the top to the bottom, so I think 120 is way too much.

**Student 3:** For the group that answered 540, I think it was because they think that painting at the top can be done by 6 different ways. Then, another 5 bottom sides can be painted in 5 different ways. However, the cube is not two-sided. Let's say, if we paint any color at the top side first, so we have other 5 colors for the rest, so only 5 ways can be painted for the bottom sides, not 5. So, I think 540 is too much.

**Student 4:** For the group that answered 360, I think it was because they thought it in a linear arrangement and then dividing it by 2. I guess we cannot use the linear pattern for the cube painting because the front of the cube we see is a circular arrangement. Since the head meets its end. So, I think the 360 is still too high.

**Student 5:** For the group that answered 180, I think it was because they counted the linear painting method, using the top 6 methods, the bottom 5 methods, but the cube has no face. Therefore, the number of the methods above does not. We can only apply the top and bottom 5 ways, so I think this 180 is over.

**Student 6 (The group that answered 30):** I think it is exactly 30.

**Teacher:** Exactly. How? Can you explain?

Then, the student that answered 30 explained the idea as shown in Figure 7:

**Student 6:** Paint one side, mark as 1 way. Then, the opposite sides can be painted in 5 different ways. The rest will be like a circle pattern. Thus, we can use circular permutation to apply with the first 2 colors. So, there are only 4 colors left, making possible ways to paint as $(4-1)! = 3!$. Therefore, a total of possible ways to paint the cube with different color of each side are equal to $1 \times 5 \times 3! = 5 \times 3 \times 2 = 30$.

![Figure 7 Students’ representation of correct calculation of the possible ways to paint a cube in different color of each side](image)
not complete. Moreover, students used concrete media, namely a cube, to better illustrate their understanding that can lead to the correct answer.

3.5 Linking images, concrete media, languages experiences, and symbols

Learning issues: The teacher showed the 6 different beads and asked students to present the highest number of possible ways that bracelets can be differently arranged.

Teacher: Each group must present as many ways of bracelet arrangements as possible from these 6 beads.

Then, the teacher asked students to present their worksheet on the board as shown in Figure 8. Each group of students colored the worksheet given by the teacher. Then, a student asked abruptly:

Student 1: I can find many more ways, but the color is not enough.

Teacher: How many more can you think of?

![Figure 8](image)

Each group of students’ representations of bracelets design of color arrangement

Teacher: Can you find out any of these bracelets that are the same?

Student 2: Yes, type 1 of my group and type 1 of the group 7 are the same.

Teacher: Why do you think they are the same? Can anyone explain?

Student 2: Well, when you held a bracelet in hand, it looked like the one of my group. When you flipped the other side, it looked like that one of my friend’s group from group 7.

Teacher: Can you calculate how many ways can ordering bracelets be?

Then, teacher asked representative of each group to present in front of the class.

Student 3: There are a total of 6 different colored beads. Firstly, choose any color beads and place the first bead in a locked position. This means wherever it is placed, it will have the same result. Secondly, arranging the second bead will have 5 possible patterns, and the remaining balls will have 4, 3, 2, and 1 pattern, respectively. Thirdly, we will be able to arrange the beads in a circle as \((6-1)! = 120\).

However, the circular 120 patterns are non-flippable arranged because when flipping the bracelet, it will make 2 patterns doubled. This means that in 120 patterns, 60 patterns will be doubled, so the possible ways of arranging bracelet should be \(\frac{120}{2} = 60\).
Figure 9 Students’ representation of how to calculate beads arrangement

After that, the teacher expanded the number of beads to 8, 10, 15, and \( n \). Then, students were asked to calculate patterns of bead bracelet arrangement as presented in the following dialogue.

Teacher: What if we have 8 different colored beads, how many patterns bracelets can be threaded?

Students: \( \frac{(8-1)!}{2} \)

Teacher: What if we have 10 different colored beads, how many patterns bracelets can be threaded?

Students: \( \frac{(10-1)!}{2} \)

Teacher: What if we have 15 different colored beads, how many patterns bracelets can be threaded?

Students: \( \frac{(15-1)!}{2} \)

Teacher: What if we have \( n \) different colored beads, how many patterns bracelets can be threaded?

Students: \( \frac{(n-1)!}{2} \)

From Figure 8, 9 and the dialogue above, it was found that the students solved the problem by using illustrations and simple drawing presentation, allowing the students to imagine that there are 2 types of arrangement: 2 circular patterns that are not flippable and 1 flippable. The students’ conceptual understanding was reflected in their spoken language. Then, they conveyed the calculation concepts in their written language, both formal and informal, used the same experience to calculate the possible patterns of circular arrangement of beads along with reasons and present them with mathematical symbols until they could lead to general conclusions.

Learning issues: The teacher showed the 3 identical magnetic buttons in blue and 2 identical magnetic buttons in pink and asked students to present the highest number of possible ways that bracelets can be differently arranged in a circular form.
Teacher: How many ways do you think you can arrange the 3 identical magnetic buttons in blue and 2 identical magnetic buttons in pink in a circular form?

Then, each group of students drew a pattern of buttons arranged in a circle.

![Pattern of buttons](image)

**Figure 10** Students’ representation of how to calculate 5-button circular arrangement

Teacher: Do you think how many can it be?

Students: 2 ways

Teacher: 2? Can it be more? Any group with high number? Can you write how did you come up with your answer.

Then the teacher asked the representatives from each group to present on the board. Surprisingly, some groups presented with by using equipment to illustrate their concept as shown in Figure 11.

Students: The buttons can be arranged in a circular arrangement as \((5-1)!\). That is, 3 identical button in pink \(3!\). (Student picked up the tray to place pink buttons that even she changed the positions of pink buttons, they all looked the same.) Then, the blue buttons can be arranged as \(2!\). Therefore, when they are arranged alternately in a circle, it became

\[
\frac{(5-1)!}{3!2!} = \frac{4!}{3!2!} = \frac{24}{12} = 2.
\]

![Presentation on board](image)

**Figure 11** Students’ representation of how to calculate 5-button circular arrangement with media

From Figure 10, 11 and the dialogue above, it was found that the students solved the problem by using illustrations with a flipped local food metal tray that the teacher had prepared as visual media. This allowed students to imagine the arrangement by moving the magnetic buttons on the tray. The students’ conceptual understanding was conveyed in their spoken and written language, both formal and informal. That is, they explained the calculation concepts from their experience in the earlier activity that the
number had to considered from the different items, then divide the number by the number of duplicated patterns. After that, they presented their calculation with mathematical symbols.

3.6 Linking experiences, images, concrete media, symbols and languages,

Learning issues: The teacher showed the 6 magnetic buttons; 3 identical magnetic buttons in blue and 3 identical magnetic buttons in pink and asked students to present the highest number of possible ways that bracelets can be differently arranged in a circular form.

Teacher: How many ways do you think you can arrange the 6 magnetic buttons; 3 identical magnetic buttons in blue and 2 identical magnetic buttons in pink in a circular form?

Then, all groups of students calculated and answered \( \frac{(6-1)!}{3!^2} = \frac{5!}{3!} = 3.33 \). However, they posed a question as shown in the following dialogue.

Student 1: We calculated in decimal, but we are not sure if we should round up or down.
Student 2: I think we should round down since we tried it on the tray and answered 3.
Student 3: I think we should round up since we answered 4.

![Figure 12 Students’ representation of how to alternatively arrange the buttons](image)

![Figure 13 Students’ representation of how to alternatively arrange the buttons of Group](image)

Teacher: Can you show us how to arrange the 6 magnetic buttons on the board?  
Student 3: We should order the magnetic buttons in a linier. We got the orange and black color instead. So, we have 3 black and 3 orange. We name orange as “O” and black as “B.” If we order them in a circle in color sequence, it will be OOOBBB, OOBBOB, OOBBOB, OBOBOB.

Teacher: From your friend’s idea of arranging OOOBBB in a linier pattern first, do you think how many ways we can arrange them in a circular pattern that are the same as OOOBBB?
Student 3: OOBBO, OBBOO, BBBOO, BBBOOB, BOOBBB, OOBBBB (which is duplicated.)

Teacher: I would arrange them in a linear pattern as OOOBBB, OOBBOB, OBBOOO, BBBOOO, BBBOOB, BOOBBO, OOBBB (which is duplicated.)

Figure 14 Students’ representation of how to alternatively arrange the buttons of Group 3

From Figure 12, 13, 14 and the dialogue above, it was found that students solved problems by using the experience previously learned. However, when they applied with the same formula, results showed in decimal, making them confused whether to round up or down. Students then conveyed the concrete media with magnetic buttons arranged on a circular tray, then switched the magnetic buttons to various positions to help them understand the concepts clearer. Then, students drew the patterns and considered the duplicated and the different ones. Finally, students found out that the relationship between linear arrangement and circular arrangement and were able to confirm the correct answer.

According to the students’ problem-solving process described above, the results were consistent with Liebeck (1990) noting that students’ understanding related to the connection among experience, language, images, and mathematical symbols by starting from recalling previous experience, added with language use, images or pictures, and ultimately mathematical symbols. The researchers found that, in solving mathematical problems for students, the experience was important foundation for their learning development. Because the construction of mathematical understanding is derived from concrete experience, bridging the unconventional ideas to abstract mathematics, and mathematical symbols as final learning. The problem-solving process relies on the linking among mathematical contents, resulting in a meaningful learning approach.
Thus, the 5 components of enhancing students’ understanding of mathematical contents are listed as follows: 1) Concrete media as teaching and learning media that lead to learning, understanding and connecting mathematics, 2) Language is the expression that students show the connection process which can be in spoken language that connects to written language. 3) Images or Pictures are representation of the connection development between mathematics and mathematical knowledge used in real life. Image usage is one of the important activities that mathematics teaching and learning can be transformed from concrete to abstract, or from abstract to concrete, 4) Mathematical symbols are the final process of learning mathematical processes development since the symbols represent the connective link among various contents.

4. Suggestions

1. Suggestions for future research

1.1 The study should expand in other mathematical connections. For example, in the circular permutation, linking contents in the model method can be used. This learning method stimulates students to recall familiar knowledge in their daily life, or in the previous lessons to tie with mathematical methods and mathematical concepts. The connection between these steps helps students to explain the content according to how they think or act in step-by-step to acquire the principles, formulas, and perceptions towards mathematics in long term.

1.2 The study should emphasize to what extent teachers’ use of board can promote the mathematical concepts learning of students in the lesson of circular permutations.

1.3 The study should investigate the role of teachers in supporting mathematical problem-solving of students in the lesson of circular permutations.

2. The limitation found in this study was that in the study related problem-solving process by connecting the experience, language, images, and mathematical symbols in teaching and learning circular permutations, the researcher should build up students’ awareness of errors that students may have from the beginning. In this study, it was found that some students were not aware of unflippable buttons in the circular permutations.

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