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# Learning engagement as moderator between self-efficacy, math anxiety, use of diagrams, and complex plane problem-solving

Yuno Shimizu [1*]

[1] Faculty of Letters, Kokushikan University, Tokyo, JAPAN

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**Abstract**

Previous research has shown that affect and heuristics influence mathematical problem-solving, but how learning engagement contributes to this process has yet to be thoroughly investigated statistically. This study examines whether learning engagement moderates the relationship between self-efficacy, math anxiety, use of diagrams, and complex plane problem-solving performance. This questionnaire-based survey involved 240 Japanese 11th-grade high school students. The results of the multiple-group structural equation modelling revealed that (1) self-efficacy was positively related to the use of diagrams and, directly and indirectly, positively associated with complex plane problem-solving performance despite learning engagement; (2) math learning anxiety was positively related to the use of diagrams and indirectly positively associated with complex plane problem-solving performance at higher levels of learning engagement; and (3) the use of diagrams was positively related to complex plane problem-solving performance despite learning engagement. The findings suggest that learning engagement moderates the associations between affect, heuristics and mathematical problem-solving.

**Keywords:** : self-efficacy, math anxiety, use of diagrams, complex plane problem-solving, learning engagement

## INTRODUCTION

Mathematics is central to people's understanding and representation of everyday and scientific events. Therefore, globally, improving mathematical problem-solving skills has long been a major goal of mathematics education (i.e., Ministry of Education, Culture, Sports, Science, and Technology in Japan, 2018; Victorian Curriculum and Assessment Authority, n. d.). However, a large number of students are reported to face challenges in mathematical problem-solving. For example, in the OECD's PISA 2022, it was reported that up to about a quarter of all students did not reach the minimum level of mathematical literacy (level 2) that is expected to be mastered (OECD, 2023). In addition, only 2.0% of all students reach a level of mathematical literacy (level 6) at which they are capable of advanced mathematical thinking and reasoning; even in Hong Kong (China), Macao (China), Singapore and Chinese Taipei., where mathematical proficiency is high, only around 10% of students reach this level (OECD, 2023). Academic research is, therefore, required to elucidate the factors that could lead to improved mathematical problem-solving and related processes.

Since affect and heuristics are significant predictors of mathematical problem-solving, they have long been considered the main factors in mathematical problem-solving (Hannula, 2020). Studies have either examined the impact of affect or heuristics on mathematical problem-solving. However, to the best of the author's knowledge, there have been no studies that have examined the processes that lead to mathematical problem-solving, using statistical methods and focusing on affect and heuristics simultaneously. As affective variables, such as math anxiety and self-efficacy, significantly predict the use of cognitive and metacognitive strategies (Özcan & Eren Gümüş, 2019; Roick & Ringeisen, 2018), it is assumed that affect significantly predicts mathematical problem-solving via heuristics. Therefore, as a collective trend of pathways leading to improved mathematical problem-solving, this


✉ yunos@kokushikan.ac.jp **(*Correspondence)**

**Contribution to the literature**

- This study, aimed at investigating the moderating role of learning engagement, statistically examined its relationship with self-efficacy, math anxiety, use of diagrams, and complex plane problem-solving performance.
- The results showed that learning engagement moderates the relationship between self-efficacy and complex plane problem-solving performance and between math learning anxiety, use of diagrams, and complex plane problem-solving.
- The finding that learning engagement moderates the associations between affect, heuristics and mathematical problem-solving provides a new framework for mathematical problem-solving and learning engagement research, underscoring its high academic significance.

process of relating affect, heuristics, and mathematical problem-solving remains open for consideration.

To provide useful insights into the teaching and learning of mathematics, it is necessary to reveal the types of student learning engagement activities that contribute to affect and heuristics, mathematical problem-solving, and related processes. Prior research has shown that learning engagement improves affect and mathematical problem-solving (Christenson et al., 2012; Ghelichli et al., 2021; Reeve & Lee, 2014). Furthermore, Wu et al. (2021) showed that learning strategies, a component of learning engagement, act as a moderating variable for the association between motivation and mathematical literacy. In light of these previous studies, it is assumed that learning engagement influences affect, heuristics, and mathematical problem-solving processes. However, no studies have been found to have examined this assumption.

Based on the above, this study aimed to examine the affect, heuristic, and mathematical problem-solving processes and the impact of learning engagement on these processes. By achieving this aim, it is hoped that the study will overcome the remaining challenges of previous research and identify variables and processes that are critical to improving mathematical problem-solving, which is a global challenge. Therefore, this study's aims are of particular relevance in academic research and educational practice.

The following section provides a literature review of the affective variables, heuristics, and mathematical problem-solving research, on which this study focuses.

## Math Anxiety

Math anxiety has received much attention over the years as an effect associated with mathematics (Ramirez et al., 2018). Math anxiety is defined as tension, anxiety, and other feelings that interfere with working with numbers and solving mathematical problems in a variety of situations and is a math-specific anxiety that is distinguished from test anxiety and general anxiety (Barroso et al., 2021; Ramirez et al., 2018). In PISA 2022, an international survey of math anxiety among 15-year-olds showed that many students are anxious about mathematics, with 58.4% of students often worrying that mathematics lessons would be difficult for them (OECD, 2023). PISA 2022 also revealed that 15-year-olds with high levels of math anxiety tend to have low levels of mathematical literacy; international differences in the index of math anxiety account for about 25% of the variation in student performance in mathematics across all participating countries and economies (OECD, 2023). Moreover, meta-analysis revealed that math anxiety was small to moderate, with a negative correlation with motivation for mathematics ($r = -0.42$, Li et al., 2021) and math achievement ($r = -0.28$, Barroso et al., 2021; $r = -0.32$, Zhang et al., 2019). Based on the above, it can be assumed that math anxiety is strongly and negatively associated with mathematical problem-solving; therefore, this study focuses on math anxiety as an affective variable.

Most math anxiety studies have focused on trait math anxiety, that is, an individual's tendency to become anxious about math and related situations (Daches Cohen et al., 2021; Orbach et al., 2019). However, more recently, based on the state-trait-anxiety model (Spielberger, 1985), the need to also focus on state math anxiety was pointed out, which is a temporary anxiety response to a particular situation. These situations could include taking a math test, being called on to solve a problem in front of the class, or even just thinking about a challenging math problem (Daches Cohen et al., 2021; Orbach et al., 2019). Spielberger's (1985) model assumes that state anxiety occurs in people with higher trait anxiety. Therefore, if we are interested in actual anxiety reactions, cognitive processes, and academic achievement-related processes, we need to focus on both trait math anxiety and state math anxiety (Daches Cohen et al., 2021). Empirical research shows that both trait and state math anxiety are negatively associated with mathematics achievement; however, state math anxiety showed a stronger association (Orbach et al., 2019). Thus, this study focuses on both trait and state math anxiety.

The disruption account, which is the prevailing theoretical explanation for math anxiety inhibiting mathematical problem-solving (Ramirez et al., 2018), posits that cognitive resources that should be allocated to mathematical problem-solving are disrupted by math anxiety. This account is based on the attentional control theory (Eysenck et al., 2007), which states that general anxiety impairs task performance by interfering with one of the executive functions, specifically inhibition. In other words, when individuals experience math anxiety, their cognitive resources are diverted from the task at hand, hindering their ability to effectively solve mathematical problems.

### Self-Efficacy

In addition to math anxiety, self-efficacy has long been highlighted as a mathematics-related effect (De Corte et al., 2011; Liljedahl & Hannula, 2016). Self-efficacy is the judgement about one's ability to plan and carry out actions to achieve a specific performance (Bandura, 1986). Put another way, math self-efficacy is the belief that one can successfully solve a math task. In general, self-efficacy is positively associated with mathematical problem-solving. PISA 2012 revealed that 15-year-olds with high self-efficacy tended to be more mathematically literate, with self-efficacy explaining approximately 29% of the variance in mathematical literacy (OECD, 2013). In addition, self-efficacy has been shown to positively influence mathematical problem-solving even when controlling statistically for affective variables like self-concept and prior academic achievement (Jiang et al., 2014; Pajares & Graham, 1999). On the basis of the above, it can be assumed that self-efficacy is strongly and positively related to mathematical problem-solving; therefore, this study focuses on self-efficacy as an affective variable.

It is believed that self-efficacy has a direct positive effect on mathematical problem-solving and an indirect positive effect on mathematical problem-solving through the mediating effects of math anxiety and heuristics. Control value theory (Pekrun, 2006) suggests that self-efficacy serves as a frame of reference for the cognitive appraisal of performance-related emotions such as math anxiety. This means that individuals process information from the external world based on their self-efficacy about a particular math task, leading to a reduction in math anxiety. Empirical studies consistently demonstrate a negative correlation between self-efficacy and math anxiety (Li et al., 2021; Pérez-Fuentes et al., 2020). Therefore, self-efficacy plays a crucial role in reducing math anxiety, promoting the use of heuristics in their mathematical problem-solving endeavors.

### Use of Diagrams

Pioneered by Polya (1945), who argued for the importance of heuristics in problem-solving, heuristics have increasingly received attention as a critical factor in mathematical problem-solving (Liljedahl et al., 2016). Heuristics are general strategies that, while not ensuring a solution to a problem, assist students in grasping the problem and developing an approach to solve it (Schoenfeld, 1985). Previous empirical studies show that teaching students about heuristics improves their mathematical problem-solving (Liljedahl et al., 2016; Schoenherr et al., 2024). A meta-analysis also revealed a positive correlation between heuristics and mathematical problem-solving (Hembree, 1992). Therefore, heuristics are assumed to act as positive predictors of mathematical problem-solving.

Among the various types of heuristics, it has been noted that using diagrams is not just beneficial, but essential in mathematical problem-solving (Schoenherr et al., 2024; van Garderen et al., 2014). Diagrams play a crucial role in understanding the problem, recording ideas about the problem, and finding ways to solve it (van Garderen et al., 2014). Furthermore, a meta-analysis showed a moderate positive correlation between the use of diagrams and mathematical problem-solving (Hembree, 1992) and a moderate effect ($g = 0.50$) of visualization interventions on mathematics learning (Schoenherr et al., 2024). Based on the above, it can be assumed that the use of diagrams is not just associated, but strongly linked with mathematical problem-solving; therefore, this study focuses on the use of diagrams within heuristics, highlighting their enlightening role in the process.

### Learning Engagement

Learning engagement denotes a proactive involvement and dedication to learning tasks, serving as a measure of learning quality (Christenson et al., 2012; Skinner et al., 2009). It encompasses three dimensions: behavioral, emotional, and cognitive (Fredricks, 2011). Behavioral engagement involves active participation and effort in learning activities. Emotional engagement reflects a positive emotional connection to learning, such as showing interest and deriving enjoyment. Cognitive engagement refers to mental involvement in learning, including goal-oriented efforts and deep learning strategies. Generally, the higher the engagement, the more adaptive the academic performance and affective variables (Christenson et al., 2012). Empirical studies show that learning engagement has a positive impact on mathematics achievement and affect, such as self-efficacy (Fung et al., 2018; Ghelichli et al., 2021; Putwain et al., 2018; Reeve & Lee, 2014). Therefore, learning engagement is posited to positively predict self-efficacy and mathematical problem-solving abilities while negatively predicting math anxiety.

Learning engagement may function as a moderator of the processes associated with affect, mathematical problem-solving, and use of diagrams. In effect, the higher the learning engagement, the more adaptive the effect and mathematical problem-solving, making these linkages more pronounced. However, the lower the learning engagement, the weaker these links become, as both affect and mathematical problem-solving become non-adaptive. Empirical studies show that elaboration strategies are significant positive moderators for the

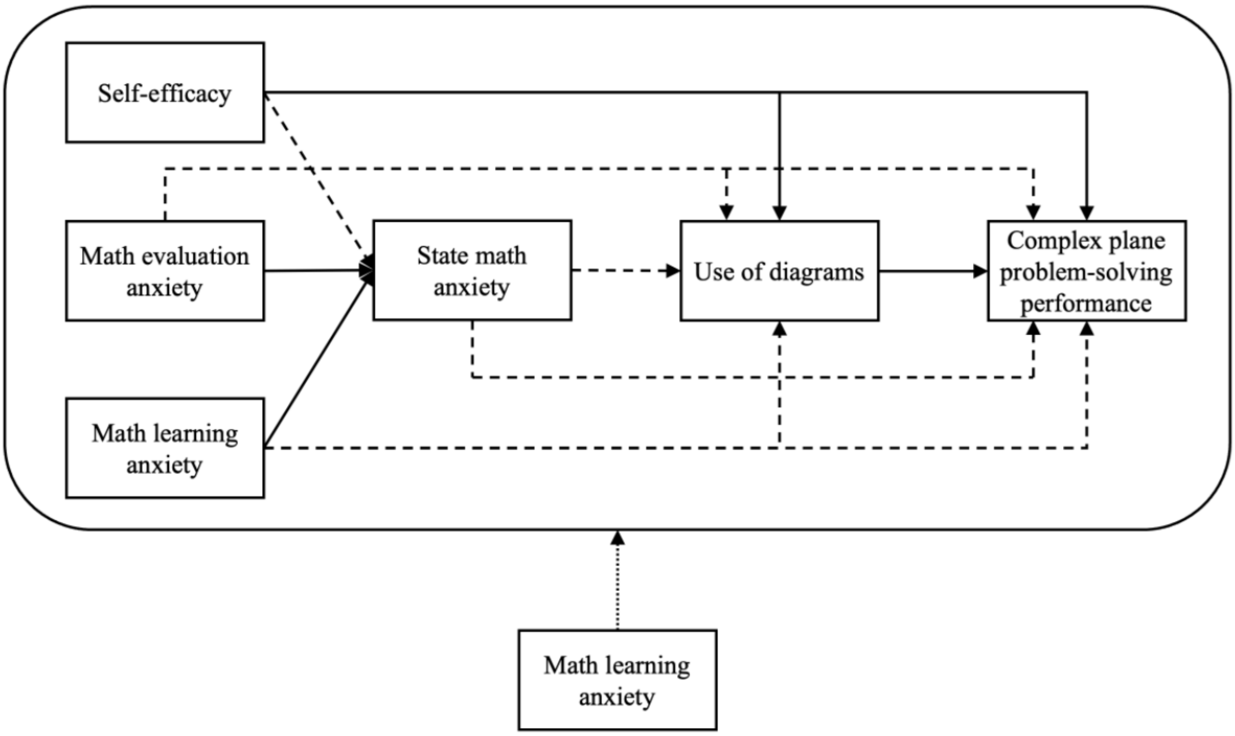


**Figure 1.** Hypothesized model (solid lines assume a positive association, dashed lines a negative association, and dotted lines a moderating effect) (Source: Author's own elaboration)

association between intrinsic motivation and mathematical literacy (Wu et al., 2021). In other words, intrinsic motivation positively predicted mathematical literacy when students were likelier to use elaboration strategies. It is important to consider the moderating effect of learning engagement as it helps identify student learning initiatives that lead to improvements in the mathematical problem-solving processes.

## Complex Plane Problem-Solving

This study focuses on the basic and standard textbook-level exercises on the complex number plane. Complex numbers are one of the most important concepts in mathematics education. They are necessary to ensure that real coefficient quadratic equations can always have solutions and identify exponential and trigonometric functions. However, little research has been done to understand and solve problems with complex numbers (Soto-Johnson et al., 2012). A few previous studies have shown that students have difficulties with complex numbers, such as difficulty in interpreting and explaining complex number multiplication geometrically on the complex plane (Conner et al., 2007; Nordlander & Norlander, 2011). However, to the best of the author's knowledge, no studies have examined the function of affect and heuristics as factors in problem-solving in the complex number plane. Given the above, focusing on basic and standard problems related to the complex number plane is essential in both academic research and educational practice.

## Current Study

This study examines the processes associated with self-efficacy and trait math anxiety, state math anxiety, use of diagrams, and complex plane problem-solving and the impact of learning engagement on these processes. Based on the aforementioned literature review, hypotheses 1 to 5 were formulated.

- **Hypothesis 1:** Self-efficacy is directly negatively related to state math anxiety and directly and indirectly positively related to the use of diagrams and complex plane problem-solving.
- **Hypothesis 2:** Trait math anxiety is positively and directly related to state math anxiety, and directly and indirectly positively related to the use of diagrams and complex plane problem-solving.
- **Hypothesis 3:** State math anxiety is directly and negatively related to the use of diagrams, and directly and indirectly negatively related to the use of diagrams and complex plane problem-solving.
- **Hypothesis 4:** The use of diagrams is directly and positively related to complex plane problem-solving.
- **Hypothesis 5:** Learning engagement has a significant moderating effect on the association between hypotheses 1 to 4.

Hypotheses 1-5 are combined to form the hypothesized model shown in **Figure 1**.

**Table 1.** Complex number problems in this study

| Q | Definition |
|---|---|
| Q1 | Let $\alpha = a - i$ and $\beta = 4 + 2i$. If the three points $O, \alpha$, and $\beta$ are on the same line, then find the value of the real number $a$. |
| Q2 | Find the distance between $3 + 2i$ and $5 + 7i$. |
| Q3 | If the modulus of the complex number $z$ is $\sqrt{2}$ and the argument is $\frac{3}{4}\pi$, then choose the one equal to $z$. (a) $\frac{i-1}{\sqrt{2}}$ (b) $i - 1$ (c) $\sqrt{2}(i - 1)$ (d) $i + 1$ (e) $\frac{i+1}{\sqrt{2}}$ |
| Q4 | Express the following complex number $z$ in polar form. However, the argument $\theta$ of $z$ is $0 \le \theta < 2\pi$. Q4.1: $z = \frac{-1+\sqrt{3}i}{4}$, Q4.2: $z = (1 + \sqrt{3}i)(1 - i)$, & Q4.3: $z = \frac{\sqrt{2}+\sqrt{2}i}{\sqrt{3}-i}$. |
| Q5 | The points A(α), B(β), C(γ), and D(δ) are on the complex plane with $\alpha = 1 + i, \beta = 3 - 2i$, and $\gamma = -1 - i$. If the points A, B, C, and D are vertices of a parallelogram, find the complex number δ. |
| Q6 | If α and β are non-zero complex numbers with $\alpha\bar{\beta} + \bar{\alpha}\beta = 0$, then find that $\frac{\beta}{\alpha}$ is a purely imaginary number. |

# METHOD

## Participants and Procedure

This study involved 240 11th-grade students at a private high school in Tokyo who identified as ethnically Japanese. Before the survey, the study's purpose was communicated to the math department's managing teacher, who obtained cooperation. The survey was conducted with the teacher's consent and occurred during mathematics classes in February 2021. The survey measured engagement, trait math anxiety, self-efficacy, state math anxiety, and complex plane problem-solving performance, in that order.

At the survey's start, the author informed students, both orally and through a worded questionnaire, of the following:

(1) their participation was anonymous, voluntary, and would not affect their math grades,

(2) responses would be statistically processed to protect participant privacy, and

(3) the author would manage and dispose of survey materials responsibly.

The study adhered to the Declaration of Helsinki guidelines, a set of ethical principles for medical research involving human subjects. The survey was designed to ensure anonymity, with no personal identifiers or invasions of privacy. Written informed consent was obtained from all participants beforehand. In Japan, ethical review is generally not mandatory for educational studies that are anonymous and non-invasive.

## Measures

### *Learning engagement*

Based on the learning engagement scale for mathematics by Shimizu (2020), nine items were developed to measure learning engagement. The scale was modified from figure learning to a complex plane. The learning engagement scale included behavioral engagement ($n$ = 3; e.g., I work as hard as I can on mathematics learning), emotional engagement ($n$ = 3; e.g., I enjoy learning mathematics), and cognitive engagement ($n$ = 3; e.g., I try to connect what I am learning with my knowledge) as subscales. The participants rated the items on a 6-point Likert scale, where 1 indicated complete disagreement and 6 indicated complete agreement. The participants were presented with an instructional statement, "Please answer your recent engagement in learning complex plane."

### *Trait math anxiety*

Eight items assessing trait math anxiety were developed, drawing from items with strong factor loadings on the Japanese math anxiety scale (Fujii, 1994). The Fujii (1994) math anxiety scale was developed based on Richardson and Suinn (1972). The subscales include math learning anxiety and math evaluation anxiety. The study measured participants' math learning anxiety ($n$ = 4; e.g., when I take a math class) and math evaluation anxiety ($n$ = 4; e.g., when I think about tomorrow's math test). The participants rated the items on a 6-point Likert scale, where 1 indicated not very anxious and 6 indicated very anxious.

### *Self-efficacy*

Eight items assessed self-efficacy. In line with Pajares and Miller (1994), participants were asked to indicate their confidence in providing correct answers before attempting each complex number problem (**Table 1**). The participants rated the items on a 6-point Likert scale, where 1 indicated not confident at all and 6 indicated completely confident.

### *State math anxiety*

One item ("I am anxious") from the Goetz et al. (2013) state math anxiety scale was used. The participants rated the items on a 6-point Likert scale, where 1 indicated not very anxious, and 6 indicated very anxious before solving the complex number problems (**Table 1**).

**Table 2.** Descriptive statistics and correlation matrix for each scale

| Variable | N | M | SD | ω | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Behavioral engagement | 229 | 3.81 | 1.20 | 0.87 | | | | | | | | |
| 2. Emotional engagement | 231 | 3.39 | 1.15 | 0.90 | 0.56 | | | | | | | |
| 3. Cognitive engagement | 231 | 4.12 | 1.04 | 0.79 | 0.72 | 0.58 | | | | | | |
| 4. Self-efficacy | 217 | 2.44 | 1.14 | 0.94 | 0.46 | 0.47 | 0.45 | | | | | |
| 5. Math learning anxiety | 227 | 3.14 | 1.23 | 0.87 | -0.03 | -0.27 | -0.14 | -0.15 | | | | |
| 6. Math evaluation anxiety | 225 | 4.79 | 1.26 | 0.94 | 0.04 | -0.20 | -0.06 | -0.12 | 0.60 | | | |
| 7. State math anxiety | 232 | 4.96 | 1.22 | — | -0.22 | -0.37 | -0.25 | -0.57 | 0.37 | 0.45 | | |
| 8. Use of diagrams | 233 | 1.88 | 1.68 | 0.71 | 0.27 | 0.29 | 0.23 | 0.36 | 0.01 | 0.03 | -0.23 | |
| 9. Complex plane problem-solving performance | 233 | 3.29 | 2.19 | 0.78 | 0.42 | 0.45 | 0.42 | 0.65 | -0.18 | -0.20 | -0.43 | 0.55 |

Note. M: Mean & SD: Standard deviation

### *Complex plane problem-solving performance*

Eight items were used to measure complex plane problem-solving performance (**Table 1**). These items were developed by modifying the values and conditions of basic and standard exercises on the complex plane and polar forms of complex numbers in the authorized mathematics textbooks in Japanese high schools (Jikkyo Shuppan, 2019; Tokyo Shoseki, 2014). Q1, Q2, Q5, and Q6 were related to the complex number plane, while Q3, Q4.1, Q4.2, and Q4.3 were related to the polar forms of complex numbers. These were all part of the content on the complex number plane present in senior high school mathematics (Ministry of Education, Culture, Sports, Science, and Technology in Japan, 2018).

### *Use of diagrams*

Similar to Fukaya et al. (2017), the existence of diagrams was coded for each complex plane problem (**Table 1**) and the total number of problems where diagrams were used was used as the scale score for the use of diagrams.

## Data Analysis

The data analysis comprised five steps. First, ω-coefficients were calculated for the subscales of all the measures to investigate the internal consistency of the scales. Second, descriptive statistics and correlation coefficients were then computed to verify the foundational information for each measure used in this study. Third, given that the moderator of this study, learning engagement, is not a single scale but has three subscales, a categorization of learning engagement by hierarchical cluster analysis was conducted following Wu et al. (2021). A scree plot displaying the within-cluster sum of squares (WSS) was generated, with the number of clusters determined at the point where the WSS transitioned from rapid decay to a more gradual decline. Fourth, descriptive statistics and correlation coefficients were calculated for each scale to verify the characteristics of the resulting learning engagement categories. Fifth, to test the hypothesized model in **Figure 1**, a multiple-group structural equation modelling was conducted with the learning engagement

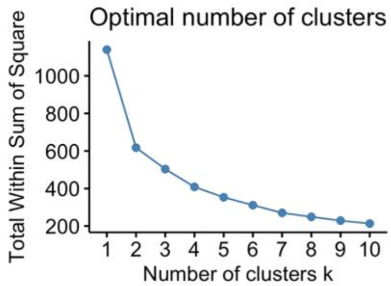


**Figure 2.** Within sum of squares by the number of clusters (Source: Authors' own elaboration)

typology as the grouping variable. The study evaluated which of the following four models was the most suitable for multiple-group structural equation modelling.

- **Model 1:** A model that does not impose equal constraints.
- **Model 2:** A model that imposes equal constraints on the intercept.
- **Model 3:** A model that imposes equal constraints on intercept and variance.
- **Model 4:** A model that imposes equal constraints on intercept, variance, and path coefficient.

# RESULTS

## Composition of Subscales and Descriptive Statistics

The ω coefficients for the subscales of self-efficacy, trait math anxiety, use of diagrams, complex plane problem-solving performance, and learning engagement are presented in **Table 2**. The ω coefficient values of 0.71 and above were sufficient for this study; consequently, the arithmetic mean of each item was utilized as the scale score. **Table 2** displays the descriptive statistics and correlation coefficients.

## Hierarchical Cluster Analysis of Learning Engagement

**Figure 2** illustrates the WSS of engagement. The study determined that the attenuation status switches from rapid to gradual when the number of clusters is 2.

**Table 3.** The differences in engagement between different clusters and the results of the t-test

| | Cluster 1 (n = 67) | | Cluster 2 (n = 152) | | t | d |
|---|---|---|---|---|---|---|
| | Mean | Standard deviation | Mean | Standard deviation | | |
| Behavioral engagement | 2.54 | 0.91 | 4.38 | 0.87 | 13.95* | 2.07 |
| Emotional engagement | 2.23 | 0.83 | 3.92 | 0.86 | 13.73* | 2.00 |
| Cognitive engagement | 3.12 | 0.95 | 4.59 | 0.69 | 11.37* | 1.76 |

Note. *p < 0.001

**Table 4.** The differences in self-efficacy, trait math anxiety, state math anxiety, use of diagrams, and complex number problem solving between different clusters and the results of the t-test

| | Low engagement | | | High engagement | | | t | d |
|---|---|---|---|---|---|---|---|---|
| | n | Mean | SD | n | Mean | SD | | |
| Self-efficacy | 62 | 1.68 | 0.73 | 139 | 2.77 | 1.11 | 8.26* | 1.16 |
| Math learning anxiety | 67 | 3.34 | 1.47 | 148 | 3.00 | 1.05 | 1.67 | 0.26 |
| Math evaluation anxiety | 67 | 4.88 | 1.45 | 146 | 4.74 | 1.17 | 0.72 | 0.11 |
| State math anxiety | 65 | 5.38 | 1.14 | 150 | 4.79 | 1.15 | 3.48* | 0.52 |
| Use of diagrams | 65 | 1.22 | 1.51 | 151 | 2.19 | 1.68 | 4.22* | 0.61 |
| Complex plane problem-solving performance | 65 | 1.94 | 1.74 | 151 | 3.82 | 2.07 | 6.87* | 0.98 |

Note. SD: Standard deviation & *p < 0.001

**Table 5.** Correlation matrixes between different clusters

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1. Self-efficacy | - | 0.02 | 0.06 | -0.30 | 0.35 | 0.35 |
| 2. Math learning anxiety | -0.17 | - | 0.64 | 0.33 | -0.14 | -0.14 |
| 3. Math evaluation anxiety | -0.14 | 0.53 | - | 0.38 | 0.03 | -0.11 |
| 4. State math anxiety | -0.57 | 0.38 | 0.47 | - | -0.16 | -0.22 |
| 5. Use of diagrams | 0.30 | 0.13 | 0.05 | -0.20 | - | 0.67 |
| 6. Complex plane problem-solving performance | 0.62 | -0.14 | -0.21 | -0.41 | 0.49 | - |

Note. Correlations for low engagement are displayed above the diagonal& correlations for high engagement are displayed below the diagonal

**Table 6.** Results of fit indices associated with the four models

| | AIC | BIC | CFI | TLI | RMSEA | SRMR |
|---|---|---|---|---|---|---|
| Model 1 | 4044 | 4193 | **0.98** | **0.94** | **0.08** | **0.04** |
| Model 2 | **3758** | 3882 | 0.81 | 0.65 | 0.20 | 0.18 |
| Model 3 | 3764 | 3869 | 0.78 | 0.69 | 0.18 | 0.23 |
| Model 4 | 3769 | **3864** | 0.75 | 0.70 | 0.18 | 0.25 |

**Table 3** presents the descriptive statistics of learning engagement in each cluster and the results of the t-test. Cluster 1 was named "low engagement" because the mean of all the learning engagement subscales was significantly lower than that of cluster 2 and had a larger effect size and a value below the semantic median of 3.50 for a 6-point Likert scale. Cluster 2, on the other hand, was labelled "high engagement" because the mean of the learning engagement subscales was above the semantic median of 3.50 for a 6-point Likert scale.

**Table 4** presents the descriptive statistics and t-test results for self-efficacy, trait math anxiety, state math anxiety, use of diagrams, and complex plane problem-solving performance by cluster. Compared to low engagement, high engagement had significantly higher means and larger effect sizes for self-efficacy, use of diagrams, and complex plane problem-solving performance. However, it had a significantly lower mean and medium effect size for state math anxiety.

## Multiple-Group Structural Equation Modelling

A multiple-group structural equation modelling was carried out using the two learning engagement types obtained as the grouping variables (**Figure 1**). **Table 5** provides basic statistical information: the correlation coefficients for self-efficacy, trait math anxiety, state math anxiety, use of diagrams, and complex plane problem-solving performance for each type. In this study, insignificant paths were eliminated at the 5% level for both high and low engagement.

**Table 6** shows the information criterion (AIC and BIC) and goodness-of-fit indices (CFI, TLI, RMSEA, and SRMR). Model 2 and model 4 had the optimal values for AIC and BIC, respectively; however, the goodness-of-fit indices for model 2 to model 4 were poor. On the other hand, the goodness-of-fit indices for model 1 were satisfactory; therefore, this study adopted model 1.

**Figure 3** shows the standardized path coefficients and the coefficient of determination ($R^2$) resulting from model 1. Self-efficacy showed a significant negative association with state math anxiety in both high and low engagement and a positive association with the use of diagrams and complex plane problem-solving performance at high engagement. Math evaluation anxiety showed a significant positive association with state math anxiety in both high and low engagement.

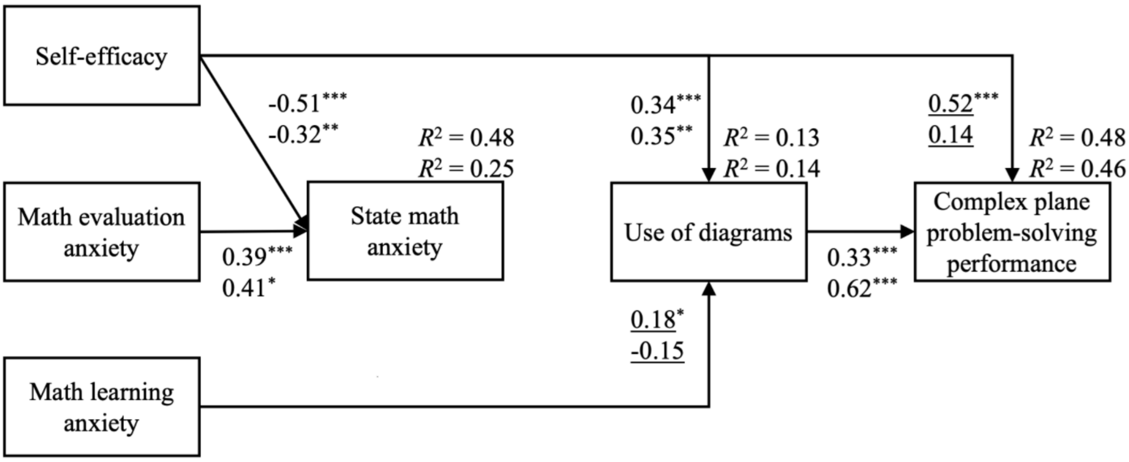


**Figure 3.** Results of multi-group covariance structural equation modelling (the upper values are for high engagement, and the lower values are for low engagement & the underlined coefficients are significant as results of the test for differences in path coefficients) (Source: Authors' own elaboration)

Note. ***p < 0.001, **p < 0.01, *p < 0.05

Math learning anxiety showed a significant positive association with the use of diagrams at high engagement. Use of diagrams was positively associated with complex plane problem-solving performance in both high and low engagement. A test of differences in path coefficients showed that the path coefficients for self-efficacy and complex plane problem-solving performance were significantly greater for high engagement ($z$ = 2.12, $p$ < 0.05). In addition, high engagement showed significantly larger path coefficients for math learning anxiety and use of diagrams ($z$ = 2.63, $p$ < 0.01).

From the above, it can be assumed that self-efficacy and math learning anxiety indirectly affect complex plane problem-solving performance through diagrams; thus, a mediation analysis (bootstrap method - number of resampling: 5,000) was conducted. The results showed that, for both high and low engagement, self-efficacy had a significant positive indirect effect on complex plane problem-solving performance mediated by use of diagrams ($\beta$ = 0.11, $p$ < 0.01; $\beta$ = 0.22, $p$ < 0.01, respectively). Math learning anxiety had a significant positive indirect effect on complex plane problem-solving performance mediated by the use of diagrams in high engagement; however, in low engagement, the indirect effect was not significant ($\beta$ = 0.06, $p$ < 0.05; $\beta$ = -0.09, $p$ = 0.23, respectively). The difference in path coefficients also showed that the positive indirect effect of math learning anxiety on complex plane problem-solving performance was significantly greater for high engagement ($z$ = 2.12, $p$ < 0.05).

The models in Figure 3 explain 25-48% of the variance in state math anxiety (48% for high engagement and 25% for low engagement), 13-14% of the variance in the use of diagrams (13% for high engagement and 14% for low engagement), and 46-48% of the variance in complex plane problem-solving performance (48% for high engagement and 46% for low engagement).

## DISCUSSION

The present study examined the processes associated with self-efficacy, trait math anxiety, state math anxiety, use of diagrams, and complex plane problem-solving performance, and the impact of learning engagement on these related processes. A multiple-group structural equation modelling, with learning engagement as a grouping variable, indicated the following results. Self-efficacy was negatively associated with state math anxiety, positively related to the use of diagrams, and positively associated, directly and indirectly, with complex plane problem-solving performance, regardless of learning engagement, supporting hypothesis 1. Math evaluation anxiety was positively associated with state math anxiety, regardless of learning engagement. Math learning anxiety was positively related to the use of diagrams and indirectly positively associated with complex plane problem-solving performance at high levels of learning engagement. The former result is consistent with hypothesis 2, while the latter contradicts it. State math anxiety was not significantly associated with the use of diagrams and complex plane problem-solving performance, which contradicts hypothesis 3. The use of diagrams was positively related to complex plane problem-solving performance, regardless of learning engagement, supporting hypothesis 4. Math learning anxiety and use of diagrams were positively associated only when learning engagement was high; self-efficacy and complex plane problem-solving performance were also positively associated. In other words, learning engagement was a moderator for these associations, partially supporting hypothesis 5.

A notable finding of this study was the moderating effect of learning engagement on the associations between math learning anxiety, use of diagrams, and complex plane problem-solving performance, and self-efficacy and complex plane problem-solving performance. Previous studies have examined learning engagement as an antecedent or mediator variable of affect and academic performance. However, few studies have examined its function as a moderator. This finding suggested that Wu et al.'s (2021) finding could be extended beyond a single aspect of cognitive engagement, namely elaboration strategies, to learning engagement, including behavioral, emotional, and cognitive aspects. Furthermore, this finding supports the findings of Wu et al. (2021) about the positive contribution of intrinsic motivation and the affective variables of math learning anxiety and self-efficacy to complex plane problem-solving, a mathematical problem that students find difficult. Therefore, the findings provide a new framework for mathematical problem-solving and learning engagement research and are highly academically significant. The moderator role of learning engagement in the associations between math learning anxiety, use of diagrams, and complex plane problem-solving performance, and self-efficacy and complex plane problem-solving performance are discussed below.

The result for learning engagement as a moderator in the relationship between math learning anxiety, use of diagrams, and complex plane problem-solving performance may be consistent with Tsui and Mazzocco (2007) who showed that math anxiety facilitates anxiety for mathematical problem-solving in students with high mathematical abilities. As noted before, students with higher learning engagement have a higher academic achievement (Fung et al., 2018; Ghelichli et al., 2021; Putwain et al., 2018; Reeve & Lee, 2014). In the present study, too, students with high learning engagement had higher complex plane problem-solving performance (**Table 4**). Given these findings, it is likely that high-engagement students were relatively more competent in mathematics. Therefore, their math anxiety acted as a facilitator for their complex plane problem-solving performance. This finding may also be explained by Yerkes-Dodson's law, which states that the relationship between the arousal level and performance is an inverted U-shaped curve with an optimal arousal level that maximizes performance (Yerkes & Dodson, 1908). In other words, for high-engagement students, math learning anxiety was at the optimum arousal level, which may have facilitated the use of diagrams and complex plane problem-solving.

Considering learning engagement as a moderator of the relationship between self-efficacy and complex plane problem-solving performance, students with higher learning engagement had more experience working with complex plane problems, as was highlighted in this study. Through these experiences, high-engagement students could, confidently and appropriately, assess their performance in complex plane problem-solving, which may have led to a greater positive impact of self-efficacy on complex plane problem-solving performance. An alternative explanation is that self-efficacy in high engagement students may have strongly functioned as a reference frame for cognitively appraising emotions involved in complex plane problem-solving; however, these were not measured in the present study. For example, enjoyment is an emotion positively associated with mathematical problem-solving (Bailey et al., 2014). In high engagement students, self-efficacy may have functioned as a powerful reference frame for cognitively appraising enjoyment, amplifying enjoyment, and, thus, facilitating complex plane problem-solving.

It is interesting to note that regardless of learning engagement, state math anxiety was not significantly associated with use of diagrams or complex plane problem-solving performance. This result is contrary to hypothesis 3 and inconsistent with Orbach et al. (2019), who state that state math anxiety, rather than trait math anxiety, predicts mathematics achievement. Among the state affective variables, self-efficacy is a strong determinant of complex plane problem-solving performance; therefore, the effect of self-efficacy on complex plane problem-solving performance may have offset the effect of state math anxiety on complex plane problem-solving performance. In fact, in the present study, self-efficacy was more positively, directly and indirectly, associated with complex plane problem-solving than trait or state mathematics anxiety (**Figure 3**). This account is consistent with Pajares and Graham (1999), who found that self-efficacy alone positively predicted mathematical problem-solving when multiple regression analyses were conducted with self-efficacy, self-concept, and math anxiety as independent variables and mathematical problem-solving as the dependent variable. Alternatively, it may be possible that students do not realistically appraise their emotional state in mathematics-related situations (Bieg et al., 2014; Goetz et al., 2013). Therefore, state math anxiety may not act as a predictor of performance in the use of diagrams or complex plane problem solving. Although the results of the present study about state math anxiety discussed above were contrary to the initial expectations, the fact that the related processes were found to be different from those of trait math anxiety suggests the importance of distinguishing between trait and state math anxiety. As previous studies (Daches Cohen et al., 2021; Orbach et al., 2019) have pointed out, there will be more demand for state math anxiety research.

## Implications For Education

The present study's findings indicate that improving complex plane problem-solving and related processes may be effective in increasing students' learning engagement and self-efficacy. Reeve and Tseng (2011) showed that the satisfaction of three basic psychological needs (autonomy, competence, and relational needs) was positively associated with high school students' learning engagement. Therefore, to increase learning engagement in complex plane problem-solving, educators must provide students with warmth, opportunities for involvement, structure, and autonomy support (Skinner & Pitzer, 2012) to satisfy basic psychological needs. In addition, to improve self-efficacy, students need to engage in their experiences of achievement and success in solving problems in the complex plane. Although mastery experience, vicarious experience, social persuasion, and physiological and affective states are sources of self-efficacy (Bandura, 1997), mastery experience, in particular, is a major source of self-efficacy (Usher & Pajares, 2008).

### Limitations

Given that this research utilized a restricted sample of Japanese high school students, caution should be exercised when generalizing the findings to other cultural contexts. Moreover, the complex plane problems addressed in this study are derived from fundamental and standard exercises concerning the complex plane and polar representations of complex numbers; thus, it remains to be seen if analogous trends would manifest in more advanced or applied problems. The research questions in this study did not include the de Moivre's theorem, which is the content of the complex plane as presented in senior high school mathematics (Ministry of Education, Culture, Sports, Science, and Technology in Japan, 2018). Future research must include a survey of students from other cultures and other complex plane content issues.

The findings of this study are based on a cross-sectional survey at a particular point in time and, therefore, cannot be referred to as a strictly causal relationship. In future research, it would be desirable to investigate self-efficacy, mathematics anxiety, use of diagrams, and complex plane problem-solving at multiple time points and use a cross-delay effect model. This would assist in approaching the long-standing issue of mathematical problem-solving (Hannula, 2012) concerning the direction of causality between affect and mathematical problem-solving.

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**Data sharing statement:** Data supporting the findings and conclusions are available upon request from the corresponding author.

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