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# Analyzing students' learning strategies using item response theory: Toward assessment and instruction for self-regulated learning

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Many previous studies related to self-regulated learning have demonstrated that students with higher academic achievement tend to use varied and effective learning strategies. However, they cannot acquire these strategies in a short period. If learning strategies are acquired and used gradually, it may help specify individual levels of use and teach its usage in a reasonable order. Therefore, this study analyzed data on strategy use with item response theory (IRT) to specify students' level of strategy acquisition and determine how they are ordered. Questionnaire data on the frequency of learning strategy use were obtained from students in five universities ( $N = 472$ ) and analyzed using the IRT model. It was shown that the average levels of students' strategy acquisition were related to their universities' academic achievement rankings.

## KEYWORDS

learning strategy use, item response theory (IRT), self-regulated learning, individual differences, students' learning strategy acquisition

## Introduction

Life in modern society is highly unpredictable, and people need to be proactive in deciding their behavior. Therefore, fostering self-regulated learners is one of the most important goals in education. Self-regulated learning is defined as involving "metacognitive, motivational, and behavioral processes that are personally initiated to acquire knowledge and skills, such as goal setting, planning, learning strategies, self-reinforcement, self-recording, and self-instruction" (Zimmerman, 2015, p. 541). This implies that these learners have sufficient skills to earn a living or acquire the necessary competencies. To deal with society's unpredictability and decide how to live proactively, students need to develop self-regulated learning skills. This idea is consistent with discussions on the importance of developing learning skills from the perspectives of key competencies, proposed by the Organization for Economic Cooperation and Development (OECD; Rychen and Salganik, 2003) and from the "21st century skills" movement (e.g., Griffin et al., 2012). The key competencies and 21st century skills are

related to the cultivation of necessary student skills that will be useful in and out of school and in future contexts.

In considering how self-regulated learners can be cultivated, an important aspect is promoting the use of effective learning strategies (e.g., Uesaka, 2012; Manalo et al., 2017). Many reviews and theoretical papers in the self-regulated learning research area have shown (Zimmerman and Schunk, 1989; Schunk and Zimmerman, 1994, 1998; Dignath et al., 2008) that these learners use effective strategies that might positively affect life-long learning. Based on this idea, various studies have examined factors that promote learning strategy use (Ames and Archer, 1988; Nolen, 1988; Zimmerman and Martinez-Pons, 1990; Lynch, 2006) and proposed educational methods that enhance students' skills by promoting the effective use of these strategies (Harris and Graham, 1999; Cleary and Zimmerman, 2004; Guthrie et al., 2004; Camahalan, 2006; Ramdass and Zimmerman, 2008).

If learning strategy use can be considered an important skill for students to become self-regulated learners, identifying the level of learning strategy use can help in considering how to promote their development. For example, as described later, some studies on knowledge acquisition with worked examples, proposed and examined the necessity of specifying students' knowledge level, which has been used to improve students' knowledge acquisition (e.g., Schwonke et al., 2007; Salden et al., 2010). To achieve these goals, computer-adaptive testing (CAT) has confirmed the effectiveness of many good practices and methodological bases of statistics for analyzing student levels. Item response theory (IRT) is an effective method for analyzing students' levels. For example, their level of English skills in second-language acquisition was analyzed using this method (e.g., Min and Aryadoust, 2021). Previous research in self-regulated learning has not applied such an idea to analyze individual differences in learning strategy use. However, specifying them regarding learning strategies using this method may facilitate the development of more effective instructional strategies for cultivating self-regulated learners.

In detail, learners may be more likely to acquire learning strategies more effectively if they receive advice and guidance that is aligned with their specific learning strategy acquisition. In fact, learning strategies range from relatively easy to difficult, and if they are not taught according to their acquisition level, they are likely to be either too easy or too difficult for the learner to acquire. However, many learning strategy teaching studies, as discussed below, teach the same strategy(ies) to participants, and such level-appropriate teaching is not currently possible. To operationalize learning strategy support in CAT, research is required to identify the underlying learning strategy and learner level. However, to date, no published study has provided the basis for operationalizing the support of such learning strategies in CAT.

The level of acquisition of the learning strategy of a student needs to be identified to take it into account for future initiatives

and to advise on appropriate learning strategies. Furthermore, the difficulty level of the learning strategy also needs to be identified (for example, which learning strategies are acquired first and which later). Additionally, it is necessary to map that level to the learner's level of acquisition of the learning strategy. If a new framework is proposed that allows this, it could enable the guidance of strategy instruction by the learner's level of acquisition of the learning strategy. Therefore, this study adopted IRT analysis, which can deal with the difficulty level of the learning strategies and the learner's level of acquisition on a unified scale.

In conducting this study, four considerations were taken into account. First, as this is the first study to determine the extent to which effective learning strategies are acquired, learning strategies that may not necessarily be initially effective were included. Learning strategies such as simple repetition are known to be less effective than those that use metacognition or elaboration organization (for example, Ramsden, 1988); however, the possibility remains that these strategies may be used in the early stages of learning. Initially, they should be seen as integrative, and if they are qualitatively different, a procedure should be followed to exclude them. Second, while using a theoretical framework, we analyzed IRT by preparing items that were in line with specific subject areas. Theoretical strategy studies are often worded in such a way that they are not subject-specific, as will be discussed later in this section. However, it is easier for learners and teachers to give advice on specific learning strategies if they are structured in a subject-specific manner. Therefore, it was decided to list and use learning strategies based on theory but also in a form that is specific to the subject areas.

Third, when analyzing the students' responses to the use of the learning strategies with IRT, we analyzed them with both polytomous and binary IRT and compared the two. Whereas polytomous IRT is an in-depth analysis that uses all the information, it is not always easy to interpret when considering the use of learning strategies. Therefore, if the results of both were found to be similar, we decided to report the results in the binary type, which is more commonly used in IRT. Finally, for this study, participants were drawn from higher-, middle-, and lower-ranked Japanese universities. University level is indicative of academic achievement in a broad sense. Even if it is difficult to verify the nature of the relationship between individual performance data and the level of learning strategies identified in this study, it is possible to argue that learning styles may underlie academic performance if even a small relationship can be demonstrated.

## Variation of effective learning strategies and possibility of cultivation

In a seminal study on learning strategy use conducted by Marton and Säljö (1976), the authors interviewed university

students to understand their learning processes and discovered two types: surface-level processing and deep-level processing. The former includes simple repetition (such as repeated reading and writing to remember the material), whereas the latter employs extra activities to improve the understanding of the material (such as elaboration of information). Successive studies have shown that learners who use deep-level processing strategies perform better (e.g., Ramsden, 1988).

Since the above-mentioned research, various effective learning strategies have been identified by questionnaire-type studies (Weinstein and Mayer, 1986; Pintrich and de Groot, 1990; Zimmerman and Martinez-Pons, 1990). Of these, the Motivated Strategies for Learning Questionnaire is one of the most well-known and frequently used methods (Pintrich et al., 1993). Prior studies have also attempted to categorize learning strategies. For example, Pintrich et al. (1993) proposed dividing them into three categories: cognitive, metacognitive, and resource management strategies. Accordingly, this study also used the framework of effective strategies considering these three main categories.

The two types of learning strategies categorizations are surface-level processing/deep-level processing and cognitive/metacognitive/resource management. These two categories are closely connected and, therefore, are not independent frameworks. Murayama (2007) indicated that cognitive strategies can be divided into two types: shallow (e.g., rehearsal and repetition) and deep cognitive strategies (e.g., elaboration and organization). Their structure is shown in Table 1. Shallow-level processing is a learning method that emphasizes simple repetition (Murayama, 2007). By contrast, here, deep-level processing is a learning method that is based not on simple repetitive processes but rather on cognitive devices in some sense. For example, it includes deep cognitive learning strategies that focus on understanding meaning in relation to existing knowledge, metacognitive strategies that focus on one's own cognitive state, and learning methods that utilize external resources such as other people and diagrams.

Whereas the structure of these learning strategies provides useful information, it is unclear which type is best in the early stages of learning and which in the later stages. Although many studies that have identified these structures also consider learning strategies in a domain-general manner (for example, "When reading I try to connect the things I am reading about with what I already know"), it is difficult to ascertain solely from these items what specific learning strategies should be developed in each subject area.

Another branch of learning strategy research has revealed other variables related to its use (Ames and Archer, 1988; Nolen, 1988; Shell and Husman, 2008; Tabachnick et al., 2008; Kesici et al., 2009). Furthermore, concrete programs to cultivate learning strategy skills to enhance student performance in a specific subject have been conducted. Reading literacy is one of the most active research areas. Concept-oriented

reading instruction, proposed by Guthrie et al. (1998, 2004), and self-regulated strategy development, proposed by Sawyer et al. (1992) and Harris and Graham (1999), were seminal works. For example, Guthrie et al. (2004) focused on promoting reading strategies among third-grade students across 12 weeks and demonstrated that their program enhanced reading performance, motivation, and strategy use among the participants. In addition to reading, strategy training has been provided in other subject areas; for example, in mathematics. Ramdass and Zimmerman (2008) provided self-correction strategy training for middle school students and demonstrated improvement in the accuracy of self-evaluation of efficacy and mathematics performance in division learning. These studies showed that learning strategy use can be enhanced by implementing thoughtful programs that are carefully planned by researchers.

Whereas these studies are unique in that they examine the promotion of specific learning strategies in a subject area, leading to actual strategy support, the idea of varying study skills interventions according to a student's level of learning strategy has been overlooked. Most studies that have supported learning strategies, even with targeted groups of participants, have provided the same instructions and materials to all participants (Sawyer et al., 1992; Guthrie et al., 1998, 2004; Harris and Graham, 1999). However, students' spontaneous use of learning strategies differs considerably according to their learning level. Students in the early stages of learning development might use easier strategies, whereas those in the latter stage might use more complex strategies. This was demonstrated by Uchida (2021), who showed that early stage learners mainly used shallow-level strategies in vocabulary learning, whereas latter stage learners used deeper-level strategies. Therefore, students might be placed on a continuum from early to late-stage acquisition of learning strategy use. However, none of the previous studies have been based on the idea of identifying the level of learning strategies within a single scale, and then identifying the learner's level within that same scale. This would make it possible to support level-based learning strategies. Therefore, in this study, based on the structure of Table 1, learning strategies for specific subjects are placed on the same scale. In addition, we aim to position the learners on the scale by using IRT, which will be described later. This will make it possible to provide support according to the level of learning strategy.

## Computer-adaptive testing and adjusting instruction according to individual levels by item response theory

Although learning strategy research has not analyzed students' levels of learning strategy use, other research areas

have conducted such an analysis to adjust for instructions and individual learning circumstances. For example, CAT is a well-known technique for language acquisition among second-language learners, in which items are adapted according to test-takers' responses; for example, following a student's response to the first item (e.g., failure or success in solving the first task), the test identifies the acquisition level and provides one of several alternative types of tasks as the second item. This is rooted in IRT, a unique test theory that calculates individual knowledge levels and hence item difficulties as probabilities based on item responses.

To explain IRT in more detail, the knowledge acquisition dimension is represented by  $\theta$ , and test responses to each item are modeled by a mathematical item response function; using students' responses to each item, their acquisition levels (called the "trait value" in IRT) are also specified. In the two-parameter model, the function in equation (1) was used. In this analysis, student knowledge acquisition and item difficulty levels are represented using  $\theta$ . In the two-parameter model, parameter  $b_i$  is called "item difficulty" of item  $i$  and is defined as the  $\theta$  score of a population in which 50% of participants pass the item. Higher scores indicate more difficult items. Parameter  $a_i$  is called "item discrimination," of item  $i$  and refers to the  $\theta$  score that can be most effectively distinguished using this item.  $D$  is a constant 1.702 to approximate the curve to the cumulative normal distribution (see [de Ayala, 2009](#), for basic information on IRT). When analyzing with IRT, a graph of the relationship between  $\theta$  and the percentage of correct responses (the item characteristic curve, ICC) is drawn for each item. IRT was developed based on the use of binary data, and in the case of binary data, a single ICC is drawn for each item. However, an IRT for analyzing multi-valued data has been proposed (for example, [Tang, 1996](#)). In the polytomous-type IRT for analyzing multi-valued data, multiple ICCs are drawn for each item for each response value, such as 1, 2, 3, or 4.

$$p_i(\theta) = \frac{1}{1 + \exp(-Da_i(\theta - b_i))} \quad (1)$$

Computer-adaptive testing, as well as various other tools and studies, has used IRT as an assessment of competencies. For example, in the OECD's Programme for International Student Assessment, students' achievement levels were represented by IRT analysis-based scores. Similarly, [Brackenbury et al. \(2017\)](#) developed a screening test using IRT to detect speech-sound disorders, and [Balsis et al. \(2017\)](#) utilized it to conduct complex personality disorder research. IRT also holds promise in many other areas.

A unique feature of IRT is that item difficulty and participant level can be represented by the same dimension ( $\theta$ ). In other words, it is characterized by the ability to select items based on the learner's level. With this feature, it can be used as a basis for determining which item (in this case, the learning

strategy) would be appropriate when teaching a learner at a particular level.

## Overview and questions of the present study

This study aims to provide a foundational framework toward a future in which learners can be supported according to their level of use of learning strategies. Currently, the idea of adjusting instruction and assessment according to the level of the student is uncommon. However, identifying students' level of mastery of learning strategies and adjusting instruction accordingly may be important for improving effective learning strategy instruction to foster self-regulated learning.

The IRT framework allows for a unified discussion of the relationship between the difficulty level of a learning strategy and the learner's level of mastery of the learning strategy; when IRT identifies the difficulty level of a strategy and the student's learning strategy level on the same dimension, the result is that appropriate learning strategies can be taught. Therefore, we aim to identify the difficulty level of the learning strategy as a continuum using IRT and represent the learner's use of the learning strategy on the same dimension. These can be used to coordinate instruction to promote the use of learning strategies in the future.

In addition to these objectives, this study examined whether there is a relationship between the level of strategy use and academic performance, which would validate the use of the continuum of individual differences obtained in the IRT analysis in educational settings.

The following steps were taken in this study. First, a list of effective learning strategies for specific subjects was made, using the framework in [Table 1](#). If questionnaires were already available, they were used, and if they were missing, we added them. At this stage, even shallow-level learning strategies were included, as they may be used in the early stages of learning. Factor analysis would then be used to confirm the unidimensionality that is the premise of the IRT analysis. If the results of the factor analysis indicated that the shallow-level learning strategies were qualitatively different from the deep-level learning strategies, only deep-level learning strategies were used and shallow-level learning strategies were excluded. If the unidimensionality was not confirmed and the learning strategies were separated by subject area, IRT was used for each one. However, if the items were not grouped by subject but constituted a single dimension, we assumed that effective learning strategies were unidimensional at a deep cross-subject area and proceeded to the next step in the analysis. Second, IRT was applied to items that were confirmed to have a one-factor structure, and acquisition scores were calculated to represent each participant's strategy acquisition level ( $\theta$ ). When analyzing the results with IRT, both

polytomous and dichotomous IRT analyses are conducted; if the two results are compared and it is confirmed that there is no significant difference between those two, the results analyzed with dichotomous IRT are reported, giving priority to ease of interpretation. Finally, the relationship between academic achievement and participants' acquisition scores was analyzed. If students who showed higher academic performance demonstrated higher acquisition scores, the strategy acquisition level might be valid for predicting underlying high academic performance. To this end, in this study, students were reminded about the learning methods used in high school. In Japan, the university entrance examinations are very competitive. Students need to use effective learning strategies acquired during their high school years to achieve academic excellence. As Shimoyama (1984) argues, Japanese students select universities that match their academic abilities. Therefore, this study examined learning strategies during high school and university levels to test their validity.

## Terminology used in the current study

As shown in Figure 1, terminologies different from the traditional IRT framework were used. While IRT analysis has primarily been used for academic achievement tests, some terminologies do not fit the context of learning strategy use. Thus, certain phrases were modified to suit the context of the study. For example, the traditional term “trait value” for the abscissa ( $\theta$ ) was replaced by “strategy acquisition level,” which represents the extent to which each student acquired higher strategies. The calculated values representing the students' levels were called “strategy acquisition scores.”

We retained the same term, “item difficulty” according to the IRT framework, for parameter  $b$ . Theoretically, we perceived it to represent an “order of acquisition” (the ranking of strategy items on the  $\theta$  scale in the IRT analysis) of each learning strategy. However, IRT analysis is not evidence of the temporal and developmental order of strategy acquisition. Therefore, the same term for “item difficulty” was used.

## Methods

### Participants

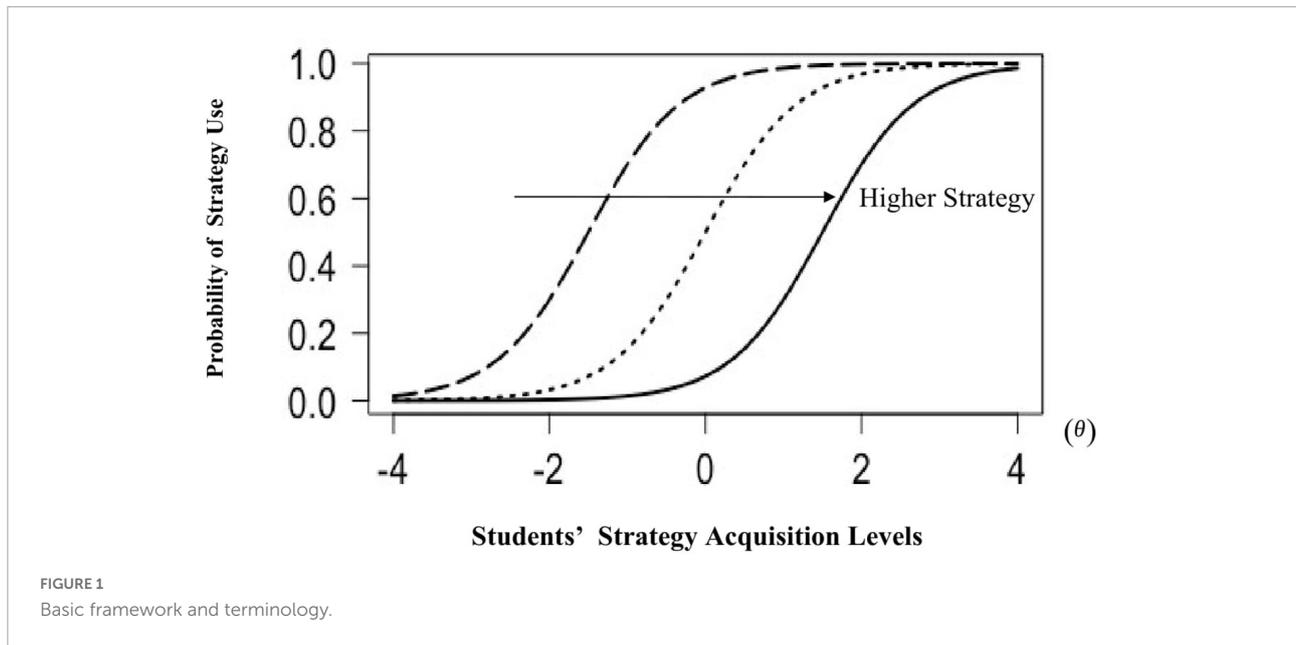
To cover a wide range of learning strategy levels of Japanese university students, participants were drawn from a balanced mix of Japan's higher-, middle-, and lower-ranked universities. A total of 472 Japanese university students (female = 180, male = 275, unknown = 17) from five universities in Tokyo and Kanagawa prefectures (mean age = 19.81 years,  $SD = 2.07$ ) were recruited. The universities represented different rankings in Japan; Universities A and B were part of the higher-ranked

universities, Universities C and D were in the middle ranks, and University E was in the lower-ranked category (Benesse Corporation, 2017). The number of students in each school was as follows: University A had 165 students, University B had 67 students, University C had 59 students, University D had 127 students, and University E had 54 students. All participants were recruited from educational psychology courses, as these courses are compulsory for students aiming for teacher qualification. Furthermore, those studying educational psychology belong to diverse disciplines, from science and technology to the humanities and economics. All students in this study participated voluntarily. We obtained ethics approval to conduct this study from the Life Sciences and Research Ethics and Safety Committee of the University of Tokyo (approval number: 18–16).

## Materials and procedure

As stated at the beginning of this manuscript, the purpose of this study is to create a foundation for specifically advising students on what learning strategies to learn next, depending on their level of learning strategy. To achieve this objective, it is necessary to list specific subject learning strategies while maintaining a theoretical foundation. Therefore, we have listed specific subject learning strategies, using the structure of Table 1 as a foundation. Specifically, we took five subjects (mathematics, English, Japanese, social studies, and science) that are relatively commonly taught in Japanese junior high and high schools and selected items in an unbiased manner, considering how the learning strategies of cognition, metacognition, and resource management can be embodied in each. In selecting items, we referred to previous studies on learning strategies (for example, Inuzuka, 2002; Murayama, 2003; Ichihara and Arai, 2006; Oyama, 2009), case reports on cognitive counseling, and educational practices using psychology (for example, Ichikawa, 1998; Uesaka et al., 2017). Where studies could not be found, we added items ourselves, taking theory into account.

Table 2 lists labels, definitions, and specific examples for each of the subcategories in Table 1. The first group is the (shallow) cognitive learning strategy group, which is a learning method that emphasizes simple repetition (Murayama, 2007). Examples of the items are “When trying to remember English words, I memorized them by writing them repeatedly” (English) and “When I learned mathematics, I remembered the procedure as much as possible” (mathematics). The second group is the (deep) cognitive learning strategy group, which is a learning method that focuses on understanding meaning in relation to existing knowledge (Murayama, 2007). Strategies such as “elaboration” and “organization” as discussed in psychology are also included in this category. Examples of the items are “When trying to remember mathematical formulas, I considered how to get the formula” (mathematics) and “When I learned social



science, I considered why such a historical event happened” (social science). The third group is the metacognitive learning strategy group, which is a learning method that monitors one’s own cognitive state and controls the learning behavior based on it. Examples of the items are “When I learned science, I tried to make clear the points that I did not understand” (science) and “When learning mathematics, to prevent failure, I wrote points for attention in my notebook” (mathematics). The final category is the external resource utilizing strategy, which is a method of learning that involves actively using things and people around oneself. Examples of the items are “When I found difficult words while reading (Japanese), I looked them up in the dictionary” (language learning), and “I tried to participate in scientific learning programmes held in the area or in the school” (science). All items used are listed in [Table 3](#).

Participants answered the questionnaires on a four-point Likert-type scale to reflect their learning strategies in high school: “1: do not use at all,” “2: use sometimes,” “3: use often,” and “4: always use.” Another choice, “not taking the course,” was also included for those who had not taken a course in the subject area.

The questionnaire included other items that were not relevant to this study’s aim, such as items on beliefs about

learning. Along with these and the focal items, the booklet additionally asked the participants to report to their university to check the validity of the connection between the level of strategy acquisition and academic achievement. Participants responded at their pace; the questionnaire took approximately 20–30 min to complete.

## Results

### Results of factor analysis to check one-dimensionality

A factor analysis was preliminarily conducted to choose one-dimensional items before the IRT analysis. R 3.4.4 with the “psych” package was employed to perform the factor analysis ([Revelle, 2018](#)). Two items that many participants responded to without having taken the course (over 10%) were excluded.

A factor analysis was conducted to determine the items to be analyzed in the IRT. Specifically, we tested the possibility that the items of the learning strategies prepared for this study would be grouped by subject area, theoretical grouping, and shallow and deep level, or as one cohesive whole. The decay of eigenvalues was as follows: 10.09, 5.10, 2.99, 2.67, 1.97, and so on. Harris–Kaiser independent cluster rotation ([Harris and Kaiser, 1964](#)) was used as the rotation method to obtain a simple structure. As shown in [Table 3](#), a two-factor model was understandable from the perspective of theories and findings in cognitive psychology. As shown in [Figure 2](#), the results of the factor analysis demonstrated that learning strategies do not cohere by five subject areas. It was also shown that they do not cohere according to theoretical groupings (shallow cognitive learning,

TABLE 1 Relationship between the two models.

Type of processing	Type of learning strategy
Shallow-Level Processing	(Shallow) Cognitive Learning Strategy
Deep-Level Processing	(Deep) Cognitive Learning Strategy
	Meta-cognitive Learning Strategy
	Resource Management Strategy

TABLE 2 Subcategories, definitions, and examples of items used in this study.

Subcategories	Definition	Examples of items
(Shallow) Cognitive Learning Strategy	A learning method that emphasizes simple repetition.	-“When trying to remember English words, I memorized them by writing them repeatedly” (English). -“When I learned mathematics, I remembered the procedure as much as possible”(mathematics).
(Deep) Cognitive Learning Strategy	A learning method that focuses on understanding meaning in relation to existing knowledge. Strategies such as “elaboration” and “organization” as discussed in psychology are also included in this category.	-“When trying to remember mathematical formulas, I considered how to get the formula” (mathematics). -“When I learned social science, I considered why such a historical event happened” (social science).
Metacognitive Learning Strategy	A learning method that monitors one’s own cognitive state and controls learning behavior based on it.	-“When I learned science, I tried to make clear the points that I did not understand” (science). -“When learning mathematics, to prevent failure, I wrote points for attention in my notebook” (mathematics).
External Resource Utilizing Strategy	A way to learn by actively using things and people around oneself.	-“When I found difficult words while reading (Japanese), I looked them up in the dictionary” (language learning). -“I tried to participate in scientific learning programmes held in the area or in the school” (science).

deep cognitive learning, metacognitive learning, and resource managing strategies). However, it is difficult to understand them as a single factor as a whole; it is more appropriate to understand them as two cohesive groups: deep-level and shallow-level learning strategies, as will be discussed below. Therefore, two factors were considered appropriate and adopted in this study.

A more detailed look at the results of the factor analysis shows that items that load highly on the first factor are generally deeper-level learning strategies. For example, “When trying to remember mathematical formulas, I considered how to get the formula” and “When I learned social science, I considered why such a historical event happened” were among the items categorized as deep cognitive learning strategies; “When I learned mathematics, I tried to consider why I failed to solve the problems” and “When I read (Japanese), I set myself some questions to check my understanding” were metacognitive learning strategies; and items such as “When I read English text, I looked words up in the dictionary if I found unknown words” and “When I found unclear points when learning science, I asked my friends and teachers” were categorized as utilizing external resource learning strategies. As indicated in the classification in [Table 1](#), these are all positioned as deep-level learning strategies.

However, items that load highly on the second factor are deemed shallow-level learning strategies. For example, “When I learned science, I memorized the content without considering the reason” and “When I learned history, I memorized years of historical events or the events.” As shown by [Ramsden \(1988\)](#), deep and metacognitive learning strategies are more effective than shallow ones. The correlation between the first and second factors was very low ( $r = 0.02$ ).

The results indicate that shallow-level learning strategies are qualitatively different from deep-level learning strategies. Therefore, since the purpose of this study was to identify the level of effective learning strategies, rather than using a

shallow-level in the early stages of learning that gradually transforms into a deep level, shallow-level learning strategies that were determined not to constitute unidimensionality with deep-level learning strategies were excluded from subsequent analyses.

Again, the factor analysis was also conducted for the 45 items loading on the first factor, with three excluded due to the small factor loadings (the criterion for exclusion was set as a factor loading value under 0.25). The decay of eigenvalues was as follows: 9.84, 2.82, 2.41, 2.07, 1.84, 1.65, and so on. The factor loading values, which are highly correlated with the first-factor loading values obtained from all items, are shown in the right column of [Table 3](#). Thus, only those items were used for subsequent IRT analysis. The alpha coefficient of these 45 items was 0.92, indicating high internal consistency.

## Item response theory analysis with learning strategy use data

Based on the results of the factor analysis, which showed that items loading on the first factor were deep-level processing learning strategies, 45 items with high loadings on the first factor were used in the IRT analysis. The analysis used both binary and polytomous IRTs. When using a binary IRT, the Likert-type data were converted into binary data. If participants answered “3: use often” or “4: always use” for a given learning strategy, it was coded as “1”; all other responses were coded as “0.” The analysis of both IRTs was conducted using R 3.4.4 and the “irtos” package ([Partchev et al., 2017](#)).

Correlations between students’ mastery scores obtained from the binary IRT and polytomous IRT were analyzed. The results are presented in [Figure 3](#). As shown in the results, the acquisition scores obtained from both analyses are very similar. However, in the case of polytomous IRT,

TABLE 3 Results of factor analysis and basic statistics.

	Item	M	SD	Factor loading		Results analyzing only one factor
				F1	F2	
59	When I learned science, I tried to consider why I failed to solve problems.	2.59	1.02	0.67	-0.14	0.66
56	When I learned science, I tried to make clear the points that I did not understand.	2.59	0.93	0.64	-0.06	0.63
61	When I learned science, I tried to focus on learning parts I did not understand.	2.62	0.97	0.62	0.05	0.61
22	When I learned mathematics, I tried to consider why I failed to solve problems.	2.91	0.92	0.60	-0.22	0.59
57	When I found new concepts in learning science, I considered the definition and example.	2.52	0.94	0.59	-0.19	0.58
58	When I learned science, I summarized what I learned with tables and figures.	2.50	1.03	0.58	-0.04	0.58
17	When I found maths problems I could not solve, I tried to do so by drawing diagrams.	2.77	1.01	0.57	-0.25	0.55
18	When I learned mathematics, I tried again to solve the problems that I had failed to solve.	2.89	0.94	0.56	-0.10	0.55
64	When I found unclear points when learning science, I asked my friends and teachers.	2.76	1.01	0.54	0.11	0.54
48	When I learned social science, I considered why such a historical event happened.	2.60	1.03	0.53	0.02	0.54
43	When I learned social science, I tried to consider how different events connect to each other.	2.62	1.06	0.53	0.04	0.54
46	When I read textbooks concerning social science, I tried to find unclear points.	2.34	1.02	0.53	0.22	0.54
7	When I read English text, I paid attention to points where I got confused.	2.44	0.95	0.51	0.05	0.52
34	When I read (Japanese) text and found a new word, I tried to consider its meaning.	2.71	0.84	0.50	-0.01	0.50
19	When trying to remember mathematics formulas, I considered how to get the formulas.	2.50	0.98	0.50	-0.37	0.48
49	When learning social science, I applied mental resources to points I did not remember.	2.71	0.96	0.49	0.23	0.49
45	When I learned history, I summarized how events happened in my notes or my mind.	2.76	1.05	0.47	0.13	0.48
15	When trying to remember mathematics formulas, I memorized situations where they were used.	2.65	0.96	0.47	-0.10	0.46
37	When I read (Japanese) text, I read slowly if I found unclear points.	3.04	0.92	0.45	0.05	0.45
8	When trying to remember English words, I concentrated on words I did not remember.	2.77	1.01	0.45	0.19	0.45
4	When trying to remember English words, I paid attention to situations where the word was used.	2.38	0.94	0.44	-0.28	0.43
30	When reading (Japanese) text, I tried to summarize the meaning of each sentence.	2.44	0.96	0.43	0.09	0.44
6	When I found unknown words, I took a guess based on the context where they were used.	2.85	0.97	0.43	-0.11	0.43
32	When I read (Japanese) text, I considered how content related to knowledge I already had.	2.37	0.95	0.43	0.04	0.44
63	When learning science, I used study aids.	2.52	1.11	0.42	0.03	0.42
23	When learning mathematics, to prevent failure, I wrote points for attention in my notebook.	1.95	0.95	0.42	0.03	0.42
35	When finding difficult words in (Japanese) text, I paraphrased using easy expressions.	2.47	0.93	0.41	0.03	0.41
24	When I found unclear points while learning mathematics, I asked my friends and teachers.	2.86	0.97	0.39	0.18	0.39
36	When I read (Japanese), I set myself some questions to check my understanding.	1.77	0.84	0.38	0.18	0.39
20	When I learned mathematics, I checked whether answers were correct after solving.	3.11	0.98	0.38	-0.23	0.37
5	When learning English, I remembered words by identifying prefixes and suffixes.	2.39	1.06	0.38	0.05	0.37
44	I talked with my friends or family about history.	2.39	1.11	0.37	0.19	0.38
29	When I found difficult words while reading (Japanese), I looked them up in the dictionary.	2.73	0.96	0.37	0.10	0.37
13	When I learned mathematics, I used study aids.	2.43	1.02	0.36	0.17	0.37
47	When I learned history, I tried to understand the big sweep of time rather than the details.	2.83	0.97	0.36	0.19	0.37

(Continued)

TABLE 3 (Continued)

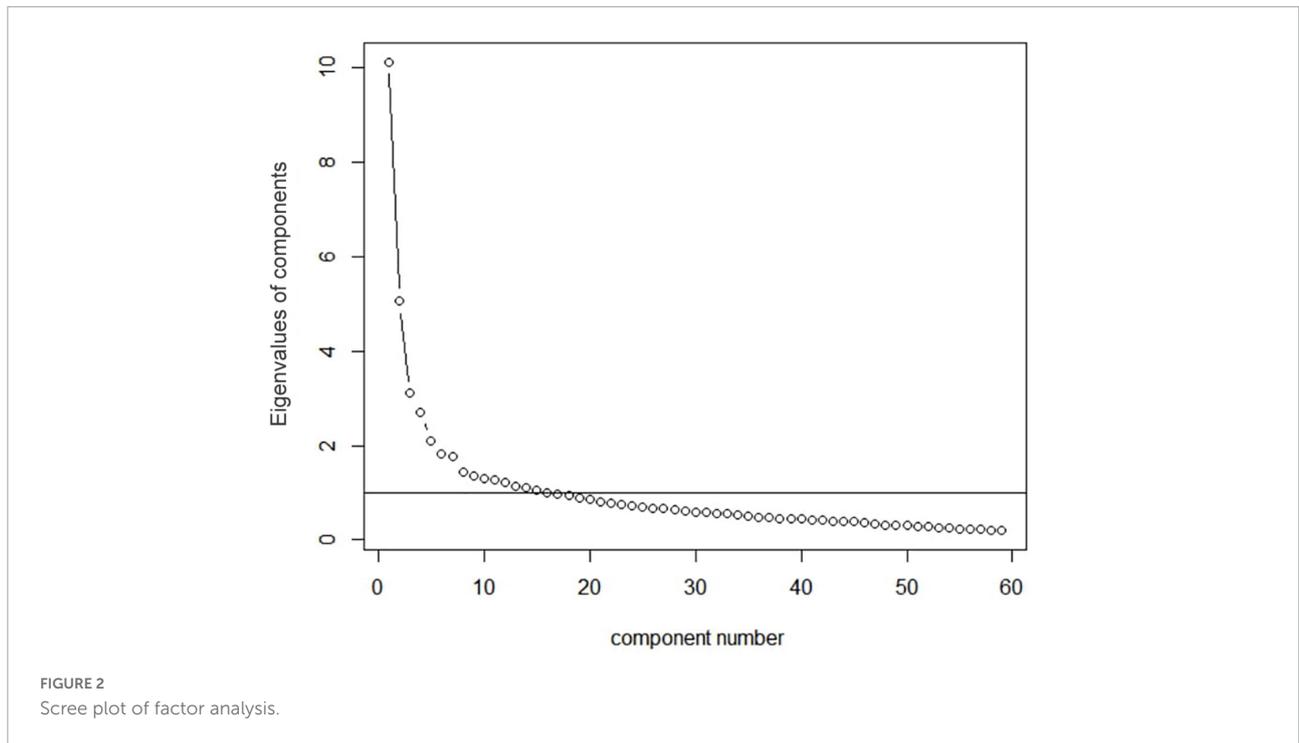
	Item	M	SD	Factor loading		Results analyzing only one factor
				F1	F2	
60	When I learned science, I watched TV programs or read journal concerning science.	2.01	1.05	0.36	0.05	0.35
31	When I found unclear meanings in conversation with others, I asked questions about them.	2.27	0.95	0.34	0.13	0.34
9	When I read English text, I looked words up in the dictionary if I found unknown words.	2.87	0.94	0.33	0.19	0.33
28	When trying to remember Chinese characters, I memorized similar or opposite ones too.	2.11	0.92	0.32	0.15	0.32
21	When I learned mathematics, I copied correct answers in my notebook or on exam papers.	2.87	1.06	0.30	0.08	0.30
16	When I learned mathematics, I considered how answers were gotten by reading correct ones.	2.76	0.91	0.30	-0.07	0.30
27	When trying to remember Chinese characters, I memorized radicals or origins of the words.	2.01	0.94	0.29	0.06	0.30
38	When I learned social science, I read books or articles on topics I found interesting.	2.77	1.05	0.29	0.11	0.30
10	When I learned English, I read English text in books, magazines, or newspapers.	1.66	0.89	0.29	-0.15	0.29
62	I tried to participate in scientific learning programmes held in the area or in the school.	1.50	0.89	0.27	0.06	0.27
53	When I learned science, I memorized the content without considering the reason for it.	2.12	1.01	-0.17	0.64	
14	When trying to remember mathematics formulas, I did not consider why they were like that.	2.11	1.03	-0.19	0.61	
52	When I found unclear points when learning science, I just memorized those.	2.51	1.03	0.13	0.58	
39	When I learned history, I remembered points that seemed important using rote memorization.	2.91	0.98	0.20	0.54	
40	When I learned history, I rehearsed years of historical events or the events themselves.	2.44	1.06	0.12	0.54	
12	When I learned mathematics, I remembered the procedure as much as possible.	2.48	0.92	0.05	0.53	
26	When trying to remember Chinese characters, I memorized them by writing repeatedly.	3.03	1.02	0.12	0.47	
1	When trying to remember English words, I memorized them by writing them repeatedly.	2.53	0.96	0.10	0.46	
3	When trying to remember English words, I used Japanese translations and no example sentences.	1.91	0.92	-0.04	0.45	
41	When trying to remember the years of historical events, I memorized them using rhyming words.	2.56	1.04	0.22	0.42	
25	When trying to remember Chinese characters, I memorized them using rehearsing.	1.90	1.04	0.09	0.42	
2	When trying to remember English words, I memorized only Japanese translations.	1.76	0.87	-0.02	0.36	
33	When learning Japanese, I used rote memorization without understanding difficult content.	1.63	0.85	-0.11	0.36	
42	When I learned history, I used comic books, TV programmes, or games concerning history.	2.10	1.08	0.17	0.33	

interpretation is difficult because an ICC is given for each response value. Therefore, the present study gives priority to ease of interpretation and reports the results of the binary IRT.

Parameters were estimated using a total of 45 items and IRT. The results are presented in [Table 4](#), grouped by subject area for readability; note that IRT is not carried out separately for each subject area. Examples of the ICCs obtained are shown in [Figure 4](#). The acquisition scores were also estimated. The value of the discrimination parameter in all items was greater

than 0.55, suggesting that there were no items with a low discrimination parameter value.

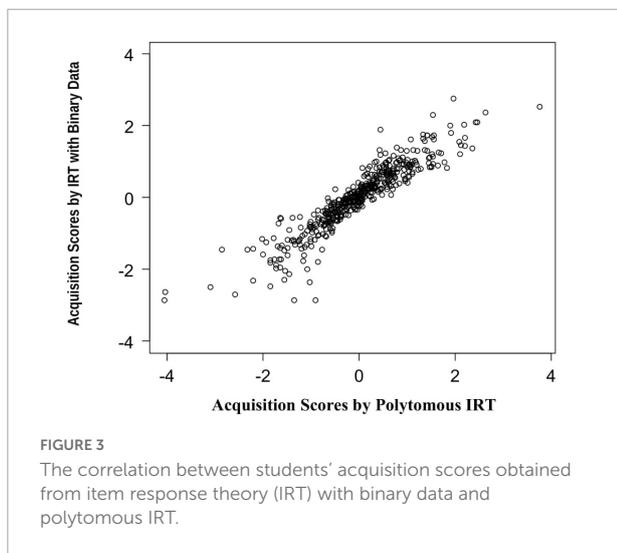
Examination of learning strategies used by each university revealed that students at the higher-performing universities actively used deep cognitive and metacognitive strategies; however, they used strategies that utilized external resources less frequently. For example, learning strategies such as “I tried to participate in scientific learning programmes held in the area or school” or “When I learned English, I read English text in books,



magazines, or newspapers” had item difficulty values above 2.0. These strategies were also used less frequently by students at universities with higher academic achievement. However, this should be examined in future studies.

### Relationship between learning strategy acquisition and academic achievement

If learning strategy acquisition level highly correlates with academic achievement, it might provide evidence for its

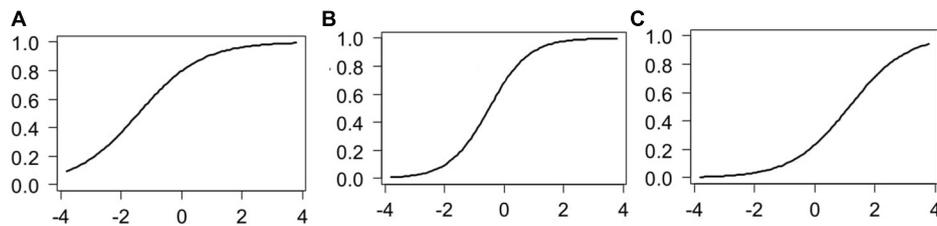


validity. The average acquisition scores for each university were calculated to examine the relationship between acquisition level and academic achievement. Note that the study included students from several universities and grades. Therefore, it is not possible to analyze academic achievements using a unified index. However, the university itself is considered to broadly reflect the learner's level of study. In particular, it has been suggested that in Japan, higher education plans are determined mainly by academic ability and less by other influences (Kariya and Rosenbaum, 1987). Kariya and Rosenbaum (1987) collected data for junior high schools, but the idea is that Japanese students do not change significantly, even when they are aiming to go on to university. Therefore, individual differences in the level of acquisition of learning strategies are related to the level of university, which is considered a manifestation of academic ability in a broad sense. The purpose of this analysis is to show that the theta resulting from this study may provide a background for a certain type of academic ability.

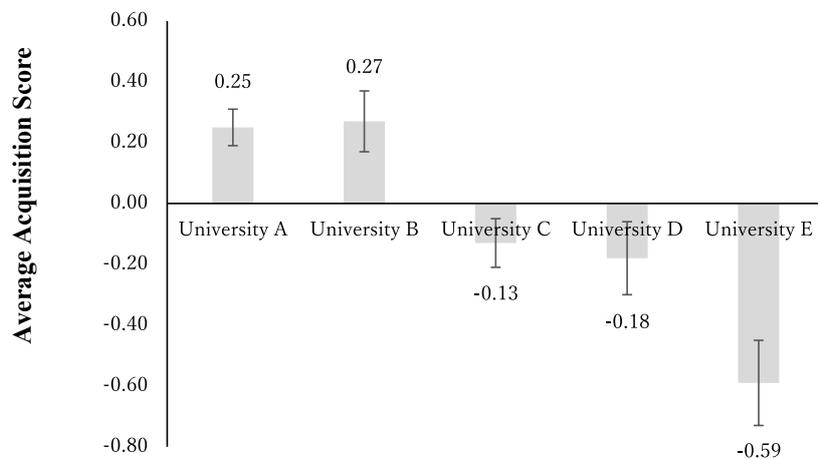
As shown in Figure 5, average acquisition scores, arranged in order, correspond to academic achievement as estimated by the Japanese university rankings (i.e., Universities A and B = comparatively higher-ranked, Universities C and D = middle-ranked, University E = comparatively lower-ranked). The result suggests that the participants' level of mastery of the use of deep-processing learning strategies may be part of the background to their high academic performance.

TABLE 4 Results of item response theory (IRT) analysis.

Item	Item difficulty		Item discrimination		
	Estimates	SE	Estimates	SE	
<b>Learning Strategies in Mathematics</b>					
20	When I learned mathematics, I checked whether answers were correct after solving.	-1.42	0.21	0.96	0.15
22	When I learned mathematics, I tried to consider why I failed to solve problems.	-0.67	0.10	1.66	0.21
18	When I learned mathematics, I tried again to solve the problems that I had failed to solve.	-0.51	0.10	1.51	0.19
24	When I found unclear points while learning mathematics, I asked my friends and teachers.	-0.82	0.17	0.84	0.13
21	When I learned mathematics, I copied correct answers in my notebook or exam papers.	-1.09	0.27	0.57	0.12
17	When I found math problems I could not solve, I tried to do so by drawing diagrams.	-0.39	0.10	1.36	0.17
16	When I learned mathematics, I considered how answers were gotten by reading correct ones.	-0.83	0.24	0.55	0.11
15	When trying to remember mathematics formulas, I memorized situations where they were used.	-0.36	0.12	1.03	0.14
13	When I learned mathematics, I used study aids.	0.09	0.14	0.77	0.13
19	When trying to remember mathematics formulas, I considered how to get the formulas.	0.07	0.10	1.07	0.15
23	When learning mathematics, to prevent failure, I wrote points for attention in my notebook.	1.15	0.18	1.05	0.16
<b>Learning Strategies in Science</b>					
64	When I found unclear points when learning science, I asked my friends and teachers.	-0.41	0.11	1.18	0.16
61	When I learned science, I tried to focus on learning parts I did not understand.	-0.19	0.08	1.68	0.21
63	When learning science, I used study aids.	-0.16	0.11	0.99	0.14
56	When I learned science, I tried to make clear the points that I did not understand.	-0.10	0.07	1.94	0.23
59	When I learned science, I tried to consider why I failed to solve problems.	-0.07	0.07	2.11	0.25
58	When I learned science, I summarized what I learned with tables and figures.	-0.02	0.09	1.42	0.18
57	When I found some new concepts in learning science, I considered the definition and example.	0.04	0.08	1.77	0.22
60	When I learned science, I watched TV programs or read journals concerning science.	1.14	0.21	0.81	0.14
62	I tried to participate in scientific learning programmes held in the area or in the school.	2.41	0.46	0.81	0.17
<b>Learning Strategies in Language Learning</b>					
37	When I read (Japanese) text, I read slowly if I found unclear points.	-1.26	0.21	0.84	0.14
34	When I read (Japanese) text and found a new word, I tried to consider its meaning.	-0.39	0.11	1.09	0.15
29	When I found difficult words while reading (Japanese), I looked them up in the dictionary.	-0.53	0.16	0.75	0.13
35	When finding difficult words in (Japanese) text, I paraphrased using easy expressions.	0.12	0.13	0.81	0.13
30	When reading (Japanese) text, I tried to summarize the meaning of each sentence.	0.35	0.13	0.82	0.13
32	When I read (Japanese) text, I considered how content related to knowledge I already had.	0.43	0.12	1.00	0.15
31	When I found unclear meanings in conversation with others, I asked questions about them.	0.88	0.21	0.66	0.13
28	When trying to remember Chinese characters, I memorized similar or opposite ones too.	1.26	0.26	0.67	0.13
36	When I read (Japanese), I set myself some questions to check my understanding.	1.67	0.25	1.05	0.18
27	When trying to remember Chinese characters, I memorized radicals or origins of the words.	1.71	0.36	0.63	0.14
<b>Learning Strategies in Social Science</b>					
47	When I learned history, I tried to understand the big sweep of time rather than the details.	-0.78	0.17	0.80	0.13
38	When I learned social science, I read books or articles on topics I found interesting.	-0.75	0.23	0.55	0.11
45	When I learned history, I summarized how events happened in my notes or in my mind.	-0.43	0.12	1.00	0.14
49	When learning social science, I applied mental resources to points I did not remember.	-0.40	0.11	1.10	0.15
43	When I learned social science, I tried to consider how different events connect to each other.	-0.14	0.09	1.36	0.18
48	When I learned social science, I considered why such a historical event happened.	-0.12	0.09	1.35	0.17
44	I talked with my friends or family about history.	0.27	0.14	0.76	0.13
46	When I read textbooks concerning social science, I tried to find unclear points.	0.33	0.10	1.26	0.17
<b>Learning Strategies in English Learning</b>					
9	When I read English text, I looked words up in the dictionary if I found unknown words.	-1.34	0.35	0.49	0.11
6	When I found unknown words, I took a guess based on the context where they were used.	-0.70	0.15	0.91	0.14
8	When trying to remember English words, I concentrated on words I did not remember.	-0.60	0.14	0.91	0.14
7	When I read English text, I paid attention to points where I got confused.	0.13	0.10	1.17	0.16
4	When trying to remember English words, I paid attention to situations where the word was used.	0.21	0.12	0.96	0.14
5	When learning English, I remembered words by identifying prefixes and suffixes.	0.27	0.13	0.81	0.13
10	When I learned English, I read English text in books, magazines, or newspapers.	2.73	0.61	0.66	0.16



**FIGURE 4**  
 Examples of item characteristic curves (ICCs) in items concerning mathematics. **(A)** ICC of Item 20 “When I learned mathematics, I checked whether answers were correct after solving.” **(B)** ICC of Item 18 “When I learned mathematics, I tried again to solve the problems that I had failed to solve.” **(C)** ICC of Item 23 “When learning mathematics, to prevent failure, I wrote points for attention in my notebook.”



**FIGURE 5**  
 Average acquisition scores for students in each university. The vertical bars show the standard deviations.

## Discussion

### Summary of the findings in the present research

This study analyzed students’ levels of learning strategies using IRT and specified the ease or difficulty level of each strategy. Traditionally, learning strategy research did not consider the level of learning strategies among students. Moreover, most research, which tried to promote students’ academic performance by encouraging the use of learning strategies, usually provided instructions that were not adjusted to individual levels. This study attempted to shed light on this aspect.

After confirming the one-dimensionality, IRT analysis was applied to all deep-level processing types of items. Moreover, the positive relationship between the acquisition score retrieved from this analysis and academic performance was confirmed. We also specified the appropriate learning strategy for a specific learner level. Although academic achievement was evaluated by the university’s rank, a

clear relationship was demonstrated. This means that the  $\theta$  assessed by the questionnaires might be the basis of academic achievement.

### How to utilize the findings of the current study

This manuscript proposes a framework as a basis for ensuring that students can be advised according to their level of acquisition of learning strategies. Although it is limited in that it only proposes a basic framework that has not yet led to actual support, it proposes a direction for the use of this framework in the future.

First, applying this idea in educational practice should involve utilizing it in assessment as well as in the results of personalized interventions. Although current personal tutoring research mainly focuses on instruction in specific subject-related knowledge, such as biology (see the review of [Chi et al., 2001](#); [Roscoe and Chi, 2008](#)), some studies and practices focus on improving learning strategy use through

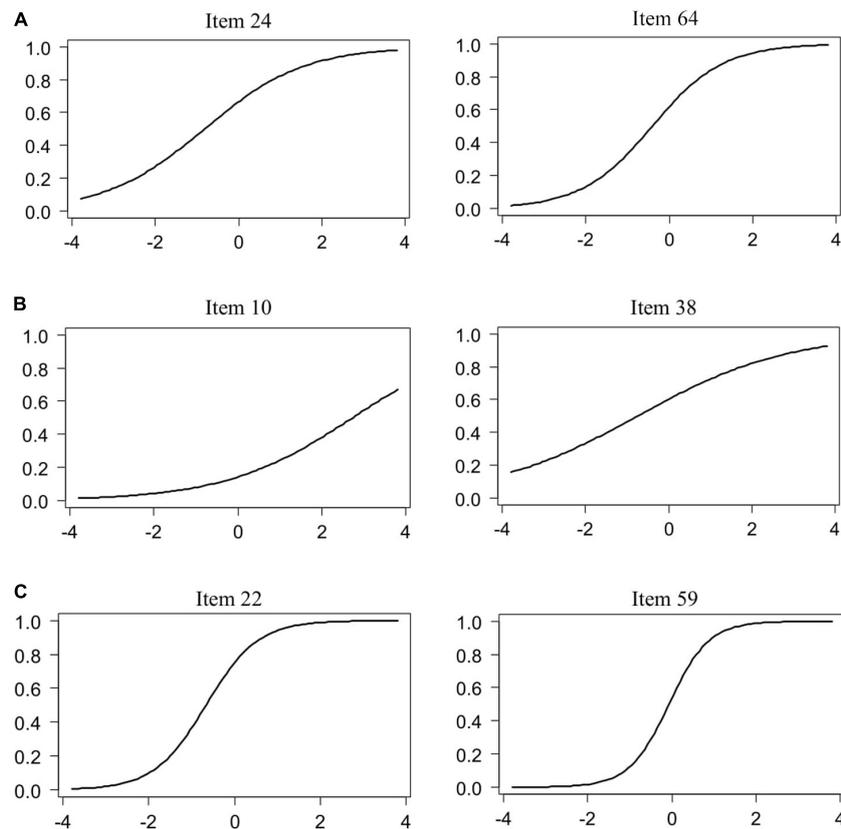


FIGURE 6

Comparison of item characteristic curves (ICCs) in different subjects. (A) ICCs of Item 24 (“When I found unclear points while learning mathematics, I asked my friends and teachers”) and Item 64 (“When I found unclear points when learning science, I asked my friends and teacher”). (B) ICCs of Item 10 (“When I learned English, I read English text in books, magazines, or newspapers”) and Item 38 (“When I learned social science, I read books or articles on topics I found interesting”). (C) ICCs of Item 22 (“When I learned mathematics, I tried to consider why I failed to solve problems”) and Item 59 (“When I learned science, I tried to consider why I failed to solve problems”).

personal tutoring; for instance, [Craig et al. \(2000\)](#) demonstrated the enhancement of questioning skills by tutoring. Another personal tutoring study conducted in Japan, referred to as “cognitive counseling” ([Ichikawa, 2005](#); [Ichikawa et al., 2017](#)), aimed to develop autonomous learners and utilized cognitive psychology. Currently, counselors with a strong background in cognitive psychology manually assess clients’ learning strategy acquisition levels based on their materials. Based on the findings of this study, tutors or counselors can assess learners’ strategy acquisition levels and teach appropriate learning strategies.

Second, this framework can also be used in classroom instructions to support the complex task of adjusting them according to each student’s needs. This can be done in several ways. For instance, the framework can provide teachers with information on what kinds of learning strategies are used. They can also assess average strategy acquisition levels among students and help teachers adjust their instructions accordingly. Moreover, effective classroom interventions can be implemented, for example, to construct subgroups that

share similar levels of learning strategies, and provide tailored instruction to the levels in those respective groups.

Based on the assumption that learning strategies with item difficulties at the same level as acquisition scores are recommended, more concrete suggestions to apply these findings in classroom instruction are reflected below. When students’ average acquisition score is approximately  $\theta = -1.0$  (not so high), the following learning strategies might be effective (many of these provide ways to deal with failure in problem-solving or perceived difficulty in learning).

- Item 20: When I learned mathematics, I checked whether answers were correct after solving.
- Item 37: When I read (Japanese) text, I read slowly if I found unclear points.
- Item 18: When I learned mathematics, I tried again to solve the problems that I had failed to solve.
- Item 24: When I found unclear points while learning mathematics, I asked my friends and teachers.

- Item 9: When I read English text, I looked words up in the dictionary if I found unknown words.

If the students' average acquisition score is approximately  $\theta = 0$  (moderate), the following learning strategies might be effective.

- Item 58: When I learned science, I summarized what I learned with tables and figures.
- Item 35: When finding difficult words in (Japanese) text, I paraphrased using easy expressions.
- Item 5: When learning English, I remembered words by identifying prefixes and suffixes.
- Item 4: When trying to remember English words, I paid attention to situations where the words were used.

If students' average acquisition score is approximately  $\theta = 1.0$  (comparatively high), more advanced learning strategies might be appropriate. At this level, advanced strategies that utilize engagement with authentic resources, such as journal articles or community-provided learning programs outside of school, would be useful. The following items provide such examples.

- Item 60: When I learned science, I watched TV programs or read journals concerning science.
- Item 10: When I learned English, I read English text in books, magazines, or newspapers.
- Item 62: I tried to participate in scientific learning programmes held in the area or in the school.

## Future directions and questions arising from this study

It is worth discussing the future research directions that emerge from this study. One such direction is to integrate more students as participants. The  $\theta$  calculated in this study was based on university students' reflections on their practices and learning during high school. However, high school is not the only stage relevant to this model. For example, Uesaka (2010) instructed junior high school students (eighth grade) in metacognitive learning strategies, reviewing how to analyze failures regarding cognitive counseling, which succeeded in inducing the transfer of learning strategies. Studies in the personal tutoring context and meta-analysis by Dignath et al. (2008) demonstrated the effectiveness of learning strategy instruction at younger school levels, specifically, elementary school. University students should also be instructed in effective learning strategies (Manalo and Henning, 2017). Integrating data right from elementary school to the university level would

reveal the learning strategy acquisition order, contributing to high-quality education over the entire learning period.

The second direction is to collect a wider range of items for the analysis. This study applied IRT analysis to items that could be retrieved from previous work and classified them as cognitive, metacognitive, or external resource utilizing strategies. The study could not integrate all types of learning strategies due to time limitation in implementing the questionnaire. However, if the range of participants were expanded, it would be necessary to integrate an increasing number of learning strategies; for example, if we want to cover elementary school students, more items with easier acquisition orders should be integrated. Although this study did not do so, the IRT equating method might be worth using, wherein common items are included for every participant and item parameters are calculated consistently for every age group.

The third direction is to examine in more detail the relationship between data on the level of learning strategies and academic achievement. In this study, we divided the university levels into three categories and examined their relationship to the learning strategy levels obtained. In the future, it will be important to obtain data on individual academic achievement and verify its relationship with learning strategy levels.

Finally, it is worth examining how the use of similar strategies varies across subjects. This study used various types of learning strategies so that the findings could help teachers gain concrete suggestions regarding which strategies should be employed in different subject areas. The results raised the question of whether learning strategy use differed depending on the subject area. For example, as shown in Figure 6, the pair of ICCs comprising Item 24 ("When I found unclear points while learning mathematics, I asked my friends and teachers") and Item 64 ("When I found unclear points when learning science, I asked my friends and teachers"), and the pair of Item 10 ("When I learned English, I read English text in books, magazines, or newspapers") and Item 38 ("When I learned social science, I read books or articles on topics I found interesting") were different, even though the types of learning strategies were similar. However, a pair of ICCs for Item 22 ("When I learned mathematics, I tried to consider why I failed to solve the problems") and Item 59 ("When I learned science, I tried to consider why I failed to solve the problems") were similar. A more detailed examination of the relationship between learning strategy use and subject areas is one of the most important topics for future investigation.

## Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: <https://doi.org/10.6084/m9.figshare.12502028.v1>.

## Ethics statement

The studies involving human participants were reviewed and approved by the Life Sciences and Research Ethics and Safety Committee of the University of Tokyo. The patients/participants provided their written informed consent to participate in this study.

## Author contributions

YU prepared the questionnaire, collected the data, and wrote the first draft. MS analyzed the data. SI initiated the original idea for this manuscript. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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