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Article

# How teaching style influences math learning: Comparing discovery and traditional instruction

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## SUMMARY

**Mathematics achievement and engagement often decline as students move through secondary school, and the way mathematics is taught may be part of the reason. In this study, we compared traditional direct teaching with discovery-based teaching in mathematics among secondary school students. Forty seventh-grade students from across Turkiye participated in a six-week virtual mathematics enrichment course on basic linear equations and combinatorics. We randomly assigned the students to two equal-sized groups that received different instructional approaches to the same content for an equivalent period of time. The teacher taught one group through structured explanations and worked examples, while the other group learned by exploring problems with guidance and feedback from the teacher. We hypothesized that students receiving discovery-based teaching would demonstrate better academic achievement and more positive attitudes towards mathematics compared to students receiving traditional teaching. We collected data using pre- and post-instruction mathematics achievement tests that assessed procedural and conceptual knowledge, alongside a mathematics attitude scale. After accounting for the differences between the two groups before instruction began, students in the discovery-based group achieved significantly higher mathematics scores. Furthermore, students who received discovery-based teaching reported better attitudes towards mathematics. Overall, the results indicate that supporting students' independent discovery of mathematical concepts benefits both learning and attitudes in online learning settings.**

## INTRODUCTION

Mathematics achievement and engagement often decrease during the secondary school years, a phenomenon that cuts across many nations in the Organisation for Economic Co-operation and Development (1). As a result of this, there has been an increase in interest in how the teaching method a student experiences influences what they learn (2).

Teaching methods are the sets of pedagogical principles that teachers use to convey knowledge, and the aims of the lesson, together with the knowledge or skill to be learned, shape which method a teacher chooses (2). Some of the teaching methods include class participation, demonstration, recitation, and memorization, among others. Each of these methods has a unique effect on student engagement; for example, interactive methods often boost intrinsic motivation, whereas memorization-heavy methods may prioritize rapid recall over deep interest (3). To understand the mechanics of these student-centered approaches, one widely used framework describes discovery-oriented learning as a four-stage process (3). These four stages – introduction, exploration, concept development, and application – form the backbone of the discovery-based learning method investigated in this study (3). The introduction stage involves sparking students' interest by presenting a challenge, while the exploration stage engages students in hands-on tasks, such as solving a sample problem or searching for a pattern across a set of examples, which the teacher guides with short questions rather than with worked solutions. Then, the concept development stage relates these exploration activities with relevant concepts, and the application stage allows students to apply learned concepts through problem-solving.

Broadening this perspective, teaching methods fall into three broad types: teacher-centered, student-centered, and teacher-student interactive methods (4). The teacher-centered method involves using direct instruction to convey knowledge from teacher to student. Although effective for rapid content delivery, it does not allow students to be actively engaged in the learning process or to independently develop appropriate cognitive skills (4, 5). In contrast, student-centered methods, such as problem-based learning, allow students to be actively engaged by motivating them through the independent discovery of concepts (6, 7). The teacher-student interactive method serves as a middle ground where the teacher and the students share the instructional lead to enhance knowledge retention, which differs from student-centered methods that place the primary responsibility of discovery squarely on the student (4).

Traditional lecture-based instruction is common in Turkish math classrooms, focusing on fluency development via repetition and examples (8). However, such instruction often leads to a neglect of conceptual understanding (9). In traditional instruction, the teacher directly instructs on the topic by describing official definitions, demonstrating key procedures, and solving examples on the board. Students are passive recipients of instruction, asking questions only when encouraged to do so. This type of instruction is teacher-led, content-centered, and has little room for student input or exploration during instruction, and students taught this way tend to develop weaker conceptual understanding than students in more interactive settings (5, 9). Problem-based learning, which we utilize as our discovery-based learning model, involves students actively participating in the exploration of mathematical concepts through inquiry and problem-solving activities (6). In other words, the instructor challenges students to discover mathematical facts on their own. Empirical findings support the effectiveness of problem-

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based learning in promoting students' intrinsic motivation and long-term retention of learned materials: students taught in this way report greater interest in the subject and retain what they have learned for longer than students taught mainly through lecture and repetition (6, 7). However, its effectiveness depends on factors such as how much guidance the teacher provides, how much prior knowledge students bring to the topic, the complexity of the task, and the age of the students, with the largest gains reported once students have enough background knowledge to reason productively on their own (10).

Previous meta-analyses indicate that student-centered approaches work best when the teacher guides students while they explore: discovery-based learning in which students receive prompts, feedback or worked examples produces larger achievement gains than explicit instruction, whereas discovery without any support does not (11). Despite this growing body of literature, the effectiveness of this teaching method for students participating in fully online learning environments for a short period of time remains a gap in the literature (12). This gap is particularly relevant to mathematics, as students in subjects requiring intensive logical reasoning have fewer opportunities to ask follow-up questions and to reason through problems with their peers in restrictive online settings, which limits their conceptual gains, making it crucial to find effective alternatives to the traditional, lecture-based methods that are currently the norm in Turkish mathematics classrooms (8, 13, 14). Thus, it is essential for us to understand how different teaching methods function within online mathematics learning environments, so we can provide students with both academic and affective benefits.

In this study, we aimed to address this gap by comparing the two contrasting extremes of mathematics instruction – strictly teacher-centered (traditional) direct instruction and strictly student-centered (discovery-based) learning – to isolate their distinct effects on 12- to 13-year-old students' procedural achievement (the ability to execute mathematical rules) and conceptual mathematics achievement (the deep understanding of relationships), as well as on their attitudes towards mathematics in a fully online learning environment. We utilized basic linear equations and combinatorics – the mathematical study of counting and arrangements – as our content benchmarks, as combinatorics relies heavily on logical reasoning rather than memorization, making it ideal for testing conceptual abilities.

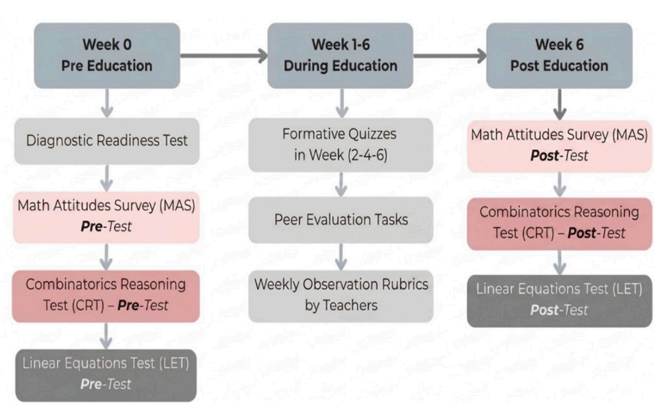


**Figure 1. Program assessment plan across the six-week instructional period.** Flow diagram showing the sequence of pre-, during, and post-intervention assessments, including diagnostic testing, formative activities, and pre- and post-tests.

We hypothesized that students in the discovery-based group would achieve better mathematics outcomes and show more positive attitudes towards mathematics than their peers in the traditional group, who received direct instruction. Our findings supported this hypothesis: students in the discovery-based group showed better mathematics achievement, more positive attitudes towards mathematics, and greater self-efficacy than students in the traditional group. Taken together, these results indicate that, in a short-term online setting, discovery-based learning is the more effective of the two approaches for both what students learn and how they feel about learning it. Ultimately, these results provide actionable insights for educators and policymakers seeking to optimize instructional design in an increasingly digital educational landscape.

## RESULTS

We conducted this study to determine whether the instructional method a student experienced changed how much mathematics they learned and how they felt about the subject in a fully online course. We hypothesized that students taught through discovery-based learning would outperform students taught through traditional direct instruction on measures of mathematics achievement and would report more positive attitudes towards mathematics. To test this hypothesis, we randomly assigned 12- to 13-year-old students to two groups, one taught through discovery-based learning and one taught through traditional direct instruction, and the same instructor taught both groups.

### Academic Achievement

To examine whether the instructional method influenced 12- to 13-year-old students' academic achievement, we analyzed pre- and post-test scores from the Linear Equations Test (LET) and the Combinatorics Reasoning Test (CRT). We chose these specific topics because they represent core foundational skills requiring algebraic fluency and logical reasoning, respectively, which are well-established benchmarks for testing both procedural and conceptual mathematical abilities (15). We designed both tests specifically for this study to align with the six-week curriculum, and each consisted of 20 points in total across 15 multiple-choice and 5 open-ended questions; we administered them within an assessment plan that also included a diagnostic readiness test, formative quizzes, and a mathematics attitude survey (**Figure 1**). Descriptive statistics indicated that both instructional groups began the program with comparable levels of prior knowledge in both mathematical domains, as reflected by similar pre-test means (representing the average total points scored out of 20) for the LET and the CRT (**Figure 2**). Overall, students in both groups entered the program with similar baseline academic profiles.

Following instruction, which lasted for a duration of six weeks, clear differences emerged between the two groups on the post-tests that we administered at the end of week six. On the LET, students in the discovery-based group ($n = 20$) improved from a pre-test mean of 11.9 ($SD = 2.4$) to a post-test mean of 17.2 ($SD = 1.6$), while students in the traditional group ($n = 20$) showed a more modest improvement, from a pre-test mean of 11.7 ($SD = 2.1$) to a post-test mean of 14.6

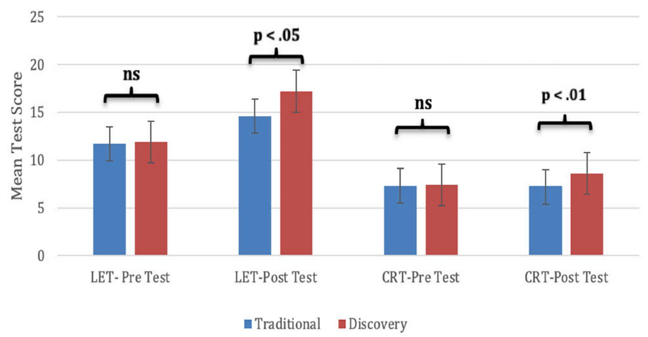


**Figure 2. Mean pre- and post-test scores on the Linear Equations Test (LET) and Combinatorics Reasoning Test (CRT) by instructional group.** Bar graph showing mean scores for traditional and discovery-based groups before and after instruction (n = 20 per group). Error bars represent standard deviations. Comparisons between the two groups are marked above the bars, where ns indicates a non-significant difference. ANCOVA controlling for pre-test scores showed significant instructional effects for linear equations ($p < 0.05$) and combinatorics ($p < 0.01$).

(SD = 1.9) (**Figure 2**). To test whether this difference between the groups was statistically significant while accounting for the differences already present before instruction, we compared post-test scores using an analysis of covariance (ANCOVA), with pre-test scores included as a covariate. Instructional method had a significant effect on LET scores ($F(1, 37) = 6.5$, $p < 0.05$, partial eta squared ($\eta^2$) = 0.15).

A similar pattern emerged for the CRT. The discovery-based group's mean score increased from 7.4 (SD = 1.2) on the pre-test to 8.6 (SD = 0.9) on the post-test, whereas the traditional group's performance remained relatively stable, changing slightly from 7.3 (SD = 1.3) to 7.2 (SD = 1.1) (**Figure 2**). The ANCOVA again revealed a significant effect of instructional method ($F(1, 37) = 9.1$, $p < 0.01$, partial $\eta^2 = 0.19$).

### Attitudes Toward Mathematics

To investigate whether the instructional method influenced students' attitudes toward mathematics, we examined changes in motivation, enjoyment, and self-efficacy using data from the Math Attitudes Survey (MAS) and weekly observation rubrics. The MAS is an 18-item survey we designed for this study, in which students rate their agreement on a 5-point Likert scale ranging from strongly disagree to strongly agree. We tracked motivation scores at four time points (Weeks 0, 2, 4, and 6) using this five-point scale. At the beginning of the program, students in the discovery-based group reported slightly lower average motivation (mean = 1.2) than students in the traditional group (mean = 1.5), a small difference on this five-point scale. Over time, however, the two groups followed different trajectories. Motivation scores in the discovery-based group increased steadily across the instructional period, reaching a mean of 4.0 by Week 6. Motivation scores in the traditional group rose between Weeks 0 and 2 and then changed little for the remainder of the program, ending at a mean of 2.6 at Week 6 (**Figure 3**). In short, students in the discovery-based group experienced a continuous positive shift in motivation, while motivation in the traditional group remained relatively stable after Week 2. To compare the two groups across these related attitudinal outcomes at the same time, we conducted a multivariate analysis of variance (MANOVA) with motivation, enjoyment, and self-efficacy as dependent variables, which revealed a significant overall effect of instructional method (Wilks' $\Lambda = 0.78$, $p < 0.05$). Follow-up univariate analyses showed that students in the discovery-based group scored significantly higher than students in the traditional group on motivation, enjoyment, and self-efficacy, with self-efficacy showing a large effect size ($\eta^2 = 0.18$).

### Classroom Observation Outcomes

We analyzed classroom observation data to document differences in student engagement and interaction patterns between instructional groups. The instructor who taught both groups recorded three behavioral indicators during each session using the weekly observation rubrics described in the Materials and Methods section: the average number of peer-to-peer explanations per 10-minute interval, the percentage of students demonstrating high persistence after initial errors, and the proportion of peer-first help requests. Students in the discovery-based group gave significantly more peer-to-peer explanations (mean = 6.8 per 10-minute interval) than students in the traditional group (mean = 2.1; $t(38) = 5.42$, $p < 0.001$) (**Table 1**). In addition, a significantly greater proportion of students in the discovery-based group demonstrated high persistence following initial errors (78%) compared to students in the traditional group (41%) ($\chi^2(1) = 5.64$, $p < 0.05$). We also observed a difference in help-seeking behavior, with peer-first help requests occurring more frequently in the discovery-based group (62%) than in the traditional group (15%) ($\chi^2(1) = 9.38$, $p < 0.01$).

## DISCUSSION

This study aimed to assess the comparative effects of traditional direct instruction and discovery-based instruction on secondary-level students' mathematical achievement and attitude in a short-term, online learning environment. We hypothesized that students taught through discovery-based instruction would achieve higher mathematics scores and report more positive attitudes towards mathematics than students taught through traditional direct instruction. The results of the study show that students who experienced discovery-based instruction achieved higher scores on measures of academic achievement and reported more positive attitudes toward mathematics than those who experienced traditional instruction. These results support that hypothesis. Overall, the results suggest that learning mathematics as a cooperative, exploratory activity, as opposed to learning mathematics in a more conventional lecture style, can be beneficial for both achievement and attitude. Students who experienced the discovery-based instruction achieved significantly higher scores on both the LET and the CRT than those who experienced traditional instruction. In addition, students in the discovery-based group made larger gains on the conceptual measure, highlighting the value of inquiry-driven methods over rote memorization.

These findings are similar to those of a controlled experimental study that investigated the effect of discovery learning and differentiated instruction on the mathematical achievement and attitudes of high school students (16). The findings of the study showed that the discovery-based group performed better than the traditional group in the areas of problem-solving and motivation. Alignment with that study is meaningful; although that study took place in a traditional

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face-to-face classroom with eleventh-grade students, who were older than the 12- to 13-year-old students of the current study, the findings support the conclusion of the current study that discovery-based learning is effective in the cognitive and motivational aspects of mathematics learning, even in a short-term, online learning environment.

We observed significant changes in students' level of motivation and attitudes towards mathematics during the six-week period. Initially, students in the discovery-based group reported slightly lower baseline motivation compared to students in the traditional group. As students in the discovery-based group became more engrossed in problem-solving activities, their level of motivation increased over time, surpassing that of students in the traditional group by the end of the intervention. According to the teacher, students learned combinatorics concepts on their own by discovering mathematical principles independently, with motivation coming from the joy of discovery. In contrast, students in the traditional group showed only a slight improvement in their level of motivation throughout the program. This pattern suggests that the repetitive nature of traditional instruction did not sustain motivation to the same extent as the discovery-based approach, although our data do not identify the reason for this difference.

The observation rubrics provided qualitative information that complemented the test scores. Students in the discovery-based group gave substantially more peer-to-peer explanations than students in the traditional group, which indicates that they were more engaged in peer-to-peer discourse. Furthermore, persistence ratings – defined as the percentage of students demonstrating continued effort after making initial errors – also improved significantly in the discovery-based group throughout the program. In contrast, persistence in the traditional group remained unchanged. Both groups worked on problems of comparable difficulty, so this difference is unlikely to reflect the problems themselves. A more likely explanation is that the discovery-based group had to search for a solution before receiving one, so an initial error was a normal step in the task rather than a sign of failure, and they had peers to consult while working through it. In addition, whereas students in the discovery-based group used peers as sources of support significantly more often when faced with challenging problems, students in the traditional group mainly relied on teacher explanations, implying that they had less confidence in their own ability, and in their peers' ability, to work through problems without the teacher.

The findings of the current study also yield several implications for teaching practice, especially in the context of online or hybrid learning settings. The current findings extend the existing literature on discovery-based learning to the domain of short-term online mathematics education programs (14). The integration of discovery-based learning activities, such as the use of thought-provoking problems at the beginning of lessons and the use of exploratory processes with the help of guiding prompts, could prove beneficial in increasing students' engagement without sacrificing the rigor of the learning process. Teachers can use aspects of discovery-based learning strategically alongside direct instruction rather than replacing it completely. For instance, educators can use discovery-based tasks to introduce new, complex concepts that require deep conceptual thinking, while reserving direct instruction for procedural skill-building or reviewing standardized definitions. This hybrid approach allows students to build ownership of their learning while ensuring core competencies are efficiently covered. Additionally, textbook authors could place these fundamental questions at the beginning of lessons in the official textbooks that teachers use. Teacher training programs could also prepare teachers to run lessons through discovery-based learning, giving students hints so that they can discover the solution, or the proof of a problem, for themselves.

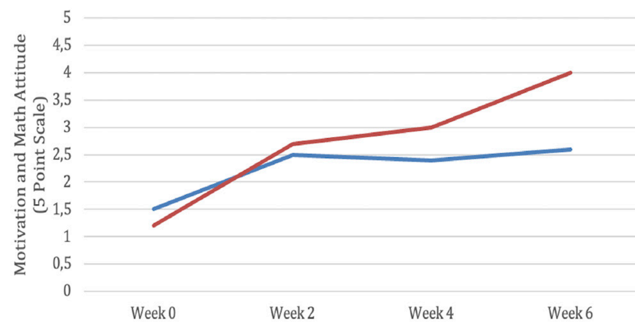


**Figure 3. Changes in students' motivation scores across the six-week instructional period by instructional group.** Line graph showing mean motivation scores on a five-point scale at Weeks 0, 2, 4, and 6 for traditional and discovery-based groups (n = 20 per group). MANOVA indicated a significant overall effect of instructional method ($p < 0.05$).

We should take certain limitations of the current study into account when generalizing these findings. The current study was limited by its small sample size, comprising only 40 students, and by the short period of the intervention, spanning only six weeks. Additionally, we recruited high-achieving students from an extracurricular mathematics enrichment program, so the participants had similar, elevated academic and socioeconomic profiles. This demographic may not accurately reflect a typical, diverse public school classroom where students have varying levels of baseline mathematical proficiency and motivation. Consequently, our findings may over-represent students who are already predisposed to academic persistence. The intervention was also implemented in the context of a fully online enrichment program. In addition, the same instructor who delivered the lessons also completed the observation rubrics, so observer expectations may have influenced the observational findings. Future studies could examine discovery-based learning in a wide range of age groups, mathematical topics, and learning settings, specifically incorporating geographically and socioeconomically diverse samples in standard classroom environments. Future research should also explore the long-term implications of discovery-based learning to determine if these initial motivational and academic gains are sustained over an entire academic year.

In conclusion, the findings of the current study suggest that discovery-based learning can be used to elevate the academic achievement and the development of more positive attitudes towards mathematics in secondary school students participating in online learning settings. Discovery-based learning enables students to explore the learning material and work collaboratively with peers, resulting in a better understanding of the material, increased perseverance, and greater motivation towards learning. Further studies

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| Activity | Traditional | Discovery |
|---|---|---|
| Peer explanations (per 10 min) | 2.1 | 6.8 |
| High persistence (% of students) | 41% | 78% |
| Peer-first help requests (% of requests) | 15% | 62% |

**Table 1. Classroom observation outcomes comparing student engagement behaviors across instructional groups.** Weekly observation data summarizing peer explanations, persistence after errors, and peer-first help requests for traditional and discovery-based groups.

are necessary to examine the generalizability of the current findings; however, they support the potential of discovery-based learning in yielding significant advantages over the traditional approach, ultimately offering a valuable pedagogical tool to combat declining mathematics engagement and foster a generation of confident, independent problem-solvers.

## MATERIALS AND METHODS

### Participants

The study had 40 participants, all seventh-grade students (20 female and 20 male), who were enrolled in an after-school math enrichment program. The participants were from various schools across Turkiye and had comparable academic and socioeconomic characteristics, representing middle-to-high income backgrounds and high academic standing due to their enrollment in an elite competitive platform (17). The participants were between 12 and 13 years of age. Informed consent from the participants and permission from the participants' parents were obtained through a mandatory agreement checkbox when participants registered online. The study protocol was formally reviewed and approved by the institutional ethics review board in accordance with guidelines for research involving human subjects. The participants were recruited through a math education platform, eCompass (17). The platform is specialized in training students for national and international math Olympiad contests, which inherently attracts highly motivated, high-achieving students. In each group, traditional and discovery-based, there were 10 female and 10 male participants, ensuring a fair gender representation. All participants were selected based on academic and math proficiencies, specifically their performance on the platform's initial screening test, ensuring that both groups possessed nearly identical baseline mathematical competence; this high-proficiency sampling minimized internal variance but limited generalizability to standard, mixed-ability classrooms. To mitigate potential recruitment bias, participants were randomly assigned to their respective groups using a computer-generated sequence. To ensure a fair comparison of the effect of the two methods on different types of content, the two groups were instructed on the same two topics: linear equations and combinatorics (permutations, combinations, and the multiplication principle). To reduce the effect of instructor-related variables and to increase the validity of the study, the same instructor taught both groups. The discovery-based group was instructed using questioning methods, while the traditional group received direct instruction on the two topics. The instructor possessed over five years of experience in advanced mathematics coaching and underwent rigorous standardization training in both direct instruction and guided discovery methods to eliminate bias in delivery.

### Settings

The study was conducted online through virtual classrooms that hosted 20 participants each through Google Classroom. The participants were from various locations across Turkiye but the majority were from Istanbul. Despite the difference in instructional style, the two groups received the same amount of instruction (90 minutes per class, twice a week, over a period of six weeks).

### Study Design

An experimental pre-test/post-test control group design was used. The two groups received the same amount of instruction to isolate the effect of instruction.

### Materials

In order to achieve a full and multi-dimensional evaluation of learning progress and perception, a number of assessment tools were created to measure cognitive, behavioral, and affective outcomes. An assessment scheme was created to be carried out before, during, and after the instructional process (**Figure 1**). A 12-item Diagnostic Readiness Test was created to assess the students' prior knowledge and misconceptions on linear equations and combinatorics. Formative assessment tools included short quizzes (5-6 items) to assess concept retention and fluency, which were utilized strictly for immediate pedagogical adjustments and student feedback rather than formal outcome data analysis. Moreover, a set of peer evaluation questions was created for the discovery-based group. Additionally, a set of classroom observation rubrics was created to assess the behavior of the students, such as collaboration, verbal reasoning, persistence, and help-seeking, using a three-point scale (low, moderate, high).

The summative assessment tools included the LET and the CRT, which consisted of a total of 20 items, 15 multiple-choice and 5 open-ended questions. These tests aimed to assess both conceptual and procedural knowledge. The open-ended questions were scored using a standardized rubric. The affective outcomes were measured using the MAS, which was a Likert-type, scale-based survey with 18 items designed to measure motivation, enjoyment, and self-efficacy (Cronbach's $\alpha = 0.87$). A sample of the assessment instruments is presented in Appendix A, and the full versions are available upon request.

### Procedure

The execution of the proposed instructional and assessment plan was divided into three distinct periods, i.e., before, during, and after the educational intervention (**Figure 1**). In the pre-education period, the students underwent the Diagnostic Readiness Test, which was a non-graded test aimed at evaluating the existing knowledge base of linear equations and combinatorics. This was followed by the LET and the CRT as a pre-test, along with the MAS to measure the initial affective profile at the beginning of the program. Following this, the students were assigned to the traditional and discovery-based groups using the computer-generated random sequence described above. Within a period of six weeks, the students of both groups received online lessons through Google Classroom. The internal validity of the experiment was improved by having the same instructor for both groups. The students of the discovery-based group received instruction through guided questioning, whereas the students of the traditional group received direct instruction on the same topic. Each lesson was 90 minutes long and was held twice a week. Quizzes were administered biweekly to evaluate the students' continuous understanding of the material, and peer feedback was also included within the discovery-based group to increase metacognitive engagement. Furthermore, the same instructor used a standardized observation rubric during each lesson to record the classroom behavior and interaction of the students; no additional observer was present in the online classrooms. In the final week, the students of both groups completed the LET, the CRT, and the MAS as post-tests.

### Data Analysis

To achieve these objectives, statistical tests were performed using IBM SPSS Statistics (SPSS), a commonly used data processing and statistical analysis program in the social sciences (18). For assessing the effects of instructional methods on academic performance, ANCOVA was used (19). This method measured the effect of instruction while controlling for pre-test score differences, thus allowing for more accurate estimation of the instructional effect while controlling for initial group disparities.

To assess changes in multiple attitudinal factors, such as motivation, enjoyment, and self-efficacy, MANOVA was used. This method assessed changes in multiple dependent measures simultaneously, allowing researchers to test whether overall patterns of attitude change were significant between groups, particularly when multiple dependent measures were correlated, thereby reducing Type I error rates (20).

The mixed-methods design, therefore, provided a comprehensive overview of the effects of instructional design on not only academic performance but also on student experiences in an online environment. For reporting results, effect size was used, specifically partial $\eta^2$, where specific thresholds were set for small, medium, and large effects, respectively, as $\eta^2 = 0.01$, $\eta^2 = 0.06$, and $\eta^2 = 0.14$, based on Cohen's guidelines (21). For assessing statistical significance, two-tailed p-values were used, where results were considered significant at $p < 0.05$.

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