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FROM THE EDITOR

It is with great pleasure that we present to you Volume 19, Issue 1 (June 2025) of the *Necatibey Faculty of Education Electronic Journal of Science and Mathematics Education*. This issue brings together a diverse and rich collection of twelve research articles that reflect current trends, innovations, and scholarly discussions in the fields of science and mathematics education.

The articles published in this issue address a wide spectrum of topics, including Cognitive Theory of Multimedia Learning, the integration of technology such as Arduino and Algodoo in mechanics teaching, the role of children's literature in mathematics, metacognitive strategies, argumentation-based teaching, mathematical modeling, and the use of artificial intelligence in STEM education. Several studies focus on special student populations, including gifted learners, and explore how educational methods influence conceptual understanding and creativity.

Also, this issue features studies that originated from the 16th National Science and Mathematics Education Congress, demonstrating the importance of academic conferences in fostering high-quality research and collaboration in the field. The inclusion of these articles further enhances the academic depth and diversity of the journal.

We believe that the wide range of methodologies and contexts represented in this issue will contribute significantly to both academic and practical discourses in science and mathematics education. We extend our sincere gratitude to all authors who submitted their valuable work, to our dedicated reviewers for their careful evaluations, and to the editorial team for their continuous support and commitment to academic excellence.

We hope this issue will serve as a valuable resource for researchers, educators, and students, and we look forward to continued engagement with the scientific community in future issues.

Sincerely,

Editor

Dr. Mustafa ÇORAMIK

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Research Article

Multimedia Principles Rubric: A New Instrument to Filter Instructional Science Videos Based on the Cognitive Theory of Multimedia Learning*

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Abstract – Today's learners simply resort to the Internet to research and meet their learning needs, especially videos. Most such resources are unsupervised and of poor quality. However, there is a lack of instruments in the literature to measure the instructional quality of such widely available videos. Moreover, cognitive aspects are frequently overlooked when judging such content. In this study, an instrument called multimedia principles rubric (MPR) was developed after consultation with experts and evaluated to fill this gap. MPR consists of 16 principles based on Mayer's cognitive theory of multimedia learning (CTML) and has been fine-tuned through a literature review. Descriptive items of MPR are organized according to a 5-point Likert scale and produce an overall mean cognitive value score. MPR was tested by multiple raters on 90 sample physics videos that were selected through cluster sampling and found to have good interrater reliability. MPR can assist its users, especially teachers, in filtering videos in light of CTML rather than relying solely on statistical indicators such as video ratings or number of views. MPR is also beneficial for identifying gaps in educational content and recommending solutions for content producers to implement.

Keywords: Design principles, instructional video, multimedia, rubric, physics.

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*This paper has been derived from the first author's master thesis titled "Analyzing physics instructional videos on YouTube with respect to the cognitive theory of multimedia learning" submitted to the Department of Educational Technology in Bahçeşehir University.

Introduction

Instructional videos have become increasingly significant in education, especially in the recent new educational transition. Videos have been shown to be efficient educational resources for grabbing students' attention and allowing teachers to deliver personalized learning opportunities (Wang et al., 2016). In terms of theories on cognition, studies on multimedia for learning such as AlShaikh et al.'s (2024) aid in determining ways to plan and enhance utilization of videos in teaching and learning. Almost all studies of this sort, on the other hand, have researchers who produce their specific videos and utilize the videos purely towards their own interests, with background, subject matter, subjects, and even teachers monitored and research elements being overseen to the greatest extent feasible. On the contrary, in the actual life, learners are increasingly utilizing platforms like YouTube for educational purposes (Khan, 2017), highlighting the need to understand user engagement with online content. Videos are abundant but not always of good educational quality. This has not gotten adequate attention in the literature, and there has not been ample research done specifically for this purpose. For people who are dealing with the influx of materials from the Internet into educational settings, it has become a serious issue that there are not effective screening mechanisms (Bengfort, 2019). Filtration has become one of the most pressing issues in recent years, even though it was not previously as serious (Frick, 2020). Filtering content that is educational in nature becomes increasingly important to ensure that what viewers, or students, watch benefits them. One such filtering technique involves examining and categorizing videos based on product quality or content accuracy. However, some essential parts of this technique may be missing, including the attention to instructional design and pedagogical principles, which have been shown to be closely linked to the cognitive processes required for acquiring and handling new information (Tim Green, 2014).

An instrument can be helpful and is needed to improve the process of filtering the vast quantity of educational videos available on the Internet, especially on YouTube (Shoufan, 2019). Sweller's Cognitive Load Theory (CLT) and Mayer and Moreno's Cognitive Theory of Multimedia Learning (CTML) provide fundamental foundations for envisioning testable strategies for creating and judging instructional videos that produce desired effects. Such theory-based strategies can help understand the potential instructional value of educational videos in trendy video databases such as YouTube. They can improve the way educational videos are evaluated for educational purposes by taking into account not only video production and content quality but also instructional approaches and cognitive characteristics.

Driven by this motive, the current study was carried out to create an instrument to rate the cognitive merit of instructional videos using multimedia design principles as the primary evaluation criteria. It was undertaken in order to assist educationalists as well as learners in overcoming the difficulty of video content filtration, particularly on YouTube, and to assist them in exploring educational videos that can provide fruitful multimedia messages for learning. Accordingly, this study specifically addressed the research question, “What is a holistic rubric grounded on multimedia principles for instructional design to assess educational videos in order to contribute to learning?”

Theoretical Background

Multimedia learning (ML) within the scope of the current study, is the use of both words and pictures to present learning materials (Mayer & Moreno, 1998). Learning in multimedia environments has been the target of many research studies throughout the past decades. Several theories have emerged and been studied to understand how learning occurs in the mind and how multimedia learning can help promote the type of thinking needed in acquiring knowledge. Our study is based on CTML, which is grounded on other ML theories such as *Dual Coding Theory* (Paivio, 1978), *CLT* (Sweller, 1988) and *Generative Learning Theory* (Wittrock & Farley, 1989). CTML argues that in ML environments the mind is involved in five central cognitive processes that explain how the auditory and visual inputs are processed (Mayer, 2014b). The first two processes are *word selection* and *image selection* where learners pay attention to specific words or visuals from multimedia inputs, resulting in the creation of sounds or images in the working memory. Subsequent processes are *word* and *image organization* where the learner’s mind focuses on discovering associations between the selected words or images to relate them to each other in the working memory to form a logical verbal or visual model mentally, respectively. The final process is *integrating representations* which refers to the learner’s process of linking and making sense of information. CTML, thus, explains how involving certain cognitive processes enables students achieve beneficial learning from a mixture of text and images (Mayer, 2014a, 2014b).

Within the framework of ML, several design principles have been introduced and studied. Following are the names of some of the principles relevant to the current study and investigated by us in the process of creating the new instrument: Principle 1–*Coherence*, 2–*Signaling*, 3–*Redundancy*, 4–*Spatial Contiguity*, 5–*Temporal Contiguity*, 6–*Multimedia*, 7–*Segmenting*, 8–*Pre-Training*, 9–*Modality*, 10–*Personalization*, 11–*Voice*, and Principle 12–*Image*.

In addition to these classical principles, another principle that involves the use of on-screen agent, the same as Principle 12 (Image), has been presented in Mayer's work as Principle 13–*Embodiment.* More instructional and design elements have been evaluated, and relatively more complex principles have been established over the years (Fiorella, 2021), such as Principle 14–*Individual Differences*, 15–*Guided Discovery*, 16–*Worked-Out Examples*, 17–*Collaboration*, 18–*Self-Explanation*, 19–*Animation and Interactivity*, 20–*Site Map*, 21–*Prior Knowledge*, and Principle 22–*Cognitive Aging*.

Mayer et al. (2020) have recently proposed five new principles with the goal of improving the usefulness of instructional videos: Principle 23–*Dynamic Drawing*, 24–*Gaze Guidance*, 25–*Generative Activity*, 26–*Perspective*, and Principle 27–*Subtitle*. Principle 28–*Seductive Details* has also been presented in the same paper, but as something to be avoided.

The main purpose of the multimedia principles generally is to help learners minimize *extraneous cognitive load*, manage *intrinsic cognitive load*, and maximize *germane cognitive load*, which are the types of cognitive loads introduced by Sweller (1988) in CLT. This theory suggests that the working memory can only process a limited amount of information at a time (Leander et al., 2010), and CTML suggests some guidelines that focus on the presentation of information in the form of words and pictures with as much possible consideration of the three cognitive loads as possible.

The current paper is not intended to redesign, redefine, or restate the multimedia design theory nor its principles. Due to space limitations, the reader is kindly advised to consult Mayer's research and books (Mayer, 2014a, 2014b; Mayer & Moreno, 1998), in addition to his recent article with Fiorella, and Stull (Mayer et al., 2020) for the definitions of the principles. The intention here is to focus more on those that apply to video, which are further elaborated in the Method section.

Related Studies

The primary goal of utilizing multimedia in educational settings is to assist students in gaining and constructing knowledge, which necessitates the creation of mental representations from visual and verbal sources of input. Educational videos have to be produced with the intent of boosting relevant mental activity; or else, viewing them might just be an unproductive exercise (Berk, 2009; Brame, 2016; Veritasium, 2014). To investigate this issue more deeply, several research studies have been conducted to study the attributes of effective instructional videos, providing us with diverse lists of video features that are thought to lead to powerful educational tools. Brame (2016) introduced and recommended some useful criteria for creating or selecting videos that achieve desired learning results: cognitive load, learner engagement, and active learning. Moreover, ten Hove and van der Meij (2015) suggested several guidelines to be respected to achieve the same goal: (1) Supporting the learning content with visuals, (2) Relying on narration more than on-screen text to present the learning content, (3) Offering closed captions as an optional feature, (4) Creating videos with high resolution and production quality, (5) Utilizing graphics components that are good in quality, (6) Avoiding any sound that is undesired or interferes with hearing in the background, (7) Providing visually descriptive examples to describe the learning content, (8) Displaying keywords on the screen, (9) Guiding learners' attention by emphasizing essential information on screen, and (10) Providing verbal directions. Furthermore, Berk (2009) stated that effective educational videos often consider common general features: (a) being short in length, preferably less than 3 minutes depending on the nature of content, (b) employing casual language, (c) using visual cues and excluding any irrelevant elements, and (d) being direct and restricting the number of characters. In another study, Kay (2014) classified 16 tested and proven guidelines designed to improve mathematics teaching through worked-example video podcasts into four broad categories: (i) establishing context, (ii) providing effective explanations, (iii) minimizing cognitive load, and (iv) engaging students. He found that paying attention to cognitive features like the segmentation of learning content, use of visuals, and fading out of steps to explain the relevant examples can influence learners positively.

Evidently, many of the guidelines in the literature are focused on the same concepts. Most of them are directly related to the cognitive features covered in the multimedia design principles. Coherence, multimedia, signaling, personalization, voice, and segmenting are some of the most widespread ones (Berk, 2009; Brame, 2016; Shoufan, 2019; ten Hove & van der Meij, 2015).

Most existing research in terms of instrument development did not primarily focus on cognitive learning. Only three studies were found that used an instrument to directly evaluate instructional YouTube videos rather than rating them based on viewer interactions (likes, dislikes, and views). One such instrument was in a thesis conducted by ten Hove (2014) who employed a 36-item questionnaire to assess 75 conceptual and instructional videos. The framework on which the questionnaire was developed had three design levels (physical, cognitive, and effective). The main outcome was a list of common characteristics found in popular instructional videos, which were turned into design guidelines: use different visuals to support the learning, minimize on-screen text by relying more on narration and optional subtitles, have high production quality, use illustrative examples to support the theoretical explanation, and support the learning process by applying various elements (cues, keywords, spoken prompts). Some of these characteristics are closely related to multimedia design principles.

Another instrument, a modified version of the previous one, was developed by ten Hove & van der Meij (2015) in a study comparing popular YouTube instructional videos to non-popular and average ones. They reported characteristics consistent with the aforementioned physical dimension of popular videos: (1) high quality materials, (2) frequent use of static visuals, (3) frequent use of a mixture of static and dynamic visuals, (4) limited on-screen texts, (5) provision of subtitles in various languages, (6) using background music, (7) having less background noise, and (8) applying a faster narration rate.

In their studies, ten Hove (2014) and ten Hove & van der Meij (2015) presented several cognitive features in the instruments, but they did not utilize them to evaluate videos or attempt to link them to learning results (Shoufan, 2019). Nevertheless, there are instructional design strategies in their list of characteristics that would be favored by learners.

Another instrument was created by Shoufan (2019) and tested on a sample of 105 videos of five topics on digital logic design. Shoufan included the multimedia design principles and used them as indicators of video cognitive features. He assumed that cognitive features are binary in nature, so he evaluated the videos using a binary scale (0, 1). He introduced a new factor, "video cognitive value" (VCV), estimated from the interaction features on YouTube videos based on the results of a survey conducted on 428 students. According to Shoufan, learners' likes or dislikes of educational YouTube videos are related to their level of understanding and whether the videos provide them with the needed information or not (Khan, 2017).

A similar approach to the current study was found to be used in an article written by Kuzu et al. (2007). In that study, an instrument was designed based on the CTML to evaluate the quality of visuals in instructional materials. However, it targeted text books instead of videos. According to the authors, the instrument is generalizable by calculating the averages of different types of visuals or pictures presented in text books in terms of each criterion (multimedia design principle: concentrated, concise, correspondent, coherent, comprehensible, and codable). The visuals are examined to get their average scores out of 100, and then classified as "appropriate" (70 to 100), "should be revised" (50 to 70), and "not suitable" (below 50). The average scores are estimated for each criterion and also for the book as a total.

The previous studies give a glimpse of the importance of scientific research in improving the design of instructional videos, thereby, boosting their viability as educational tools (Mayer, 2010). It is how you use a tool in education, not the tool itself, that matters, and mastering the ML theories can have a significant impact on how technology is used in educational settings. Accordingly, educators' main goal should be to support learners in experiencing meaningful thought processes and promote the type of thinking needed for learning (Veritasium, 2014). We aspire to contribute to the solution to this quest by providing a comprehensive rubric for rating educational videos.

Method

Research Design

The core of this study was to develop an instrument, first, by reviewing the previous literature regarding multimedia learning, characteristics of an effective educational/instructional video, and YouTube analysis, then by forming the instrument based on the results and findings reviewed, and finally by collecting data to build on and enhance the use of the new instrument and confirm its application to make it more reliable and generalizable (Creswell, 2005).

Multimedia Principles Rubric (MPR) Design Procedure

After reviewing literature on educational videos and YouTube clips, we found that most instruments and approaches are centered on production quality or content analysis, with the use of different instruments depending on discipline (explored further in the following paragraphs). Only a handful pay attention to instructional and design characteristics that may have an impact on learners' cognitive processing. Accordingly, the instruments found were unsuitable to address the current research question. Therefore, a new instrument called Multimedia Principles Rubric (MPR) was developed (Appendix A) based on the CTML to analyze instructional videos more purposefully. The multimedia design principles were the main themes of the rubric's items, criteria, and scale. In MPR, we refer to the principles as *items* so that it is clear that we are referring to the rubric, not the literature, whenever we mention them.

A relatively relevant instrument is presented in Shoufan's (2019) study by referring to VCV, as introduced earlier in this paper. Although it included a section to address cognitive features, its binary scale is rather narrow, where 1="the video entirely and essentially supports the cognitive feature," and 0="the video does not entirely or essentially support the cognitive feature." This scale was initially tested in the current study, but it turned out that most videos were difficult to evaluate using only two options. Thus, MPR was constructed as a rubric to be more flexible and accurate in detecting gaps in instructional design and presentation of videos.

When developing MPR, we considered the design, implementation, and analysis processes of the instruments of Brame (2016) and ten Hove (2014). We used a five-point Likert scale to rate and classify videos more precisely, where 1="Very poor," 2="Poor," 3="Fair," 4="Good," and 5="Excellent." The *criteria* under each item explain a specific level of agreement with the corresponding concept rather than just simply assessing its presence or absence. Because the criteria are inherently lengthy, we have also created a concise version of the rubric to enhance clarity and usability. This short form, presented in Appendix B, allows for quicker reference and evaluation. As raters become more familiar with the criteria, they may find themselves relying primarily on the short form rather than the detailed version.

The left side of the rubric (Appendices A and B) displays labeled items, with item numbers assigned for identification purposes, without implying any specific order or hierarchy of importance. There is no distinction or rating indicating the superiority of one item over another. At the top row, you will find the presentation of the five scale levels mentioned earlier. Under them, the criteria for each item are listed.

It is important to mention that it is not necessary/reasonable for all of the rubric's items to be applicable to each video. There are videos where one or more MPR items may not apply. Such items are not included when determining the mean score for each video in MPR, but they are not missing values either. So, no videos were eliminated during the evaluation in this study. Basically, this is an assumption based on the idea that an instructional video does not have to adhere to all principles to be considered effective. However, when considering them, it has to be done appropriately or it might have no, little, or negative impact on learners. For example, if a video is designed in the Khan-Academy style, with no agent on the screen, then Principle 13 (embodiment I13) does not apply and will be classified as 'Not Applicable' (N/A) rather than 'Very Poor' (1), yet this does not negate the video's cognitive impact. However, if an animated video with an on-screen character fails to address Principle 13, then the cognitive impact on learners will be impaired (Fiorella & Mayer, 2018), corresponding to a lower cognitive value for the video.

Moreover, despite our conviction that each design principle's contribution to the overall cognitive impact on learners should not be equal, the rubric fails to meet this demand. As a result, while the rubric does not account for variances in the weights of distinct multimedia principles, it does give a sense of their individual contribution to the assessment.

Finally, the mean score of MPR can be used as an indicator of cognitive features of examined videos. This value is referred to as mean MPR score (M_{MPR}) throughout this paper. For each video it can be estimated using Equation 1.

$$M_{MPR} = \frac{\text{Summation of MPR item scores}}{\text{Number of items that apply to the video being evaluated}} \tag{1}$$

Equation (2) demonstrates how the width between cut points for M_{MPR} levels is determined:

$$\text{Level Width} = \frac{\text{Range of MPR scale (4)}}{\text{Number of levels (5)}} \tag{2}$$

The range is calculated as the difference between the lowest (1) and highest (5) scores on the five-point Likert scale (Alkharusi, 2022; Pagano, 2013). Using this framework, videos are classified into five cognitive levels: "Very Poor," "Poor," "Fair," "Good," and "Excellent." While these levels align with the MPR rubric's scale, classification is based on calculated M_{MPR} levels as follows:

Very Poor ($1.00 \leq M_{MPR} \leq 1.80$): Low cognitive value.
Poor ($1.80 < M_{MPR} \leq 2.60$): Low-medium cognitive value.
Fair ($2.60 < M_{MPR} \leq 3.40$): Medium cognitive value.
Good ($3.40 < M_{MPR} \leq 4.20$): High-medium cognitive value.
Excellent ($4.20 < M_{MPR} \leq 5.00$): High cognitive value.

This classification was reviewed and approved by the experts (details in the "Expert Review" section).

MPR Items

The MPR items (referred to as I01–I16, i.e., Item01–Item16) were formed based on Principles 1–13, which are known as the classical multimedia design principles, in addition to three new Principles 23, 24, and 27. These items are introduced very briefly below in this section; the reader is invited to review the MPR in Appendix A for a better understanding of the incorporated principles and to refer to Mayer's studies (e.g., Mayer, 2014a, 2014b; Mayer & Moreno, 1998; Mayer et al., 2020) for more detailed descriptions.

***I01**–Coherence*................ : exclude irrelevant and unnecessary material.
***I02**–Signaling*.................. : highlight key aspects and significant information.
***I03**–Redundancy* .... : use narration & graphics, rather than narration, graphics & text altogether.
***I04**–Spatial Contiguity*..... : place relevant on-screen text & visuals near to each other.
***I05**–Temporal Contiguity* : present relevant words & visuals together at the same time.
***I06**–Multimedia* .... : add pictures to words.
***I07**–Segmenting* .... : divide learning content into learner-pace segments rather than one continuous unit.
***I08**–Pre-Training*............. : introduce the main terms & key concepts of leaning content at the beginning.
***I09**–Modality* .... : use narration rather than on-screen text to support the visuals.
***I10**–Personalization*......... : use a conversational tone rather than a formal one.
***I11**–Voice*........................ : use a narration of a clear human voice rather than a robotic one.
***I12**–Image*........................ : having the narrator's image on the screen is not necessarily beneficial to learners.
***I13**–Embodiment*.............. : use an on-screen narrator\character that has a high embodiment.
***I14**–Dynamic Drawing* .... : draw relevant visuals while lecturing rather than pointing to already drawn ones.
***I15**–Gaze Guidance* .... : the on-screen instructor shifts their gaze between the learning materiel and the camera rather than looking constantly at one of them.
***I16**–Subtitle*..................... : provide on-screen subtitles with a slow-paced narration or without a narration.

The conditions, or indicator expressions, specified within each rating level/column were inspired by Mayer's studies on the corresponding principles, except for Principle 27 (I16–subtitle), as it was originally considered for non-native learners (Mayer et al., 2020). The straightforward application of this principle may conflict with Principles 3 and 9 (redundancy and modality, respectively). Therefore, to avoid the possible contradiction and to better generalize to a wider YouTube audience, the corresponding item (I16) was designed as a compromise solution for native and non-native speaker learners. The conditions or *criteria* within each rating level/column of I16 were modified in the current study to consider the three principles cited above, with priority given to Principle 27.

Except for the 16 principles just mentioned, the other multimedia principles were excluded from the scope of this study. For one thing, prior to the development of the MPR, an extensive list of principles was reviewed to select the principles applicable to video as a unit rather than to students in an academic context. Most of the principles eliminated are typically related to learners or learning settings rather than multimedia presentation or design, because assessing them in a video context would be challenging, if not impossible. Therefore, they are better studied in trial research because they involve modifying some factors and introducing learners to a new learning event that necessitates in-class facilitation. Another reason is that multimedia does not refer exclusively to videos; it can also encompass websites and various other media forms. Since this study is on videos, the principles that do not apply to videos were omitted. Other than that, there are several reasons why some of the principles were excluded.

Some were left out since they required direct interaction with students, which was not addressed in this research. An example is Principle 17 (collaboration), which suggests that collaborative online activities are an effective way for teachers to achieve the best outcome. This principle has specific considerations and "must-follow" guidelines such as selecting a suitable task, creating a communicative learning environment, and having teachers fulfill their responsibilities correctly. All those and more should be taken into account, or the collaborative activities may have the opposite effect (Mayer, 2014b). Principles 14, 18, 21, and 22 were excluded for the same or similar reasons.

Some principles were complicated in comparison to the classical ones, making them unsuitable for use in the same instrument. Such principles appear to have been created in a context-specific fashion, as they include more conditions and have some strict boundaries. In Principle 16 (worked-out examples), for example, Mayer (2014b) highlighted five strict criteria important for its implementation in a context of multimedia learning. For this reason, it was decided to exclude this principle even though it is important particularly in science education. The same was true for Principles 15 and 25.

Some principles were left out since they only apply to certain types of videos. For example, while being a principle that directly concerns a form of instructional video, Principle 19 (animation and interactivity) was dropped since it is confined to animated videos and includes some criteria that cannot be overlooked. Similarly, Principle 26 (perspective) is best applicable to experimental videos that show how to do certain things; hence it was omitted.

In the context of this study, Principle 28 (seductive details) was found to be almost identical to Principle 1 (coherence) in terms of cognitive features, so it was not covered in the rubric. Principle 20 (site map) was not included, either, because it works exclusively on sites with hypertext.

Instrument Validity and Reliability

To achieve acceptable levels of reliability and validity, this paper describes the important parts of the development process of MPR in detail throughout the paper to signify its reliability (Creswell, 2005). Other than that, experts in the field of instructional technology were involved throughout the different stages to establish validity (Creswell, 2005). Additionally, the rubric's interrater reliability was examined and reported (Creswell, 2005). And finally, concurrent validity was sought by comparing the rubric with a comparable index (Fraenkel et al., 2011).

Expert Review

The initial version of MPR was reviewed by four experts to confirm its validity: an expert on instructional design and technology with 9 years of experience, two experts on instructional systems technology with 4 and 13 years of experience, and an expert on computer education and instructional technology with 9 years of experience.

The experts revised the instrument and provided significant feedback regarding the items, levels, overall design, and application. Feedback was discussed in meetings lasting between one and two hours, and on some occasions up to three hours, before the content validity of MPR was approved. They were involved at various stages. One of the experts helped to improve the rubric from the early stages, giving feedback on which principles to include or exclude. He had some minor wording recommendations regarding the personalization, voice, and image principles that were incorporated into the rubric, and some initial criticism regarding the presence of possible cases. After negotiations, it was agreed that the possible cases were necessary to cover the variety of instructional videos, but they were improved in terms of expression. After this, the MPR had 16 items and was shared with the other three experts. One's feedback focused on the harmony of the rubric and the proper way to design a rubric as a pedagogical tool. A third expert mentioned that the coherence item was the most problematic due to its overlaps with other items, so it had to be improved until the expert was satisfied with the final version, which was achieved by trying and rethinking it on different types of videos and considering the most common cases to include. The final expert provided feedback on the wording and length, helping improve the accuracy, conciseness, and scope of the rubric. He also provided feedback on the image and subtitle principles as well as the way the possible cases appeared on the rubric and the overall design of MPR. Overall, the coherence, image, and subtitle principles received the most critical discussion from the experts. After incorporating their recommendations, the final version of the MPR (Appendix A) was used to score the 90 videos included in this study.

Interrater Reliability

To establish the interrater reliability of MPR, an intraclass correlation coefficient (ICC) analysis was conducted. Two raters, each possessing expertise in physics as physics teachers, independently evaluated a set of 90 physics videos retrieved from the YouTube platform. These videos were selected using a cluster sampling approach: 5 physics topics (e.g., "Work and Energy") were chosen as search keywords, and for each topic, 6 videos were selected across 3 length categories (short: under 3 minutes (Berk, 2009); medium: 3-6 minutes; long: 6-20 minutes (Knott, 2020)). This resulted in a total of 5 topics × 3 lengths × 6 videos = 90 videos, ensuring a balanced representation of topics and video lengths. The raters were chosen based on their familiarity with the video content and proficiency in English, as the evaluation rubric was composed in English. To minimize the influence of personalized search algorithms, an incognito browser window was used during the video selection process.

Prior to the evaluation, raters received basic instructions from one of the researchers, including both the application of the MPR rubric and a general overview of multimedia learning principles. Raters then simultaneously, but independently, viewed and evaluated the videos. Each video was assessed item-by-item using the MPR. Raters were instructed to refrain from discussing their ratings with one another during the evaluation process. Each rater submitted their scores independently upon completion of their review of all videos.

The SPSS file contained two columns, each representing the ratings of a different rater. Each video received 16 ratings, corresponding to the 16 MPR items listed in rows. Interrater reliability was assessed using a two-way random effects ICC with absolute agreement and average measures in SPSS. This model was chosen to allow for generalization to a wider population of raters with similar expertise. The results of the ICC analysis indicated a strong level of agreement among the two raters (ICC = 0.88, 95% CI [0.853, 0.902]), suggesting high interrater reliability for MPR (Koo & Li, 2016).

Following the evaluation of videos, raters provided qualitative feedback regarding the MPR. A recurring concern was the potential for confusion between items I12 (Image Principle) and I13 (Embodiment Principle). Initially, raters perceived the two principles as interchangeable, with some suggesting that the Image Principle might be redundant since the Embodiment Principle appeared to cover similar ground in a more holistic manner. Both principles involve the presence of an instructor or on-screen agent, which contributed to this confusion. However, after clarifying the distinctions—where the Image Principle evaluates whether the instructor's image is shown and its purpose, and the Embodiment Principle assesses the instructor's use of gestures, expressions, and movements to enhance engagement—raters recognized the unique importance of each principle.

To address this issue, raters were provided with a clear example: in a Khan Academy-style video where only the content is displayed and the instructor's face is absent, the Image Principle would be rated highly, while the Embodiment Principle would be non-applicable. Over time, with repeated use of the rubric, raters became more adept at distinguishing between the two principles, leading them to revisit their previous ratings to ensure accuracy and consistency. The raters also noted that the detailed levels and descriptors for each rubric item helped them better understand and check the corresponding principles.

Furthermore, raters noted that accurate evaluation of certain items, particularly I01 (Coherence), may necessitate subject matter expertise like theirs. Despite these concerns, raters generally expressed positive feedback regarding the rubric's usability, noting that it facilitated a more structured and confident evaluation process, particularly given the diversity of video content encountered. While raters found the rubric to be somewhat verbose, they acknowledged that the level of detail was necessary to adequately address the wide range of video characteristics observed.

Findings

The final version of the MPR is presented in Appendix A, with its short form in Appendix B. Each of the 16 MPR items has a five-level description of what may be expected from a video's instructional quality and content. A YouTube video, "Work and Energy" by

"Professor Dave Explains," was rated using MPR as an example. The results are illustrated in Table 1.

Table 1 An Example Evaluation of the Video "Work and Energy" Using MPR

MPR Items		Example video 1	
		Score	Rating
I01	Coherence	5	Excellent
I02	Signaling	5	Excellent
I03	Redundancy	4	Good
I04	Spatial contiguity	5	Excellent
I05	Temporal contiguity	5	Excellent
I06	Multimedia	5	Excellent
I07	Segmenting	5	Excellent
I08	Pre-training	5	Excellent
I09	Modality	5	Excellent
I10	Personalization	4	Good
I11	Voice	5	Excellent
I12	Image	1	Very Poor
I13	Embodiment	2	Poor
I14	Dynamic drawing	2	Poor
I15	Gaze guidance	1	Very Poor
I16	Subtitle	5	Excellent
	Total	64 (n=16)[a]	

[a]n denotes the frequency of MPR items that apply to the video

M_{MPR} for this particular video was found to be 4.00. In Table 1, n denotes the frequency of MPR items that apply to the video.

Although it is difficult to demonstrate in a paper how the videos were reviewed without playing them, Figure 1 and Figure 2 provide screen captures of the reviewed YouTube video to demonstrate the existence of cognitive features to the greatest extent possible.

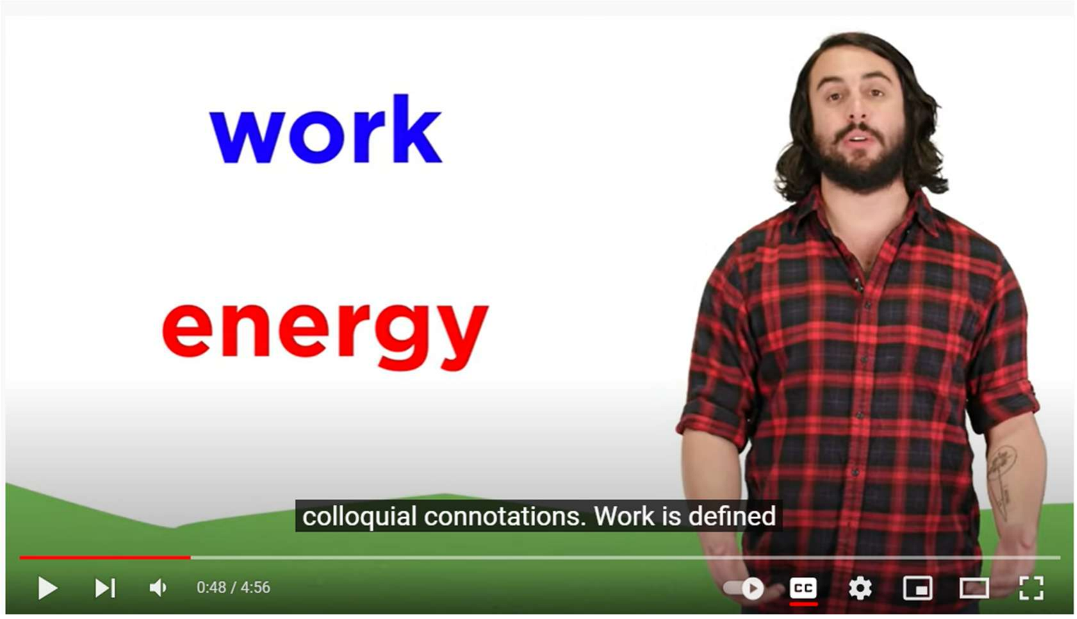

Figure 1 A Screenshot from the Reviewed Video "Work and Energy" Demonstrating Coherence (I01), Signaling (I02), Redundancy (I03), Personalization (I10), Image (I12), and Subtitle (I16) in MPR

Figure 2 A Screenshot from the Reviewed Video "Work and Energy" Demonstrating Multimedia (I06), Embodiment (I13), Dynamic Drawing (I14), and Gaze Guidance (I15) in MPR

Figure 1 presents an idea of the effectiveness of some items such as, coherence (I01), signaling (I02), redundancy (I03), personalization (I10), image (I12), and subtitle (I16). Figure 2 is a screenshot from the same video displaying multimedia (I06), embodiment (I13), dynamic drawing (I14), and gaze guidance (I15).

Discussion

MPR utilizes 16 principles of multimedia design as a rubric to assist educators in choosing the most useful videos as instructional tools out of the numerous available on the Internet, all based on CTML. If used suitably, those principles are thought to yield effective results; nevertheless, "the cognitive theory of multimedia learning is dynamic. Therefore, the twelve principles should not be taken as a rigid canon, but rather a starting point for discussion" (Sorden, 2013, p. 159). Thus, this rubric was developed and should also be regarded as a dynamic scale. Its items and criteria can be enhanced. It is possible to incorporate more items and criteria into it, but this will likely render it more complex, and verbose, which are typical shortcomings of rubrics, making them less useful.

MPR paves the way for the quantitative examination of cognitive features of instructional videos (i.e., various statistical tests may be run on them), while the full description at each level allows for the qualitative understanding of the same features.

MPR is a comprehensive and useful instrument, but it may not be useful to just anybody as some items require being a subject matter expert (SME) at least to some extent. For example, since deciding whether elements in a video are relevant or not can be done by those who know the learning content, it is suggested that the coherence principle (I01) is evaluated by SMEs. Because teachers are SMEs of their own disciplines, they should easily be able to benefit from MPR.

Segmenting suggests that multimedia-supported materials give learners a certain level of control over the instructional unit (Mayer, 2014b). Therefore, an instructional video should be well-structured. It should have distinct learner-paced pieces as well as options for speed control, volume adjustment, playing/replaying/stopping/pausing, and back and forth skipping. Because YouTube provides such options at present, this criterion was disregarded in MPR, but it should be checked in other video sources.

It is probable that the "accent" aspect of the voice principle (I11) is valid only for native learners watching a video in their own language narrated by a non-native speaker. So, if the narrator of a video has a heavy Chinese accent, for instance, Chinese audience are unlikely to be upset by the narration, at least not to the same extent as native speakers or even other non-native speakers. It is crucial to note that this is only a supposition intended to explain why certain videos that contravene the principle of voice in terms of accent are popular. So, more research is necessary to confirm or refute this supposition. One other factor to bear in mind about the voice principle is that at level 1, "very poor," the first criterion is sufficient to specify whether a video falls into this category/level. At upper levels, however, it is essential to seek out all criteria.

Image (I12) refers to all forms of narrators that appear on screen, not just characters called talking heads, as is usually assumed. Although studies disagree on this principle, still images, talking heads, or character animations are all valid, Mayer (2014b) claims. Nevertheless, in order to truly comprehend and implement this principle, it is necessary to recognize its relationship with embodiment (I13). The majority of the favorable image principle results (presenting effect sizes that are medium or high) were linked to an agent or a drawn character who exhibited a significant level of embodiment, interacting with the viewer to the greatest extent possible through gaze, directing attention, gestures mimicking humans, facial expressions, and motion. If these features are not available, having no character in the video is more effective. This requirement was included in the relevant MPR items because it is considered a major criterion regarding the image principle (Mayer, 2014b). The image principle (I12) was also reported by the raters to be somewhat harder to judge at least at the beginning of their use of MPR.

Gaze guidance as a principle (I15) was initially developed as a result of research on lesson videos with a teacher on the screen. In this respect, eye contact and gaze shifting via the camera are accounted for between the teacher and students. However, when testing YouTube videos, particularly the ones with character animation, such gaze guidance was found to be non-applicable. According to Mayer et al. (2020), the key social premise emphasized by this principle is eye contact — not the agent — which assists viewers in establishing a partnership with the teacher and can be true for any on-screen agent. Therefore, based on theoretical considerations, gaze shifting was counted for any form of on-screen agent in the current study.

As it can be seen in the MPR, the subtitle principle (I16) is based on two criteria: displaying on-screen text as subtitles and delivering narration in a slow way. This principle was created with learners who are learning anything in a language other than their native language in mind. For that reason, for native speakers, its presence may conflict with certain other principles, particularly with redundancy and modality (I03 & I09) (Mayer et al., 2020). Since there can be two kinds of viewers (native and non-native), the rubric incorporated a balanced option that gives priority to second-language learners but still considers native speakers. This was accomplished by reminding the rater to look for the availability of optional subtitles, which second-language viewers can use directly whereas native viewers can switch them off to avoid redundancy. MPR allows a video to be rated 5 “excellent” in terms of subtitles, if it appeals to both kinds of viewers, keeping in mind that the priority is given to the redundancy effect before modality as emphasized by Mayer et al. (2020). The first criterion at *level 5* (I16) is backed by Shoufan’s (2019) findings which suggest that native speakers’ YouTube videos are more likely to be enjoyed by viewers. The second criterion (I16), however, contradicts his findings, which demonstrate that YouTube providers with faster speaking speeds are more likely to be enjoyed by viewers. This was also one of the findings of ten Hove (2014), and ten Hove & van der Meij (2015) as well as Guo et al. (2014), but the latter’s findings were related to videos in MOOCs. More research on this principle is needed to explain the lack of consistency in findings. One argument is that the subtitle principle was considered for non-native learners who may not represent most learners in the videos sampled for the research cited above and particularly that the videos in question may not be videos on science, which amount to Mayer’s main focus. Or, simply put, popularity does not ensure the success of educational videos.

As is known, MPR is an instrument that was tested on a number of YouTube videos, and the main limitation in such samples is the fact that it is not possible to find out who watches them. This complicates the task of selecting appropriate content and design principles, because principles that benefit people with limited knowledge might not benefit people with superior knowledge (Mayer, 2014a). This means that people who design such videos or use them must check the presence of suitable principles and take them into account for certain learners, otherwise their endeavors will be in vain. The stated issue is among the justifications for why certain principles were left out of the rubric since their light application may exacerbate rather than alleviate learning-related struggles.

Shoufan (2019) proposed a video cognitive value (VCV) indicator depending on viewers’ ratings, especially the number of likes, to rate the popularity of YouTube videos. He found cognitive features are partially significant for VCV, but the main reason why people like educational videos is the ability the videos offer for them to understand content. This finding is in line with ours because, as per CTML, a video’s adherence to multimedia and instructional design principles are strongly tied to its content’s understandability. This is why MPR was founded on the multimedia principles as the first consideration. This can be better realized if one recalls that the primary goal of establishment of the principles was to assist learners in taking part in a deep learning experience by handling the cognitive loads theorized in CLT — extraneous, intrinsic, and germane cognitive loads (Mayer, 2014a). Although Shoufan argues that VCV is a suitable instrument for assessing instructional effect on learning, it may not be the greatest technique to assess the cognitive merit of instructional science videos. Techniques that rely on people's self-reports such as likes/dislikes on YouTube and surveys/questionnaires are not necessarily ideal ways to look into learning results. Muller elaborated on this concept in a Ted Talk, using examples and facts to show how learner's pre-knowledge can lead them to believe that they understand the content (TEDTalentSearch, 2012). To overcome this issue, he stated that the way you present content might affect the way viewers watch it and thus the extent to which they come to know, which is precisely what M_{MPR} is intended to convey.

Conclusions and Suggestions

Instruments to measure the instructional quality of widely available videos are lacking in the literature. What is more is that while judging online instructional content, cognitive aspects are frequently overlooked. In this study, the multimedia principles rubric (MPR) was developed and evaluated to fill this gap. MPR can assist its users in filtering videos in the light of CTML rather than solely depending on video ratings or number of views. MPR is also beneficial for identifying instructional content gaps and recommending a certain level of solutions for content producers to implement. The mean value of MPR (M_{MPR}) is proposed to determine the cognitive value of instructional videos. This value offers the potential to investigate variations and relationships among a variety of aspects (such as the learning content, duration, popularity of videos and so on) and how videos impact learning.

We believe the rubric in its current form will be useful to creators and producers of video content, designers of massive open online courses, instructional designers, educators, as well as teachers, by assisting in the filtering and design of more effective multimedia productions that capture the attention of viewers and prolong their engagement in a deeper learning experience. Notably, the rubric is not intended to directly minimize extrinsic load, manage intrinsic load, or maximize relational load; rather, it filters for videos that are designed to address these challenges. In this way, content creators who adhere to the rubric's principles can better overcome these load challenges, and educators who select videos accordingly can more effectively support their students.

Although every attempt was made to construct a comprehensive rubric, it can yet be improved. Further studies would be useful to corroborate and endorse our findings, as well as to enhance MPR. One such study can be on transforming MPR into a survey form that is even more user friendly for instructors who are not much knowledgeable about the multimedia design principles. By analyzing the relationship between M_{MPR} and learner performance, experimental studies might be one other prospective research approach to test MPR's generalizability. Examining the link between M_{MPR} and VCV would also be a worthwhile endeavor. Another possible future study would be to explore how to incorporate the multimedia design elements that have been left out in this study. A final suggestion would be to look into the possibility of improving the rubric using the worked-out examples concept, building on Kay (2014) and Kay & Ruttenberg-Rozen (2020).

Compliance with Ethical Standards

Disclosure of potential conflicts of interest

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CRediT author statement

Fatma Mohamed Taher: Conceptualization, Methodology, Formal Analysis, Writing - Original Draft.

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Research involving Human Participants and/or Animals

This study involves no human participants or animal subjects.

Çoklu Ortam Prensipleri Rubriği: Çoklu Ortamla Bilişsel Öğrenme Kuramına Dayalı Fen Öğretimi Videolarını Filtrelemek İçin Yeni Bir Araç

Özet:

Günümüz öğrencileri, araştırma yapmak ve öğrenme ihtiyaçlarını karşılamak için basitçe internete, özellikle de videolara, başvurmaktadır. Bu tür kaynakların çoğu denetimsiz ve niteliksiz olabilmektedir. Ancak, literatürde bu tür yaygın olarak bulunan videoların öğretim kalitesini ölçen araçların eksik olduğu göze çarpmaktadır. Dahası, bu tür içerikleri değerlendirirken bilişsel yönler sıklıkla göz ardı edilmektedir. Bu çalışmada, uzmanlarla gözden geçirildikten sonra çoklu ortam (multimedya) prensipleri rubriği (MPR) adı verilen bir araç geliştirilmiş ve bu boşluğu doldurmak için değerlendirilmiştir. MPR, Mayer'in Çoklu Ortamla Bilişsel Öğrenme Kuramı'na (CTML) dayanan 16 ilkeden oluşmaktadır ve literatür taraması yoluyla detaylandırılmıştır. MPR'nin tanımlayıcı maddeleri, 5 puanlık bir Likert ölçeğine göre düzenlenmiştir ve genel bir ortalama bilişsel değer puanı üretmektedir. MPR, küme örneklemesiyle seçilen 90 örnek fizik videosu üzerinde birden fazla değerlendirici tarafından test edilmiş ve iyi bir değerlendiriciler-arası güvenilirliğe sahip olduğu bulunmuştur. MPR, kullanıcılarına, özellikle öğretmenlere, yalnızca video derecelendirmeleri veya görüntüleme sayısı gibi istatistiksel göstergelere güvenmek yerine, videoları CTML ışığında filtrelemede yardımcı olabilir. MPR'nin ayrıca eğitim içeriğindeki boşlukları belirlemek ve içerik üreticilerinin uygulayabileceği çözümler önermek için de faydalı olabileceği düşünülmektedir.

Anahtar kelimeler: Tasarım ilkeleri, öğretici video, multimedya, değerlendirme ölçütü, fizik.

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Appendix A

MPR DETAILED FORM

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	VERY POOR 1	POOR 2	FAIR 3	GOOD 4	EXCELLENT 5
I01 COHERENCE	None of the multimedia elements (visuals / text / sounds) in the video are related or essential for the learning content. The video has complex and distracting backgrounds (visuals / sounds).	Most of the multimedia elements (visuals / text / sounds) in the video are not related or essential for the learning content. The video may have complex or distracting backgrounds (visuals / sounds).	Some of the multimedia elements (visuals / text / sounds) in the video are not related or essential for the learning content. The video may have complex or distracting backgrounds (visuals / sounds).	Most of the multimedia elements (visuals / text / sounds) in the video are directly related and essential for the learning content. The video has simple and clear backgrounds (visuals / sounds). **OR** All of the multimedia elements (visuals / text / sounds) in the video are directly related and essential for the learning content. The video has complex or distracting backgrounds (visuals / sounds).	All of the multimedia elements (visuals / text / sounds) in the video are directly related and essential for the learning content. The video has simple and clear backgrounds (visuals / sounds).
I02 SIGNALING	None of the important elements are highlighted in the video's screen. Learners cannot spot the significant information of the learning content. None of the design features are used in the video.	The video highlights few important elements on the screen. The video points out few significant information from the learning content. The keywords are emphasized with a poor choice of features.	The video highlights some of the important elements on the screen. The video points out some of the significant information of the learning content. The keywords are emphasized with a poor choice of features.	The video highlights most of the important elements in the learning content on the screen. The video points out most of the significant information of the learning content. Various cues and features are used properly to emphasize on the keywords (such as: arrows, font, size, color, or spoken emphasize). **OR** The video highlights all of the important elements in the learning content on the screen. The video points out all of the significant information of the learning content. The keywords are emphasized with a poor choice of features.	The video highlights all of the important elements in the learning content on the screen. The video points out all of the significant information of the learning content. Various cues and features are used properly to emphasize on the keywords (such as: arrows, font, size, color, or spoken emphasize).
I03 REDUNDANCY	The narrator of the video reads on-screen text throughout the whole video to explain the visuals. Narration, on-screen text, and visuals all are presented simultaneously throughout the whole video.	The narrator of the video reads on-screen text most of the time to explain the visuals. Narration, on-screen text, and visuals are presented simultaneously throughout most of the video.	The narrator of the video sometimes reads on-screen text to explain the visuals. Narration, on-screen text, and visuals are presented simultaneously throughout some parts of the video.	The narrator of the video rarely reads on-screen text to explain the visuals. Narration, on-screen text, and visuals are rarely presented simultaneously throughout the video.	The video has only narration to explain the visuals (supported by on-screen keywords). Narration, on-screen text, and visuals are not presented simultaneously at all throughout the whole video. **OR** The video has only on-screen text to explain the visuals. Narration, on-screen text, and visuals are not presented simultaneously at all throughout the whole video.
I04 SPATIAL CONTIGUITY	None of the related text & visuals presented in the video are physically close to each other on the screen rather they are separated and presented in different slides (It is hard to know where to look for information in the video).	Most of the related text & visuals presented in the video are not physically close to each other but still appear on the same slide rather than different ones (It is hard to know where to look for information on the screen).	Some of the related text & visuals presented in the video are physically close rather than far from each other on the screen (Text & visuals can be related but not easily).	Most of the related text & visuals presented in the video are physically close rather than far from each other on the screen (text & visuals can easily be related).	All of the related text & visuals presented in the video are physically close rather than far from each other on the screen (text & visuals can easily be related).
I05 TEMPORAL CONTIGUITY	Words (narration / text) & visuals are never presented simultaneously (words are displayed before / after the visuals).	Words (narration / text) & visuals are not presented simultaneously throughout most of the video.	Words (narration / text) & visuals are presented simultaneously rather than successively only throughout some parts of the video.	Words (narration / text) & visuals are presented simultaneously rather than successively throughout most of the video (the video only misses the timing in few times).	Words (narration / text) & visuals are always presented simultaneously rather than successively throughout the whole video.
I06 MULTIMEDIA	The video does not have any visuals to support the words (narration / text) in explaining the learning content, rather, only words are used.	There are few (only one or two) relevant visuals to support the words (narration / text) in explaining the learning content throughout the video (not enough to cover the learning content).	There are some relevant visuals to support the words (narration / text) in explaining the learning content at some parts of the video (still not enough to cover the learning content).	There are relevant visuals to support the words (narration / text) in explaining the learning content throughout most of the video.	There are always relevant visuals to support the words (narration / text) in explaining the learning content throughout the video (enough to cover the learning content).

MPR DETAILED FORM

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	VERY POOR 1	POOR 2	FAIR 3	GOOD 4	EXCELLENT 5
I07 SEGMENTING	The video's pace is too fast for learners to adequately process the information. Too much information and complicated concepts are packed in the video. (Continues unit with a fast pace)	Most of the information in the video is presented at a fast-pace. Most of the learning concepts are packed in the video instead of being segmented.	Some of the information in the video is presented at a learner-pace. Some of learning concepts are divided into smaller segments throughout the video. **OR** The current video is part of a series of related videos that presents some of the information at a learner-pace. Some of the learning concepts are divided into smaller segments throughout the video series mentioned in the current video.	Most of the information in the video is presented at a learner-pace. Most of the Learning concepts are divided into smaller segments throughout the video. **OR** The current video is part of a series of related videos that presents most of the information at a learner-pace. Most of the learning concepts are divided into smaller segments throughout the video series mentioned in the current video.	All of the information in the video is presented at a learner-pace. All of the Learning concepts are divided into smaller segments throughout the video. **OR** The current video is part of a series of related videos that presents information at a learner-pace. All of the learning concepts are divided into smaller segments throughout the video series mentioned in the current video.
I08 PRE-TRAINING	No introduction / guide is given at the beginning the video. The video does not mention any key terms, concepts, or definitions regarding the learning content (the video jumps directly to the topic).	A short general introduction of the purpose of the video is given at the beginning where the learning content is mentioned but not explained. The video does not mention the key terms, concepts, or definitions regarding the learning content (only the title and the topic area are given with no terms, concepts, or definitions).	A short general introduction about the learning content is given at the beginning of the video. The video does not mention the key terms, concepts, or definitions regarding the learning content directly (only the main topic is introduced without its terms, concepts, or definitions).	An introduction / guide is given at the beginning of the video. The video mentions the key terms, concepts, or definitions regarding the learning content at the introduction / guide and refers to other videos to cover them (presenting the links on the video itself or in the description box).	An introduction / guide is given at the beginning of the video. The video introduces the key terms, concepts, or definitions regarding the learning content at the introduction / guide.
I09 MODALITY	The video uses on-screen text rather than narration to explain or support visuals. Narration may be used in the video but not for the purpose of supporting the visuals.	The video relies on on-screen text more than narration to explain or support visuals. On-screen text is used with both simple and complex visuals throughout most of the video.	The video relies on narration more than on-screen text to explain or support visuals. The video has some parts where the narration is used with visuals and other parts where on-screen text is the format used, without consideration of the complexity of the visuals and the pace of lesson.	The video uses narration more than on-screen text to explain or support visuals. On-screen text is used with simple visuals in the video, but only narration is used when the visuals are complex and the lesson is fast-paced.	The video always uses narration rather than on-screen text to explain or support visuals. On-screen text may be used in the video but not simultaneously with visuals (with the exception of keywords and labels).
I10 PERSONALIZATION	The video uses words (narration / text) in a formal style rather than a conversational style. The video relies on third-person statements rather than first and second-person statements (you, I, we, our). The video uses overly professional language and complex words (narration / text) instead of simple and casual language. The video has a formal serious tone without making direct comments to the learner.	The video uses words (narration / text) in a formal style more than a conversational style. The video relies on third-person statements more than first and second-person statements (you, I, we, our) most of the time. The video involves overly professional language and complex words (narration / text) instead of simple and casual language most of the time. The video has a formal serious tone without making direct comments to the learner.	The video uses words (narration / text) in conversational style more than formal style. The video relies on first and second-person statements (you, I, we, our) more than distant third-person statements. The video involves some overly professional language and complex words (narration / text) instead of simple and casual language. The video makes some direct comments to the learner in a friendly and polite tone.	The video uses words (narration / text) in conversational style rather than formal style. The video relies on first and second-person statements (you, I, we, our) rather than distant third-person statements. The video uses some complex words (narration / text) or difficult language. The video makes some direct comments to the learner in a friendly and polite tone.	The video uses words (narration / text) in conversational style rather than formal style. The video relies on first and second-person statements (you, I, we, our) rather than distant third-person statements. The video uses simple and casual language and avoids overly professional or complex words (narration / text). The video involves sentences that speak directly to the learner, in a friendly and polite tone instead of just giving orders.
I11 VOICE	The video is narrated by a machine-synthesized voice rather than a human voice. The narrator's accent is not an issue. The narration's quality is not an issue.	The video is narrated by a human voice rather than a machine voice. The narrator's accent is not an issue. The video is recorded with low quality.	The video is narrated by a human voice rather than a machine voice. The narrator speaks English with a noticeable foreign accent. The video is recorded professionally with high quality.	The video is narrated by a human voice rather than a machine voice. The narrator speaks clear English (no noticeable foreign accent). The video has a low-quality audio (not recorded professionally).	The video is narrated by a human voice rather than a machine voice. The narrator speaks clear English (no noticeable foreign accent). The video is recorded professionally with high quality.

MPR DETAILED FORM

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	VERY POOR 1	POOR 2	FAIR 3	GOOD 4	EXCELLENT 5
I12 IMAGE	The narrator's image (whether as a static image, a talking head, or an animated character with low human like motion) is showing on the screen all the time throughout the presentation of the learning content, so it clashes with the presentation of all of the complex visuals.	The narrator's image (whether as a static image, a talking head, or an animated character with low human like motion) is showing on the screen when presenting most of the learning content, and it clashes with the presentation of most of the complex visuals.	The narrator's image (whether as a static image, a talking head, or an animated character with low human like motion) is showing on the screen when presenting some parts of the learning content, and it clashes with the presentation of some complex visuals.	The narrator's image (whether as a static image, a talking head, or an animated character with low human like motion) is not showing on the screen when presenting most of the learning content, and it does not clash with the presentation of complex visuals.	The narrator's image (whether as a static image, a talking head, or an animated character with low human like motion) is not showing on the screen when presenting the learning content.
I13 EMBODIMENT	The video has an on-screen agent with no embodiment (static image). The on-screen agent is standing motionless, without any eye gaze, pointing, facial expressions, human-like gesturing, or movements. The on-screen agent is considered neutral or dislikable rather than likable.	The video has an on-screen agent with a low embodiment rather than a high embodiment. The on-screen agent does not interact enough with learners / viewers because of lack of eye gaze, pointing, facial expressions, human-like gesturing & movements. The on-screen agent may be considered likable, neutral, or dislikable.	The video has an on-screen agent with a medium embodiment. The on-screen agent is interacting with learners / viewers by displaying an average amount of eye gaze, pointing, facial expressions, human-like gesturing & movements. The on-screen agent is considered likable rather than neutral or dislikable.	The video has an on-screen agent with a high-medium embodiment. The on-screen agent is interacting with learners / viewers by displaying a reasonable amount (not high) of eye gaze, pointing, facial expressions, human-like gesturing & movements. The on-screen agent is considered likable rather than neutral or dislikable.	The video has an on-screen agent with a high embodiment rather than a low embodiment. The on-screen agent is interacting with learners / viewers by displaying high quality eye gaze, pointing, facial expressions, human-like gesturing & movements. The on-screen agent is considered likable rather than neutral or dislikable.
I14 DYNAMIC DRAWING	The instructor points to already drawn visuals rather than drawing the related visuals while lecturing throughout the whole video. The video does not involve a writing instrument on the screen. (No drawing & no gradual appearance of visuals)	The instructor points to already drawn visuals rather than drawing the related visuals while lecturing throughout the whole video. The video does not involve a writing instrument on the screen but the related visuals are appearing gradually while the instructor is lecturing (as images instead of being drawn). (No drawing but the visuals are gradually appearing)	The instructor draws related visuals while lecturing rather than pointing to already drawn visuals throughout most of the video. The writing instrument / the instructor's hand is not shown while drawing the visuals throughout the whole video (Khan Academy style). (Drawing visuals while lecturing but not showing the instrument)	The instructor draws related visuals while lecturing rather than pointing to already drawn visuals throughout most of the video. The video contains some instances showing the instructor's body, particularly the hand while drawing the visuals. (Drawing most of the visuals while showing the instrument / hand)	The instructor draws related visuals while lecturing throughout the whole video rather than pointing to already drawn visuals. The instructor's body, particularly the hand is shown on the screen while drawing visuals. (Drawing all of the visuals while showing the instrument / hand)
I15 GAZE GUIDANCE	The on-screen instructor / agent looks exclusively at the learning content, or exclusively at the learners / camera while lecturing rather than shifting gaze between the learning content and the learners / camera throughout the whole video. The instructor / agent's gaze is not used at all to direct learners to look at the relevant information on the screen.	The on-screen instructor / agent looks exclusively at the learning content, or at the learners / camera while lecturing rather than shifting gaze between the learning content and the learners / camera throughout most of the video. The instructor / agent's gaze is used few times to direct learners to look at the relevant information on the screen.	The on-screen instructor / agent shifts gaze between the learning content and the learners / camera while lecturing rather than looking only at the learning content or only at the learners / camera throughout some parts of the video. The instructor / agent's gaze is used sometimes to direct learners to look at the relevant information on the screen.	The on-screen instructor / agent shifts gaze between the learning content and the learners / camera while lecturing rather than looking only at the learning content or only at the learners / camera throughout most of the video. The instructor's / agent's gaze is directing learners to look at the relevant information on the screen most of the time.	The on-screen instructor / agent shifts gaze between the learning content and the learners / camera while lecturing rather than looking only at the learning content or only at the learners / camera throughout the whole video. The instructor's / agent's gaze is always directing learners to look at the relevant information on the screen.
I16 SUBTITLE	There are no subtitles at all in the video. The video has a fast-paced narration. (Not good for non-native speaker learners especially, according to the Subtitle principle)	There are no subtitles at all in the video. The video has a slow-paced narration. (Not good for non-native speaker learners, according to the Subtitle principle) **OR** There are nonoptional subtitles in the video. The video has a fast-paced narration. (Not good for both non-native learners, according to the Subtitle principle, and native speaker learners, because of the redundancy effect)	There are nonoptional subtitles in the video. The video has a slow-paced narration. (Good for non-native speaker learners but not for native learners, because of the redundancy effect) **OR** There are optional subtitles in the video which learners / viewers can activate if they need. The video has a fast-paced narration. (Not good for non-native speaker learners according to the Subtitle principle)	There are nonoptional subtitles in the video. The video does not have a narration. (Good for non-native speaker learners but not for native learners, because of the modality effect)	There are optional subtitles in the video which learners / viewers can activate if they need. The video has a slow-paced narration. (Good for both native & non-native speaker learners)

Appendix B

MPR QUICK FORM

	VERY POOR 1	POOR 2	FAIR 3	GOOD 4	EXCELLENT 5
I01 COHERENCE	Unrelated multimedia elements, distracting backgrounds.	Mostly unrelated elements.	Some unrelated elements.	Mostly relevant elements, clear background OR all elements relevant but with distracting background.	All elements relevant, clear background.
I02 SIGNALING	No key elements highlighted.	Few key elements highlighted.	Some key elements highlighted.	Most key elements highlighted OR all key elements highlighted but with poor emphasis choices.	All key elements effectively highlighted.
I03 REDUNDANCY	Narrator reads all on-screen text.	Narrator reads most text.	Narrator sometimes reads text.	Rarely reads text.	Narration explains visuals with only key text on screen OR only text is used with no narration.
I04 SPATIAL CONTIGUITY	Related text & visuals are far apart.	Most are far apart.	Some are close together.	Most are close together.	All are close together.
I05 TEMPORAL CONTIGUITY	Text & visuals never appear simultaneously.	Mostly not simultaneous.	Sometimes simultaneous.	Mostly simultaneous.	Always simultaneous.
I06 MULTIMEDIA	No visuals, only text/narration.	Few relevant visuals.	Some visuals, but insufficient.	Mostly well-supported visuals.	Always relevant visuals.
I07 SEGMENTING	Fast pace, too much information.	Mostly fast-paced.	Some learner-paced sections.	Mostly learner-paced OR video is part of a series with clear segmentation.	Fully segmented, learner-paced OR entire series is segmented for learners.
I08 PRE-TRAINING	No introduction or key terms.	Minimal introduction, no key terms.	Brief introduction, no key terms.	Introduction with key terms, references to other videos for details.	Full introduction with key terms and concepts.
I09 MODALITY	Only text explains visuals.	Mostly text, minimal narration.	Mixed, without clear consideration of complexity.	Narration for complex visuals, text for simple ones.	Narration supports visuals, text used only for labels.
I10 PERSONALIZATION	Formal, impersonal language.	Mostly formal, few direct addresses.	Some conversational tone.	Mostly conversational, engaging.	Fully conversational, engaging, and friendly.
I11 VOICE	Machine-generated voice.	Low-quality human voice.	Human voice with a strong accent.	Clear human voice, low recording quality.	High-quality, clear human voice.
I12 IMAGE	Narrator always on-screen, distracting.	Mostly on-screen, somewhat distracting.	Sometimes on-screen, minor distraction.	Rarely on-screen, no distraction.	Never on-screen.
I13 EMBODIMENT	Static image, no gestures.	Limited movement, minimal engagement.	Moderate gestures and facial expressions.	Frequent gestures, engaging.	Highly expressive gestures, natural interaction.
I14 DYNAMIC DRAWING	Only pre-drawn visuals.	Gradually appearing visuals.	Some hand-drawn visuals, hand not shown.	Mostly drawn visuals, hand sometimes shown.	Fully drawn visuals, hand/instrument visible.
I15 GAZE GUIDANCE	Instructor stares at content or camera only.	Mostly fixed gaze.	Occasionally shifts gaze to guide attention.	Frequently shifts gaze to direct attention.	Always shifts gaze to guide attention.
I16 SUBTITLE	No subtitles, fast narration.	No subtitles, slow narration OR mandatory subtitles with fast narration.	Mandatory subtitles, slow narration OR optional subtitles, fast narration.	Mandatory subtitles, no narration.	Optional subtitles, slow narration.

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Research Article

Influences of Arduino and Algodoo Based Mechanics Teaching on Achievement*

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Abstract – This work focuses on investigating the influence levels of Arduino and Algodoo based mechanics teaching activities on academic achievement. The research was carried out based on a pre-test post-test quasi-experimental method with two experimental groups totally consisting of 61 pre-service science teachers studying at a state university. Specifically, Arduino based STEM and Algodoo based education materials are carefully developed on the units of vectors, kinematics, dynamics, and work-energy in accordance with teaching objectives. The influences of the teaching materials on achievement are measured by Mechanics Achievement Scale. The findings demonstrate that Arduino based education has improved the achievement by 28.21% and Algodoo based teaching has improved by 28.83%, both influencing significantly. It was also revealed that simplicity of the activities and prior knowledge of the groups related with experimental processes were factors that increased the effectiveness of the applications.

Keywords: Physics education research, Arduino, STEM, Algodoo, mechanics teaching, academic achievement.

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Introduction

The teaching of mechanics aims to facilitate the understanding of physical laws, the application of mathematical modeling, and the development of analytical problem-solving skills. This process plays a fundamental role in both engineering and science fields and is critical for students to succeed in advanced courses requiring in-depth technical knowledge (Hopf et al., 2011). However, the abstract nature of concepts, the likelihood of misunderstandings, and the limitations of traditional teaching methods etc. can make mechanics instruction challenging for students at times. For instance, students' failure to accurately utilize free-body diagrams or to account for physical dimensions may lead to fundamental comprehension deficiencies (Papadopoulos et al., 2006).

Innovative methods are of great importance in overcoming these challenges. Technology-enhanced educational tools, interactive digital simulations, and curricula integrated with experiments enable students to gain a deeper understanding of concepts. For example, computer-assisted instruction on Newtonian mechanics has been shown to correct students' misconceptions and foster a more concrete understanding (Hennessy et al., 1995).

One of the fundamental commitments of the Physics Education Research (PER) is to develop novel or alternative teaching materials in order to reduce recognized learning/teaching difficulties (Docktor & Mestre, 2014). The other important issue is to integrate up-to-date technological tools into teaching activities. In this sense, Arduino microprocessors are very convenient tools that can be introduced to teaching processes with almost no cost (Goncalves et al., 2023). Employing simulations can be another up-to-date approach to get rid of certain teaching difficulties and to achieve deeper conceptual understanding. Algodoo, in this sense, is a very handy software that can easily be reached and employed within teaching activities (Gregorcic & Bodin, 2017).

Arduino microprocessors are specifically very valuable due to their ability to measure the instant forces and displacements of a body as a function of time with a time sensitivity of 1 microsecond and displacement sensitivity of 1 micrometer. Accordingly, one can precisely measure the time dependence of the displacements and forces, which can then be employed to obtain various quantities, such as velocity, acceleration, momentum, etc. Therefore, it is very important to introduce Arduino microprocessors in physics teaching in order to provide students with deeper learning levels and 21st-century skills (Bao & Koenig, 2019).

Algodoo simulation program also offers a valued tool for teaching physics in the sense that almost every parameter can be varied to see and measure the effect of the change. Algodoo bridges the gap—crucial for deeper learning—between the unreachable region that is the measurement of the instantaneous displacements or forces and the theoretical formulations of that specific subject (Özdemir & Coramik, 2022).

In previous studies, numerous alternative teaching materials have been developed and reported based specifically on Arduino microprocessors. Specifically, kinematics (Çoban & Erol, 2021a), dynamics (Çoban & Erol, 2022), work-energy theorem (Çoban & Erol, 2021b), Newton's second law (Çoban & Erol, 2020), and impulse-momentum law (Çoban & Erol, 2021c) have been tackled and studied by means of Arduino microprocessors. Algodoo-based teaching material on impulse-momentum has also been developed and reported earlier (Çoban, 2021).

In this work, carefully developed Arduino and Algodoo teaching materials are employed at mechanics unit with pre-service science teachers within the 5E teaching approach, and the effectiveness of the materials is determined. The teaching materials are specifically tested to determine their impact on academic achievement at mechanics.

Previous Research

Mechanics is the most fundamental sub-topic of physics and is experienced countless times every day; however, it is also one of the most problematic topics in physics education. Difficulties in teaching mechanics, to some extent, originate from the lack of verification of mathematical models due to the insufficiency of measuring instantaneous displacements, velocities, and forces. Therefore, introducing novel teaching materials based on technological developments is essential to improve conceptual learning.

Mechanics teaching has been a hot topic in Physics Education Research (PER), addressing numerous teaching difficulties and misconceptions. In this sense, a paradigmatic change concerning mechanics teaching was addressed almost 30 years ago (Schecker, 1992). Misconceptions and difficulties in teaching mechanics among high school and university students were also tackled by Daud et al. (2015). In another work, introductory mechanics was studied in terms of students' learning difficulties (Nguyen & Rebello, 2011).

Vectors, on the other hand, have been one of the trickiest concepts in mechanics, evidently including several conceptual difficulties. Various works have concentrated on teaching vectors. In this sense, student use of vectors in introductory mechanics has been addressed, and some problems have recently been mentioned (Flores et al., 2004). In another study, students' learning difficulties regarding symbolic and graphical representations of vector fields have been handled (Bollen et al., 2017). Similarly, students' difficulties regarding vector representations in the free-body system have also been studied comprehensively (Poluakan & Runtuwene, 2018).

Student learning difficulties and conceptual problems in kinematics have likewise been studied by a number of researchers. To mention some, student difficulties in connecting graphs and kinematics have been addressed, and some important findings were underlined (McDermott et al., 1987). Lichtenberger et al. (2017) reported validation and structural analysis of the kinematics concept test. Assessment of representational competence in kinematics has also been handled by Klein et al. (2017). In another study, the effect of conceptual change texts on physics education students' conceptual understanding in kinematics was studied (Syuhendri, 2021).

Teaching dynamics and related fundamental concepts, namely force and acceleration, have also been studied extensively. For instance, Rosenblatt et al. (2009) have studied modeling students' conceptual understanding of force, velocity, and acceleration. In another study, a systematic study of student understanding of the relationships between the directions of force, velocity, and acceleration in one dimension was tackled (Rosenblatt & Heckler, 2011). Liu and Fang (2016) have recently studied student misconceptions about force and acceleration in physics and engineering education. Force, acceleration, and velocity during trampoline jumps have been examined in terms of a challenging assignment (Pendrill & Ouattara, 2017). Molefe and Khwanda (2020) have recently studied activities to enhance students' understanding of acceleration.

Work and energy concepts have also been tackled by numerous studies. In one study, multiple representations of work–energy processes were examined (Van Heuvelen & Zou, 2001). Tang et al. (2011) addressed students' multimodal construction of the work–energy concept. Gutierres-Berraondo et al. (2019) studied addressing undergraduate students' difficulties in learning the generalized work-energy principle in introductory mechanics. In another study, the analysis of students' difficulties with work and energy was tackled (Rivaldo et al., 2020).

There have been various studies concerning the STEM approach to teaching mechanics. Applying a simple model aiding in understanding the acceleration of a bungee jumper has been studied by Kesonen et al. (2019). Büyükdede and Tanel (2019) studied the effect of

STEM activities related to work-energy topics on academic achievement and prospective teachers' opinions on STEM activities. Arduino-based STEM education materials concerning work-energy theorem, Newton’s second law, and impulse-momentum have been studied by Çoban and Erol (2021a, 2021b, 2020). Erol and Oğur (2023) studied the large-angle pendulum via Arduino-based STEM education material.

De Lima et al. (2020) developed Arduino-supported experiments in the fields of thermology and optics, implemented them in two public high schools in Brazil, and identified their positive contributions to students' learning processes. Schnider and Hömöstrei (2024) designed Arduino-based classroom experiments for teaching electromagnetism and observed that these experiments enhanced students' conceptual understanding. Petry et al. (2016) integrated Arduino into physics laboratories to develop project-based teaching methods and reported that students gained interdisciplinary skills. Similarly, Xianfeng et al. (2020) implemented electronics circuit design experiments based on the Arduino platform and noted improvements in students’ practical abilities and problem-solving skills. These studies demonstrate that Arduino is an effective tool in physics education for enhancing student engagement and improving learning outcomes. Algodoo is a well-known simulation platform employed in numerous studies. Gregorcic (2015) studied exploring Kepler’s laws using an interactive whiteboard and Algodoo. Çoban (2021) studied Algodoo for online education concerning impulse and momentum activities. Algodoo has also been used to study the force that makes a car accelerate and what the acceleration depends on (Radnai et al., 2023). Additionally, a study focused on educational experiments with motion simulation programs, questioning whether gamification can be effective in teaching mechanics (Radnai et al., 2019).

Sontay and Karamustafaoğlu (2023) examined the perspectives of physics teachers on Algodoo training and reported that teachers provided positive feedback, indicating that using this software in lessons increased students' motivation and made the topics more comprehensible. Similarly, Cayvaz and Akçay (2018) investigated the effects of using Algodoo in middle school science teaching. The results demonstrated that Algodoo-supported instruction facilitated students’ understanding of scientific concepts and increased their interest in the subject. These studies highlight that Algodoo software is an effective tool in physics education, playing a significant role in enhancing students’ conceptual understanding, motivation, and engagement in lessons.

Theoretical Framework

Physics education efforts, in general, employ various theoretical frameworks to improve student achievements and conceptual learning. Conceptual learning is crucial because it substantially enhances students' cognitive skills, thereby improving their readiness to solve original problems. In this work, resource-based learning has been employed. This theoretical framework develops and provides various resources available to students, including textbooks, educational technologies, and laboratory experiments, and researchers analyze the effectiveness of those resources in facilitating learning. Resource-based learning is a pedagogical approach that actively involves students and teachers in applying a range of resources in the learning process (Brown & Smith, 2013; Turner, 1974). This theoretical framework offers a flexible structure to learning, allowing students to develop their varied interests, experiences, learning styles, needs, and ability levels (Hill et al., 2005; Stewart, 1998). Resource-based learning also focuses on the resources available to the learners and how the learners interact with these resources, which leads to an interest in using technology to support and develop a learning environment. Essential features of resource-based learning can be summarized as follows (Kononets et al., 2020; Rumahlatu et al., 2021).

- A wide variety of resources are prepared in harmony with the proposed gains
- Learning experiences are planned in accordance with instructional objectives
- Teaching strategies and skills are identified and thought with the context of relevant and meaningful components of work
- Adapted to different learning styles and subject areas

In today's world, providing students with a deep and lasting learning experience has become increasingly important. Particularly in application-oriented fields such as physics, methods that offer students opportunities to explore real-world phenomena, conduct observations, and enhance their learning by developing their own projects have gained significant importance. In this context, tools such as experiment kits (e.g., Arduino) and simulation programs (e.g., Algodoo), stand out as valuable resources for enriching the teaching process.

The primary aim of this study is to investigate the impact of innovative teaching approaches utilizing Arduino and Algodoo on students' success in mechanics education. The significance of the study can be addressed from several perspectives. First, the study offers concrete recommendations on how cost-effective experimental tools developed using Arduino can be employed in teaching, along with data on their effectiveness in enhancing learning outcomes, demonstrating the strength of practical applications.

Second, by providing specific insights into how the free Algodoo simulation program can be integrated into lessons and how the effectiveness of this integration can be evaluated, the study addresses the potential to overcome cost and infrastructure challenges, particularly in remote or blended learning models.

Furthermore, another notable aspect of this study is the comparison of hands-on experimental processes conducted with Arduino, whose advantages over traditional methods have been demonstrated in previous studies, and simulations performed using the Algodoo program, in order to identify the similarities and differences between these two approaches. Particularly following the extensive experience with online education during the pandemic, the results obtained from comparing these methods will provide valuable insights into which approaches offer greater added value when planning future mechanics education.

Research Questions

1. What is the influence of Arduino based teaching on achievement regarding mechanics teaching?
2. What is the influence of Algodoo based teaching on achievement regarding mechanics teaching?
3. Is there any significant difference between Arduino based and Algodoo based teaching on Mechanics achievement?

Method

Research Design

The design of the study is pre-test post-test quasi-experimental model with two experimental groups. The research was carried out within the scope of the Physics 1 course in the fall semester of the 2022-2023 academic year. The teaching practices were carried out using two different teaching approaches in two different branches in weekly 180-minute lessons for four weeks. To investigate the impacts of these pedagogical methods on achievement, the measurement tools were applied to the study groups before and after the teaching processes and evaluated carefully.

Participants

The sampling of the research consists of a total number of 61 teacher candidates, between the ages of 18 and 22, studying in two different branches of the Science Education department of a state university. The sampling students were randomly and naturally assembled and divided into branches from the moment they registered to the department. In one of the branches, all courses were carried out experimental activities using Arduino microcontroller (n = 28, 20 females and 8 males), while in the other branch all courses were carried out with the Algodoo simulation program (n = 33, 20 females and 13 males).

Data collection

Mechanics Achievement Scale

The scale employed to measure the success within the scope of the study is the Mechanical Achievement Scale (MAS) developed by the researchers. Validity and reliability studies of the scale were carried out in the fall semester of the 2021-2022 academic year. After the necessary adjustments were made by consulting expert opinions within the scope of validity of the studies, the scale was applied to students who had previously taken Physics 1 courses and the obtained data were evaluated by two different experts. As a result of the evaluations, the compatibility of the results was tested via Kendall analysis and the concordance coefficient between the two rates was determined as 0.990 and it was concluded that the scale was highly reliable. The scale consists of four separate parts namely vectors, kinematics, dynamics, and work-energy units and each one includes 5 true-false, 2 classic and 2 multiple choice questions within the framework of a daily life problem case related to the subject. The maximum score that can be obtained from the scale is 100. In order to give an idea about the content of the scale, the scale section regarding the vectors unit is given as Apendix 1.

Teaching Materials

In this study, teaching materials using Arduino microcontrollers and Algodoo simulation programme were developed and used concerning the units of Vectors, Kinematics, Dynamics and Work-Energy in accordance with undergraduate Physics 1 course. The source book and teaching sequence were identical for both approaches. Before starting the development process of the instructional materials, initially learning gains of the related units were determined based on the source book and those learning gains were taken into consideration in the teaching activities in both groups.

Materials and Teaching Sequence Involving Arduino

In the first step of the preparation of Arduino-based instructional materials, specific mental models of the activities were designed by considering the proposed learning outcomes. The mental models for each activity were converted into three-dimensional instructional materials and the activities were tested through the material. At this point, activities that did not have any problems in their implementation as mentally planned were made ready to be used in the study. The activities that could not be implemented as planned and had problems in their implementation were revised and made suitable for the use. The materials that caused problems despite the revisions, were improved and new applications were developed and tested in the same way.

The developed materials were implemented in the teaching processes in accordance with the 5E pedagogical model. The implementation is managed in the following manner. In the Engage stage of the 5E model, a stimulating question related to the subject was asked to the students to attract their attention and increase their learning motivation by triggering their curiosity. The applications using Arduino are included in the Explore and Explain sections. In these stages, firstly, the working principle, coding and connections of the sensors to be used in the Arduino application planned to be realised in the course were explained to the students. Then, detailed lectures and question solutions were made through the source book, and after these lectures, the whole class was asked to brainstorm on how an experiment could be designed using Arduino and the sensors introduced in this subject by discussing among themselves. At this stage, the researchers ensured that the students are well guided during the brainstorming in the classroom environment. The predetermined material was not shown or explained to the students in any way and the students were enabled to be active in the process as if they were producing a new material from scratch. At this stage, the process carried out in the classroom is very important to increase activity and co-operation. During the process, it is important that the students communicate among themselves about the experimental material that needs to be done and get results. The process of programming the experimental equipment used in the study takes time and there is a high chance of making mistakes at the first attempt. If such studies are carried out in the classroom in addition to the lectures, there may be some problems in terms of time. For this reason, the researchers have prepared planned and tested activities that can be performed for each subject. However, bringing them to the classroom and giving them to the students is not the best way to teach in a way that encourages creativity and co-operation. Considering both situations, the researchers asked the students to identify the materials by talking among themselves and guiding them in this process. As a result of this guidance, the students were able to design and test the materials that the researcher had previously designed and tested. Thus, both the problems that may arise during the development of the material were eliminated and the applications were carried out as planned by ensuring that the students were active. As a result of the brainstorming, three-dimensional material design, electronic connections, code writing and programming applications were carried out within the scope of the studies for the development of the experimental setup for the experimental activity determined by a common decision. The experimental activity was carried out using the experimental setup developed at the end of the Explore and Explain steps and the results were obtained by analysing the collected data. In the Elaborate stage, the subject was summarised and in the Evaluate stage, problem solutions related to the subject were carried out.

Arduino based teaching materials have been developed using Arduino UNO microcontroller and some related sensors for vectors, kinematics, dynamics, and work-energy units. The materials were specifically designed to gradually improve students' coding and electronics skills throughout the course. For this reason, in the vectors unit, which is the first unit where the HC-SR04 distance sensor is used, applications with basic level connections and programming have been carried out. In this application, the position data measured using the HC-SR04 distance sensor with the help of the setup in Figure 1a are tested experimentally and theoretically with the applications in the vector subject. The HC-SR04 distance sensor is an easy-to-use sensor that requires basic skills and is suitable for use in the most basic applications. In the first lesson, students learnt the basic working principles of the distance sensor that will be used in all other applications. In addition, with the distance sensor, which requires easier connection and coding compared to other sensors, difficult applications were avoided and students were involved in the robotic coding process without reducing their learning motivation.

In the applications performed in the second unit, the kinematics unit, three different materials were used (Figures 1b,1c, 1d). HC-SR04 distance sensor, which was also used in the first lesson, was used as the sensor in both materials. In this lesson, the connections and programming processes were completed in a shorter time with the students who learned how to use distance sensors in the previous lesson, and the next process, the analysis of the collected data, was carried out in detail, especially emphasising the methods of determining the instantaneous velocity and acceleration magnitudes, which will be carried out in other lessons. The materials used are shown in Figure 1b, Figure 1c and Figure 1d. The data obtained using the system in Figure 1b were copied to Excel where the basic concepts of kinematics and motion graphs were analysed. The system in Figure 1c was developed to analyse the bottom-up throwing motion and the values such as acceleration, velocity, and position during the movement of the wooden block thrown vertically upwards were analysed. At last, for kinematics, with the system shown in Figure 1d, 2D motion was analyzed (Çoban & Erol, 2021a).

In the third unit, the dynamics unit, force, and uniform circular motion analyses were performed. Load-cell force sensor was used in the analyses of the force. The connections and coding processes related to the force sensor to be used both in this unit and in the applications in the other unit, the work-energy unit, were carried out with the students in the classroom and used in force-related applications. After the load-cell force sensor was programmed, the developed material was attached to the wooden block as shown in Figure 1e and Figure 1f. Using the system shown in Figure 1e, detailed force-related information such as force properties, equilibrium, and friction force was analyzed, and by using the system shown in Figure 1f, analyses regarding Newton's 3rd law were made (Çoban & Boyacı, 2020). For the analysis of uniform circular motion, a material with slightly more complex coding and electronic connection processes than the others were developed. The purpose of the current development of this content is to further challenge and develop the creativity of students who have already acquired most of the basic robotic coding skills. The basic concepts were introduced with the help of the system shown in Figure 1g used in the teaching process about uniform circular motion. Unlike the others, this system used a tracking sensor, a motor driver, and a potentiometer. Since it may take a long time to code it from the beginning, it was thought that it would be more effective to prepare this material before the lesson and to introduce the coding in writing and this method was followed.

In the applications carried out in the last unit, both the applications related to the friction force and Newton's fundamental law within the scope of the force unit explained in the previous lesson and the applications including analyses related to the concepts in the work-energy unit were made. Within the scope of these analyses, two applications were carried out and the sensors used in these applications are like those used in previous lessons. With the help of the system in Figure 1h, the analyses of the basic law of dynamics and the relationship between work and energy were performed (Çoban & Erol, 2020, 2021b). During these analyses, a Bluetooth sensor was used to transfer data from the force sensor and distance sensor to the computer. With the help of the same system (Figure 1c), as the application was carried out within the scope of the kinematics unit, analyses on energy conservation were conducted (Çoban et al., 2023). The last teaching practice of the energy subject, and therefore the last teaching practice of the study, was carried out using the material shown in Figure 1i, which includes experimental processes for the concepts of elastic potential energy, reactive force, and spring constant (Çoban & Çoban, 2020).

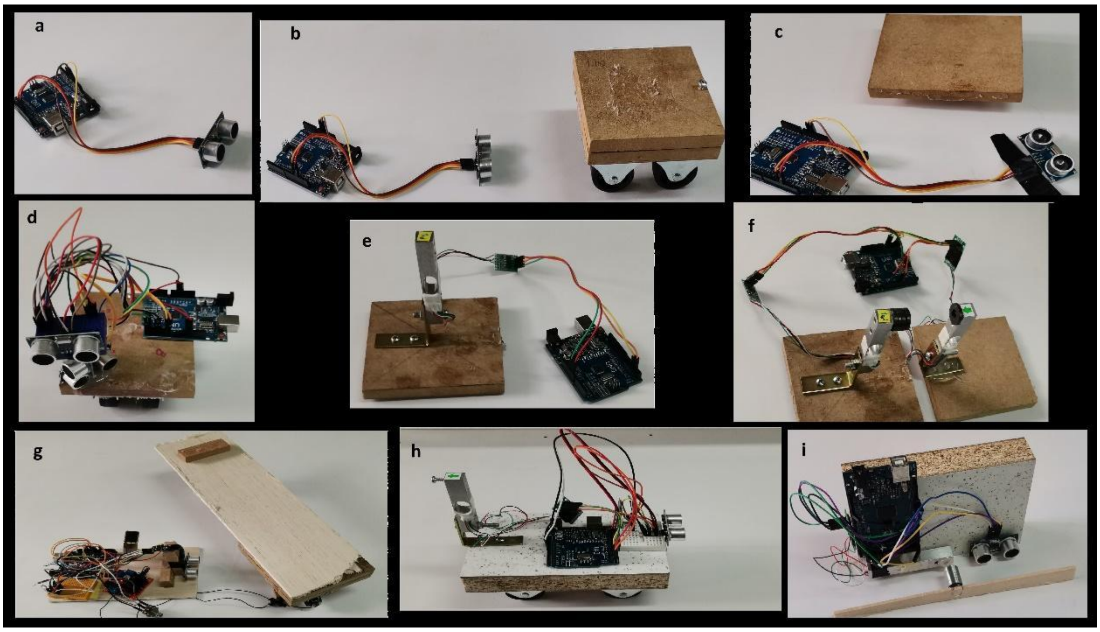

Figure 1 Experimental Setup Used for; **a** Vectors, **b** 1st Application of Accelerated Motion in One Dimension, **c** 2nd Application of Accelerated Motion in One Dimension and Experimental Setup Used in Conservation of Energy, **d** Accelerated Motion in Two-dimension, **e** Force Concept and Friction Force **f** Newton's 3rd Law, **g** Uniform Circular Motion, **h** Work-energy and Newton's 2nd Law, and **i** Elasticity Potential Energy.

Materials and Teaching Sequence Involving Algodoo

Concerning the second experimental group, educational activities were carried out by using the Algodoo physics-based simulation program regarding the Vectors, Kinematics, Dynamics, and Work-Energy units. In the process of designing the activities, firstly a mental model was developed for the proposed activity considering the course objectives and then a simulation activity was designed based on this mental model. It was then analyzed whether the designed simulation functioned as intended, and adjustments were made when necessary. The simulations were accordingly finalized and included in the teaching materials. While determining these simulations, it was also aimed to use the content of the Algodoo programme in the most efficient way during the lectures and the most frequently used features were vector representation, adding external forces to the objects, adjusting the masses of the objects, adjusting the frictions, information window with information about velocity, acceleration and position, and a wide variety of graphical representation namely, acceleration-time, velocity-time, position-time, total energy, kinetic energy, potential energy-time graphs. In addition to the main objective of teaching the subject matter in the course content in the best way, a secondary objective was to improve the Algodoo usage skills of the prospective teachers. Screenshots of some of the simulations used during the lectures are shown in Figure 2.

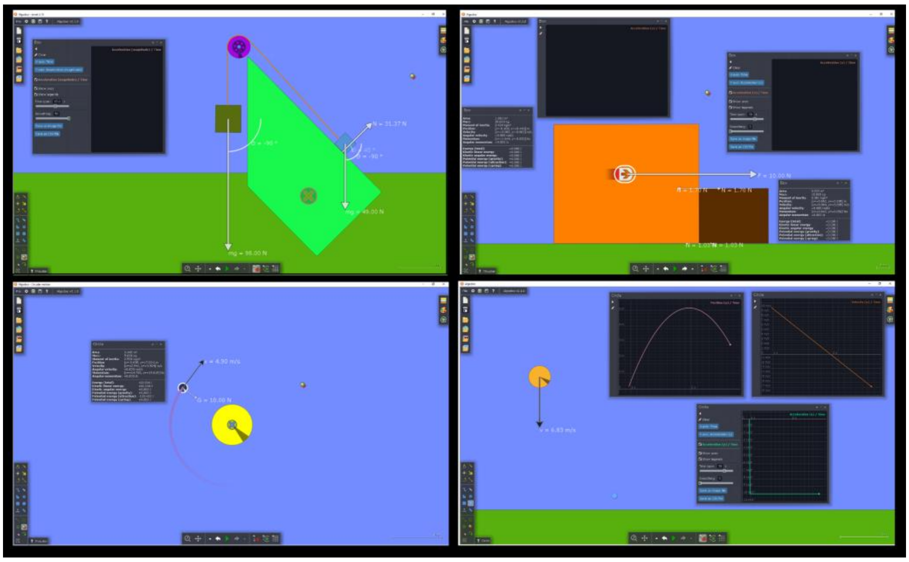

Figure 2 Screenshots of Algodoo Simulations Used During Lectures in the Algodoo Group.

Applications using Algodoo were implemented using the 5E pedagogical model similar to the first experimental group. In the Engage stage, students were asked an interesting question about the subject to attract their attention to the lesson and to increase their learning motivation. The questions asked in this section are the same as the questions in the STEM group. In the Explore phase, an example simulation was developed and necessary explanations were made to show the students the use of the Algodoo program through an example and to increase their desire to use the Algodoo. In the Explain phase, subject explanations were managed. Simulations were used in three different ways, summarized below, during the lecturing. First, a theoretical explanation was given on the subject, then a volunteer was selected from the students, and they were asked to design a simple case study on the subject of simulation, guided by the results reached by other students by brainstorming. In this way, the scope of the subject was learned by discovering its equivalency in daily life and the students were also enabled to go through creative thinking processes.

At the other method, initially, a sample problem from the source book was solved with the class after the lesson. Then, a simulation of this problem case was developed and the simulation was started through which the problem was analysed by the students. The information learned was reinforced by testing the accuracy of the result obtained through theoretical calculationIn another approach, lectures were delivered directly using the Algodoo program. In Algodoo, firstly, the situation related to the subject was shown and questions were asked to make the students wonder and think about the subject. Then, the lesson was conducted with theoretical explanations on the situation, and the simulation was taken back and analyzed again with theoretical calculations. For example, the simulation was started until the object under the influence of a force made a certain displacement and stopped after a certain period. The steps to be followed and the equations to be used to determine the speed of the object at the point it reaches are explained. Then, by opening the vector representation of the velocity, it is shown that the calculated value is consistent with the value in the simulation.

Although the activities designed considering the achievements and what can be done with Algodoo correspond to most of the targeted achievements regarding mechanics, they cannot meet all the achievements. These achievements that cannot be met are explained with the traditional method. After these, a summary of the subject was made at the 'Elaborate' stage. Lastly, during the 'Evaluate' process, problem solutions related to the subject were carried out.

Data Analysis

In the study, with 28 pre-service teachers in the Arduino group and 33 pre-service teachers in the Algodoo group, subject lectures related to the Mechanics unit were carried out using Arduino and Algodoo for 4 weeks and data collection tools were applied to the experimental groups both before and after the application. Table 1 below shows the experimental design of the study.

Table 1 Experimental Design of the Study

Group	Pre-application	Experimental procedures	Post-application
Arduino (n=28)	MAS	Arduino supported physics education (4 weeks)	MAS
Algodoo (n=33)	MAS	Algodoo supported physics education (4 weeks)	MAS

During the study, the MAS was applied to the experimental groups as pre-test and post-test before and after the study. SPSS 23 statistics program was used to analyze the data obtained. During statistical analyses, the pre-test post-test scores of the same groups, the pre-test scores between two groups and the post-test scores between two groups were compared and it was checked whether the difference was statistically significant. Considering the characteristics of the research questions, normal distribution analysis was first performed on all test results, and parametric tests (dependent sample t-test for comparisons of same groups and independent sample t-test for comparisons between two groups) were used to compare normally distributed scores, while non-parametric tests (Wilcoxon signed rank test for comparisons of same group and Mann-Whitney U test for comparisons between two groups) were used to compare scores that did not show normal distribution.

Results and Discussions

In this section, the results obtained after the comparison of the pre-test and post-test scores obtained from MAS both within and between groups and the discussion based on these results are presented.

Before comparing the scores, normal distribution analysis was performed on the findings obtained in both pre and post-tests and it was concluded that the scores were normally distributed. Based on this result, the dependent sample t test and independent sample t test, which are parametric tests, were employed for comparisons. The results obtained and the discussion about them are given below.

Results

Change in Achievement for the Arduino Group

In this section, findings acquired as a result of the comparison of the scores obtained from the MAS applied to the study groups as pre-test and post-test in order to analyse the effects of Arduino-based teaching on the achievement are presented. Since the scores obtained from the both tests showed normal distribution, these scores were compared using the parametric test. The dependent sample t test and the results are presented in Table 2.

Table 2 Results of the Dependent Sample t-test Analysis Comparing the MAS Pre-test and Post-test Scores of the Arduino Group Students.

Test	N	$\bar{X}$	sd	t	p	Cohen's d
MAS pre	28	18.61	7.95	-11.24	0.00*	2.33
MAS post	28	46.82	15.47			

maximum score: 100

When table 2 is examined, it is seen that the difference between the two mean scores is statistically significant ($p<0.05$) in favour of the post-test. This result shows that the teaching using Arduino has an increasing effect on the achievement. It is also seen that the mean scores of the pre-service teachers in the Arduino group increased more than two times (% 28.21) after the instructions and the Cohen's d coefficient was 2.33. It can be said that the educational practices based on the experimental activities using Arduino had a significant effect on the achievement.

MAS consists of 4 separate sections including questions on vectors, kinematics, dynamics and work-energy. Each section has an equal score of 25. Throughout the statistical analyses, the changes occurring in these 4 sections were examined in detail. Since the scores of the pre-service teachers in the Arduino group on vectors, kinematics and work-energy were not normally distributed, the analyses were performed with Wilcoxon signed-rank test and the results are presented in Table 3. On the other hand, since the scores obtained from the dynamics subject showed normal distribution, the analyses were performed with the dependent sample t test and the findings are presented in the Table 4.

Table 3 Wilcoxon Signed-rank Test Analysis Results Comparing the Pre-test and Post-test Scores of Arduino Group Students in MAS Vectors, Kinematics and Work-energy Subjects

Subject	Post-test-Pre-test	N	Mean rank	Sum of rank	Z	p	Cohen's d
Vectors	Negative ranks	0	0	0	-4.623	0.00*	1.69
	Positive ranks	28	14.50	406.00			
	Ties	0					
Kinematics	Negative ranks	2	4.25	8.50	-4.34	0.00*	1.50
	Positive Rranks	25	14.78	369.50			
	Ties	1					
Work-energy	Negative ranks	2	2.50	5	-4.51	0.00*	2.03
	Positive ranks	26	15.42	401.00			
	Ties	0					

** difference is significant (p<.05), maximum score:25*

Table 4 Dependent Sample T-test Analysis Results Comparing MAS Dynamic Pre-test and Post-test Scores of Arduino Group Students

Test	N	$\bar{X}$	ss	sd	t	p	Cohen's d
MAS dynamics pre	28	2.61	1.72	27	-6.31	0.00*	1.56
MAS dynamics post	28	9.92	6.54				

**difference is significant (p<.05), maximum score:25*

When the Tables 3 and 4 are examined, it is revealed that the teaching via Arduino increased the achievement level of each subject at a statistically significant level. When the effect level of the teaching is examined, it is seen that the Cohen's d effect coefficient ranking is in the order of work-energy, vectors, dynamics and kinematics.

Before addressing this difference, it would be useful to mention the effects of cognitive load on learning during training. Many studies on cognitive load and learning reveal that an increase in extraneous cognitive load, which is not related to the main topic, has a detrimental effect on learning, whereas an increase in germane cognitive load, which is related to the subject content, has an enhancing effect on learning (Sweller et al., 2019).While analysing the difference between subtopics, evaluations will be made relating these two cases.

When the Arduino application in the work-energy topic, which is the highest, is analysed, it is seen that the distance sensor used in the previous lessons and similar data analysis processes carried out in the previous lessons were covered. Since the students who are more familiar with these electronic devices and the data analysis process have already learnt the force sensor and distance sensor, they have not gone through an extra cognitive process to understand the features of these devices such as connection and coding, and therefore, by reducing the extraneous cognitive load and increasing the germane cognitive, it may lead to a higher level of understanding of the subject in the course content. In the teaching of the vectors subject, where Arduino applications were the second most effective subject, a very simple material was preferred as an introduction to Arduino programming and a very basic level activity was carried out. Therefore, it can be easily said that the extraneous cognitive load in this process is less compared to kinematics and dynamics topics. The reason why the effect in the dynamics unit was higher than the effect in the kinematics unit may be that the materials of the kinematics topic contain more complex electronic connections and data analyses compared to the vectors unit. The students encountered these processes for the first time during the teaching of the kinematics unit, and the data analyses performed similarly in the dynamics unit may have caused less extraneous cognitive load than in the kinematics unit.

Change in Achievement for the Algodoo Group

In this section, the results of the dependent sample t-test obtained by comparing the MAS pre-test and post-test scores in order to analyse the effects of Algodoo-based training on the achievement levels in mechanics are presented. The results are shown in Table 5.

Table 5 Results of the Dependent Sample T-test Analysis Comparing the MAS Pre-test and Post-test Scores of Algodoo Group Students.

T-Test	N	$\bar{X}$	sd	t	p	Cohen's d
MAS pre	33	18.88	6.04	-13.88	0.00*	3.02
MAS post	33	47.71	12.31			

maximum score: 100

When Table 5 is examined, it is understood that the difference between MAS pre-test and post-test mean scores is statistically significant (%28.83) and in favour of the post-test ($p<0,05$). Cohen's d coefficient also shows that there is a highly significant difference between the scores of the group before and after the application. Such a high effect can be clearly seen when the difference between the post-test mean scores and the pre-test mean scores is taken into consideration. This result shows that the teaching activities using Algodoo have a significant effect on academic success.

Similar to the analyses performed for Arduino applications in the previous section, statistical analyses were performed to test the effectiveness of Algodoo applications in vectors, kinematics, dynamics and work-energy topics. The scores of vectors, dynamics and is-energy topics, which do not show a normal distribution, were tested using the Wilcoxon signed-rank test and are presented in Table 6. Since the scores obtained from the kinematics section were normally distributed, they were analysed by using the dependent sample t-test and the findings are given in Table 7.

Table 6 Wilcoxon Signed-rank Test Analysis Results Comparing the Pre-test and Post-test Scores of the Algodoo Group Students in MAS Vectors, Dynamics and Work-Energy Subjects

Subject	Post-test-Pre-test	N	Mean rank	Sum of rank	Z	P	Cohen's d
Vectors	Negative ranks	0	0	0	-5.01	0.00*	1.96
	Positive ranks	33	17.00	561.00			
	Ties	0	-	-			
Dynamics	Negative ranks	1	9.00	9.00	-4.85	0.00*	1.86
	Positive ranks	32	17.25	552.00			
	Ties	0	-	-			
Work-energy	Negative ranks	2	3.75	7.50	-4.88	0.00*	1.67
	Positive ranks	31	17.85	553.50			
	Ties	0	-	-			

**difference is significant (p<.05), maximum score:25*

Table 7 Dependent Sample T-test Analysis Results Comparing MAS Dynamic Pre-test and Post-test Scores of Arduino Group Students

Test	N	$\bar{X}$	ss	sd	t	p	Cohen's d
MAS kinematics pre	33	5.98	2.10	32	-8.95	0.00*	2.16
MAS kinematics post	33	12.86	4.07				

**difference is significant (p<.05), maximum score:25*

When Tables 6 and 7 are analysed, it is perceived that the achievement in each subject has increased statistically significantly. Among the effects causing these increases, the order from the highest Cohen's d effect level to the lowest is kinematics, vectors, dynamics and work-energy.

In the teaching process of work-energy, relatively higher-level graphical analyses such as force-position, kinetic energy-time, potential energy-time and total energy-time graphs have been carried out and simulations with more complex content have been used. The results show that although such complex applications have the effect of increasing the success, they fall behind other, somewhat simpler level lecture contents in terms of Cohen's d effect coefficient. The main reason for this may be the high level of extraneous cognitive load similar to the situation discussed in Arduino applications. In kinematics, visualisation of motion graphs and detailed examination of the graphs simultaneously with the motion were carried out thanks to Algodoo. Compared to the energy topic, it contains fewer types of graphs and also the graphs in these applications are the graphs that are mostly taught at high school level. Such convenience and prior knowledge seem to have an effect on the effectiveness of the Algodoo programme. The simulations used in the subject of vectors are simulations that are very simple and complex at the lowest level, and it is seen that such simulations also have a high effect. It is thought that the reason why the applications on dynamics are ranked 3rd in the ranking is that they contain relatively more complex simulation contents compared to the others.

Comparison of the Achievement Levels of the Groups

In this section, the MAS scores of the Arduino group and Algodoo group before and after the application were compared. Since all of the MAS scores of the groups showed normal distribution, an independent sample t test was used in the comparisons between the groups. The results obtained are as shown in Table 8.

Table 8 Independent Sample T-test Analysis Results Comparing the MAS Pre-test Scores of Arduino Group and Algodoo Group Students

Test	Group	N	$\bar{X}$	sd	t	p
MAS pre	Arduino	28	18.61	7.95	-0.146	0.88
	Algodoo	33	18.88	6.04		
MAS post	Arduino	28	46.82	15.48	-0.25	0.80
	Algodoo	33	47.71	12.31		

maximum score: 100

It is clearly detected from table 8 that there was no statistically significant difference ($p>0.05$) between the MAS scores of Arduino group and Algodoo group both before and after the application. In both groups, both pre-test and post-test scores were quite close to each other and it was seen in the previous sections that both methods had similar effects on achievement. It is, based on the resolutions, concluded that there is no significant difference between the two groups in terms of mechanics achievement both before and after the application. Additionally, comparisons of each sub-score were made for both pre-test and post-test, but no statistically significant difference was found for any of the sub-scores, and the tables of these findings are not included in the article to avoid too much data overload.

These results are not surprising based on the outcomes of the previous sections which showed that both methods have an effect on increasing success. Although there is no statistically significant difference between the two methods, there is a difference in terms of Cohens' d coefficients and this difference is in favour of the Algodoo group. In the previous sections, it is understood that the effect coefficient of Arduino applications is 2.33 and Algodoo applications is 3.02. Although this difference is not a very big difference, it shows that the applications using Algodoo have a higher effect on the success of the mechanics subject compared to those using Arduino. In terms of sub-subjects, Algodoo supported training has a higher effect on vectors, kinematics and dynamics, while Arduino has a higher effect on only work-energy. In general, it is seen that the effect of Algodoo supported training is higher both in terms of the effect on total scores and in 3 out of 4 subjects. Among the reasons why Algodoo applications have a higher impact level in general may be that the applications carried out with Algodoo programme contain much less detail than the applications using Arduino and the cognitive load is less. While there are extra processes such as the working principle of the sensors, electrical connections, data collection and data analysis in the lessons carried out with Arduino, in the applications carried out with Algodoo, only the tools in the programme were used in the process of designing the relevant simulation. In addition, the people in the classes in which the lessons were conducted were people who received distance education for 2 years between the years of 2020-2022, and this may have created a higher learning disposition towards virtual learning environments.

Conclusions and Suggestions

Under the illuminations of the results presented, it can generally be concluded that Arduino-based and Algodoo-based teaching efforts have both positive effects on achievement. The importance of adapting experimental and up-to-date activities to courses such as physics is obvious. Therefore, it is essential to maintain this need via experimental activities using microcontrollers such as Arduino, which would motivate the students by increasing the sense of curiosity compared to the usual ordinary content. Teaching sequences including very important skills such as technological literacy, coding, programming, and data analysis can be very inclusive and beneficial for the students in addition to very high achievements. Such experimental activities, which have serious advantages in terms of cost, have the potential to replace very high-cost experimental equipment and serve equal opportunities in education. There are many studies on the development of experimental activities using Arduino in physics education (Çoban & Erol, 2020; Erol & Oğur, 2023; Sarı & Kırındı, 2019). However, the number of empirical studies investigating the effects of these materials on students is relatively less. Therefore, the conclusion reached in this study that experimental applications using Arduino increases student achievement, is important.

The result that the courses using Arduino increase the success is in harmony with the results obtained in similar studies. Yıldırım (2020), concluded in his study that Arduino robotic coding-based STEM training increased the academic achievement of pre-service science teachers. Karim et al. (2015), stated that the use of robotic coding-based STEM training in science and mathematics courses has many positive effects on students, including success. Sarı et al. (2022), observed an increase in the problem-solving skills and entrepreneurship of pre-service teachers in their study in which they discovered that the integration of experimental activities using Arduino into STEM education has positive results. Ramadhan et al. (2023), concluded in their study that physics experiment-based learning blended with LabVIEW and Arduino was better than traditional teaching in improving students' critical thinking skills and academic achievement. Similar to these studies, in this study, it was underlined that teaching activities involving experimental applications using Arduino microcontroller have increased the achievement of pre-service science teachers in Physics 1 course. In addition to this result, it was observed that the pre-service teachers' motivation towards learning was high throughout the applications, and they had an attitude of learning by having fun in the lessons.

When the effects of the experimental activities using Arduino on mechanics subjects are analysed in detail, it is revealed that the simplicity of the activity and the awareness of the experimental processes in the activity increase the effects of the activities on success. The highest level of effect was observed in the work-energy unit, which was the last unit of the applications, and this situation shows that the increase in the awareness of the pre-service teachers towards extra processes such as programming and electronic connection increased the effect on success. Because these experimental processes carried out in this unit are almost the same as the ones carried out in the previous 3 units and therefore it is obvious that the study group's knowledge level towards these processes has improved. Another important factor, the simplicity of the activity, also comes to mind in view of the high impact result obtained in the vector topic. In the vectors unit, applications involving basic level data analyses were carried out with a single sensor and a very short code. These results are in parallel with the results obtained in previous studies that low cognitive load has positive effects on learning (Sweller et al., 2019). Therefore, in training supported by experimental activities using Arduino, it is important to equip the study group with basic electronics and software knowledge skills before the activities or to use activities at a basic level with simple content in order to have a higher impact on success. It will be useful to pay attention to these two factors in similar studies to be carried out in the future.

Algodoo physics simulation programme, which was used in the lessons carried out with the other experimental group, meets the need for experimental activities in physics education and at the same time directly serves the equality of opportunity in education, both because it is completely developed by considering the laws of physics and because it is completely free to download and use. In addition, the fact that it has an interface that can be easily used on smart boards and personal computers makes Algodoo programme very important in terms of physics courses, especially regarding the distance education, as well as ease of use in the classroom. In this study, it has been established that Algodoo-enhanced education increases the success in mechanics and this result is similar to the results obtained in previous studies in this direction in the literature. Çelik et al. (2015), found that the lessons carried out with high school 10th grade students using Algodoo increased academic achievement in physics courses and students presented original solutions to problems. Hırça and Bayrak (2013), in their study conducted with gifted students, mentioned that thanks to the features of Algodoo, it is motivating that users can create customised designs, make fun drawings based on physics and provide an interactive learning environment. Özer and Bilici (2021), revealed that the use of Algodoo-based activities in the force and motion subject of 6^{th} grade students had an effect on increasing students' engineering skills and conceptual understanding.

When the effect differences observed for the units were analysed, it was observed that the effect coefficient decreased as the complexity level of the tools included in Algodoo simulations increased, while the effect coefficient increased when simple simulations were used. In addition to this, it was also observed that the effect on achievement was increased when the simulations had content related to the basic knowledge and skills that the students already had. Both results are in line with previous studies showing that an increase in extraneous cognitive load has a negative effect on learning, while an increase in germane cognitive load has a positive effect on learning (Sweller et al., 2019). The large number of different contents of the simulations increases the extraneous cognitive load and this may be the main reason for the lower success effect in units such as dynamics and work-energy. In vectors, where the content is very simple, the effect level can be considered high, and here too the effect of low extraneous cognitive load is likely to be a factor. When the teaching practices carried out during the kinematics unit, in which the greatest effect was observed, are analyzed, it is seen that the content is very similar to the information at the high school level and from this point of view, it can be said that it increases the germane cognitive load. Therefore, it is important that the Algodoo applications have simple content and that they are connected with the students' prior learning in order to carry out more effective teaching processes on success.

Although there is no direct comparison of the two methods in the literature, there are studies showing that the two methods are superior to the traditional methods in previous studies. From this point of view, it can be assumed that the two methods show similar effects and that there is no difference between them in terms of success, which is consistent with the results in the literature. This result is important in terms of being a result comparing the two methods. In addition to these results, determining whether the fact that students were away from physical experiments in the distance education they received during the pandemic and that simulations were frequently used during distance education had any effect on their learning in their educational life after the pandemic is another situation examined in this study conducted with face-to-face education after the pandemic. It is important that the two different methods, whose superiorities over the traditional teaching method have been revealed in the studies, are basically separated from each other in terms of teaching lessons with experimental applications in the virtual environment and physical environment, and in this way, it is important to compare the two methods among themselves. This result is in line with other results showing that there is no difference between the learning status of students before the pandemic (Burkholder & Wieman, 2022; Nemeth et al., 2023; Zohbi et al., 2023).

When the effect coefficients are compared, it is seen that the effect level of the teaching activities using Algodoo is higher than those using Arduino. Algodoo applications have a higher effect level both in total scores and in sub-scores except for the energy unit. One of the two possible reasons for this situation is thought to be that Arduino applications involve more complex experimental processes and therefore more extraneous cognitive load. The other reason can be considered as the fact that the study group, which has been involved in distance learning for 2 years, has a higher ability to learn in a digital environment. In addition to these, the fact that the change in the scores of the study group in the Arduino group in the energy unit was higher than the Algodoo group shows that although the teaching using Algodoo was found to be more effective, Arduino experimental applications carried out in study groups equipped with the necessary prior knowledge have the potential to be more effective than Algodoo simulations.

As a result, in the study, it was seen that two different teaching practices, which were carried out by using experimental activities in physics education and had significant advantages in terms of cost, time and gaining different skills, were effective in increasing the achievement of pre-service science teachers in mechanics. Additionally, it was determined that there was no difference between the two methods in terms of the effect on achievement and therefore, virtual experiments and physical experiments did not have different effects on pre-service teachers in the subject of mechanics. Innovative experimental processes carried out in teaching practices are critical in terms of training teachers with 21st century skills, ensuring equality of opportunity in education and eliminating the lack of activities encountered in physics education in possible distance education. Therefore, this study showing that these methods have an effect on increasing success is important. It was also observed that the simplicity of the applications and the fact that the study group had the necessary prior learning were factors that increased the effect on success, and this result is also important for future studies.

Compliance with Ethical Standards

Disclosure of potential conflicts of interest

The author declares that there are no conflicts of interest, financial or otherwise, directly or indirectly related to the work submitted for publication.

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CRediT author statement

Atakan Çoban: conceived and designed the study, collected and analysed the data, and wrote the original draft of the manuscript.

Mustafa Erol: supervised the entire research process, provided guidance on data interpretation, and contributed to the review and editing of the manuscript.

All authors have read and approved the final version of the manuscript.

Research involving Human Participants and/or Animals

This study was reviewed and approved by the Ethical Committee of the Educational Sciences Institute at Dokuz Eylül University, Türkiye. All procedures followed national ethical guide-lines, and informed consent was obtained from all participants prior to their involvement in the study.

Arduino ve Algodoo Tabanlı Mekanik Öğretiminin Başarı Üzerindeki Etkileri

Özet:

Bu çalışma, Arduino ve Algodoo tabanlı mekanik öğretim etkinliklerinin akademik başarı üzerindeki etki düzeylerini araştırmaya odaklanmaktadır. Araştırma, bir devlet üniversitesinde öğrenim gören toplam 61 fen bilgisi öğretmen adayından oluşan iki deney grubuyla ön test-son test yarı deneysel yönteme dayalı olarak gerçekleştirilmiştir. Özellikle, vektörler, kinematik, dinamik ve iş-enerji üniteleri üzerine öğretim hedeflerine uygun olarak Arduino tabanlı ve Algodoo tabanlı eğitim materyalleri titizlikle geliştirilmiştir. Öğretim materyallerinin başarı üzerindeki etkileri Mekanik Başarı Ölçeği ile ölçülmüştür. Bulgular, Arduino tabanlı eğitimin başarıyı %28.21 oranında ve Algodoo tabanlı öğretimin başarıyı %28.83 oranında önemli ölçüde artırdığını göstermektedir. Ayrıca, etkinliklerin basitliği ve grupların deneysel süreçlerle ilgili ön bilgileri, uygulamaların etkililiğini artıran faktörler olarak ortaya çıkmıştır.

Anahtar kelimeler: Fizik eğitimi, Arduino, STEM, Algodoo, mekanik öğretimi, akademik başarı.

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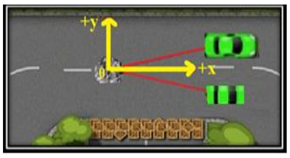
Appendix 1. Vector unit part of Mechanic Achievement Scale

MECHANIC ACHIEVEMENT SCALE



While Ahmet is driving, he sees that there is a huge rock on the road and tries to pull the rock using the rope in his car. However, Ahmet's car alone is not enough to pull this big stone. Thereupon, another vehicle passing by comes to help Ahmet. Initially the two cars try to move the rock by positioning the two vehicles far away from each other consequently they cannot move the rock again. Then, Ahmet as a good physicist says that they need to bring the vehicles much closer to each other and finally they could pull the stone to a safe place.

Answer the following questions by considering the problem situation and information given.

***1.** Express the following statements as true or false. Explain why you have identified it as incorrect. (5 points)*

i. If the angles of the cars and ropes with respect to +x axis were identical, the tension forces on the ropes would be equal.

ii. As the angle between the vectors is increased, the magnitude of the resultant vector decreases.

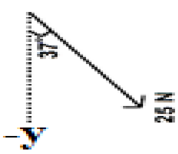
iii. Polar coordinates of the small car's position at the moment seen in the figure can be (+10, 30°).

iv. Cartesian coordinates of the big car shown in the figure can be (+10, +10).

v. If the coordinates of the position of the big car at the initial moment are (+10, +5), its position in unit vectors can be given as $\vec{r} = 5\vec{i} - 10\vec{j}$ in unit vectors.

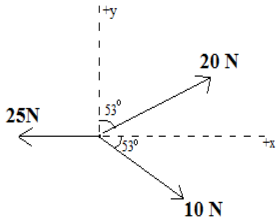
***2.** Consider that Cartesian coordinates of the stone's position are (0, 0) before the vehicles start pulling the rock. The Cartesian coordinates of the rock are (+9, +12) after pulling Calculate the polar coordinates of the final position of the stone and show it by drawing a figure. (5 points)*

***3.** Answer the following multiple choice questions. (2x2.5 points)*



i. Let the polar coordinates of the tension force on the rope attached to the small car be as shown in the figure. Accordingly, in which option are the Cartesian coordinates of the rope given correctly? (cos37=0.8; sin 37=0.6)

a) (20,15) b) (15,-20) c) (-15,-20) d) (-20, 15) e) (20, -15)



ii. If the forces acting on the stone as a result of the tensions and friction in the ropes were as in the figure, what would be the resultant force in Newton? (cos 53=0.6; sin 53=0.8)

a) 5 *b) 6* *c) 10* *d)* $6\sqrt{3}$ *e)* $10\sqrt{2}$

***4.** As soon as the vehicles start to apply force on the ropes, the tension force on the rope connected to the small vehicle is 15 N and the polar coordinates of the location of the small vehicle* (R_s, 307^0)*. The tension force in the rope attached to the large vehicle is 20 N and the polar coordinates of the location of the large vehicle are* ($R_{b,}$ 37^0)*. Determine the magnitude and direction of the resultant force acting on the stone at that instant. (10 points)*

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Research Article

Determining Gifted Students' Nature of Science Images, Creativeness, Nature of Science Metaphors, and Nature of Science Myths through Image Art*

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Abstract – The current research aimed to explore gifted students' perceptions of the nature of science, creativity, metaphors related to the nature of science, and myths about the nature of science through image art. Image art allows students to depict their mental representations of concepts by drawing and making analogies. The study was conducted with 17 gifted students at a school for gifted students in Ankara Province during the 2023–2024 academic year. The research employed a case study design, one of the qualitative research methods. In the data collection process, gifted students were asked to draw "how the scientists construct scientific knowledge" based on image art. The primary data collection tool was "art sheets illustrating how scientists construct scientific knowledge," created by the gifted students. Descriptive and content analysis techniques were applied to analyze the collected data. At the end of the study, the gifted students' representations of scientific inquiry and scientists were predominantly traditional. The inventiveness of their drawings was average. Also, they had different nature of science metaphors such as "Science is brain." being the most frequented one. While the students exhibited some myths about the nature of science, they also demonstrated an understanding of certain aspects of it. The importance of the current research was to give an idea to researchers working on gifted students' nature of science perspectives so that they would be able to construct proper teaching environments.

Keywords: Gifted students, nature of science knowledge, creativity, metaphors, myths.

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Introduction

In today's globalized world, it is crucial to determine students' images of the nature science and then to design learning environments for them based on the true knowledge of the nature of science being aware of their prior science images in their mental schemes. This approach enables students to develop proper scientific skills, enhancing their ability to compete in international job markets and contribute to creating new scientific knowledge and technologies.

Among all students, those who perform significantly better in academic settings are recognized as gifted students. Gifted students represent only a small percentage of the total population. However, educating gifted students—particularly by helping them develop accurate scientific understandings—is crucial, as they tend to have the highest motivation for science. This motivation positions them as key contributors to the future creation of scientific advancements and technologies.

Giftedness refers to the sum of biological, pedagogic, psychological, and psychosocial factors that are higher than the average values (Subotnik et al., 2011). Gifted students show higher potential at least in one of the fields such as intellectual ability, specific academic ability, productivity ability, leadership ability, art ability, and psychomotor ability according to the Maryland report (Schiver & Maker, 2003, as cited in Sak, 2017, p.5). In a more specific definition, gifted students were defined as students showing higher performance than their peers in specific fields or at least in a specific field (Ataman et al., 2018, p. 24).

The gifted students' education environments must be constructed according to their learning needs (Bilim ve Sanat Merkezleri Yönergesi, 2024). The gifted students' education environment must be on the philosophy of acceleration and enrichment. Acceleration means utilizing higher teaching targets from upper-class levels to the current ones. Enrichment refers to providing learners with opportunities to engage with diverse subjects that differ from their regular school curriculum (Rogers, 2007; Subotnik et al., 2011). But first of all, when designing teaching environments aimed at helping gifted students develop scientifically accurate conceptions—whether for advanced objectives or diverse topics—it is essential to understand their existing knowledge about the nature of science.

There were so many studies in literature researching the gifted students' science images (Bayri et al., 2016; Camcı-Erdoğan, 2013a; 2013b; 2018; Ozel & Dogan, 2013; Turgut et al., 2017). However, the studies in the literature are limited only to seeking the gifted students' scientific images. The findings of these studies revealed that gifted students also held traditional perceptions of scientists. For example, they often depicted scientists as male and portrayed their appearances as eccentric or crazy.

In the literature, Gorgulu and Unlu (2024) uncovered the nature of evaluations of students enrolled in Science and Art Centres in Türkiye. A case study design, which is a qualitative research method, is utilized. The study focused on 60 gifted secondary school students educating Seljuk Science and Art Centre in the 2022-2023 academic year. Nature of Science Assessment Scale was employed as a data collection tool. Descriptive analysis was used for the gathered data. At the end of the study, it was found that most gifted students believed the views of scientists would not influence scientific knowledge. The study indicated that talented students predominantly held the belief that scientists' observations were fundamental to the development of scientific knowledge and that both conclusions were inconsistent with the perspective on the nature of the science.

Ersanli et al. (2018) investigated attitudes and images of gifted students towards scientists in their research. They conducted their study on 34 gifted students from 5th, 6th, and 7th grades. “Chambers' (1983) Draw a Scientist Scale”, “Scientific Person Attitude Scale” and “Personal Information Questionnaire” were utilized as data collection tools. According to findings of the story, it was found that the gifted students thought that scientists wore lab coats and glasses, appeared messy, and worked in laboratories. Also, it was found that the gifted female students generally drew female scientists whereas the gifted male students drew male scientists.

Camcı-Erdoğan (2013a) investigated the images of scientists held by gifted students. The study involved 25 gifted students from 7th and 8th grade levels. The "Chambers (1983) Draw-A-Scientist Scale," a well-known tool in the literature, was used for data collection. Specific criteria were applied to analyze the collected data. The findings revealed that the gifted students often depicted scientists in stereotypical ways, such as wearing glasses and laboratory coats, working with test tubes, beakers, and books, and being portrayed as solitary males.

Bayri et al. (2016) studied 64 secondary school gifted students to seek their scientific understanding. Drawing a scientist scale was used as a data collection tool. Also in this research, the students compared their scientists with worldwide popular scientists and their national scientists. Glasses and lab coats were the findings of both worldwide popular scientists and the national scientists. Ozel and Dogan (2013) studied with 42 gifted students.

They also utilized drawing a scientist scale as a data collection device. The findings also showed that the gifted students had typical images of scientists, consistent with those reported in the existing literature.

In another study Turgut et al. (2017) investigated 24 secondary school gifted students' images of scientist at a science and art center, which is a school for gifted students in Sinop province. The researchers devised a data-gathering instrument of six open-ended questions. Content analysis was utilized for the gathered data. Lab environment, lab coats, glasses, and hair were apparent parameters identified in the study for students' science and scientist determination.

Camcı-Erdoğan (2013b) conducted another study focusing on gifted girls' scientific attitudes and their images of scientists. The study included 11 gifted girls from 7th and 8th grade levels. The "Chambers (1983) Draw-A-Scientist Scale" and the "Moore and Foy (1997) Scientific Attitude Inventory" were used as data collection tools. The findings revealed that the girls' perceptions of science and scientists revolved around themes such as laboratories, lab coats, glasses, and the use of test tubes and beakers, with scientists often depicted as working in isolation.

Camcı-Erdoğan (2018) also compared the gifted students' scientist images with the scientist images of the pre-service teachers' images. The pre-service teachers were educated on gifted education field. 27 gifted students and 32 pre-service teachers participated in the study. The research was conducted based on a survey model. Drawing a scientist scale was used. According to the results, gifted students showed more typical characteristics in their drawings compared to pre-service teachers, including elements such as glasses, lab coats, a messy appearance, and laboratory settings.

In the literature, there is also a study investigating gifted education candidate teachers' and elementary education candidate teachers' perceptions of scientists (Camcı-Erdoğan, 2019). 92 volunteer teacher candidates, from gifted education and elementary education, participated in the study. The study was a survey research. "Draw-a-Scientist Test" and "Science/Pseudoscience Distinction Scale" were utilized as data collection tools in the study. The study results showed that both groups of teachers' drawings reflected stereotypical perceptions of scientists in terms of appearance, work, and gender. Moreover, the elementary education teacher candidates were found to reflect more stereotypical characteristics in their drawings of scientists than the gifted education teacher candidates according to the results of the independent samples t-test. Also, the candidates‘ science/pseudoscience distinction scores did not significantly differ. Being aware of candidate teachers' scientist images and then educating them according to these findings are important since in future classes, they would be the priors for teaching the nature of science knowledge to their students.

Also, in the literature, Kocak et al. (2016) studied gifted students' metaphors about scientists. 56 gifted students educated at a school for gifted participated in the study in Erzurum province. Phenomenological design was used. Sentences like "Scientists resemble … because …" were used as data collection tools and content analysis was conducted. Six categories: "concerning their necessity", "concerning their hard work", "concerning their usefulness", "concerning productivity", "concerning the source of variety" and "concerning intelligent individuals" were created by the students as metaphors. It was seen that they had positive metaphors for scientists.

In the literature, most studies have focused on gifted students' images of scientists. However, the current research aims to go beyond this by exploring gifted students' perceptions of the nature of science, their creativity, metaphors related to the nature of science, and myths about the nature of science through the use of image art. Image art allows students to depict their conceptual understandings and mental representations through drawings, using analogies to illustrate abstract concepts.

Understanding the nature of science equips students with knowledge about how science is conducted. Possessing an accurate understanding of the nature of science is essential, as it enables students to engage in scientific inquiry by designing and conducting their research projects in schools. Given that gifted students typically exhibit higher levels of motivation toward science compared to their peers, they are more likely to pursue scientific endeavors during high school and higher education. Moreover, assessing students' creativity is crucial not only because it is a key 21st-century skill but also because creativity is fundamental to producing innovative science.

Clarifying the nature of scientific knowledge and addressing myths surrounding it would be beneficial. Nature of science myths are common misconceptions about how science works. Some examples include: "Scientists do science alone", "Scientific knowledge can only be constructed through experiments", "Scientific knowledge is always current", "Scientific knowledge is objective", "Scientific theories eventually become scientific laws", "Scientific knowledge does not involve creativity or creative thinking" and "Social and cultural phenomena do not influence the nature of scientific knowledge". The scientifically accurate perspectives that challenge these myths are as follows: "Scientists work collaboratively to conduct scientific research" ,"Scientific knowledge can be constructed in various ways, including through experiments, observations, and critical thinking", "Scientific knowledge is not static; it is progressive and can change over time", "Scientific knowledge is subjective and includes the experiences and perspectives of scientists", "Scientific theories do not become scientific laws; they are distinct types of scientific knowledge", "Scientific knowledge involves creativity and creative thinking" and "Social and cultural phenomena influence the nature of scientific knowledge" (Lederman & Lederman, 2004; McComas, 1998).

The problem statements of the current research are as follows: "What are the gifted students' perceptions of the nature of science?" "What are the gifted students' levels of creativity in their nature of science image art drawings?" "What metaphors related to the nature of science do gifted students use?" and "What myths about the nature of science do gifted students hold?" Since the current study is qualitative, no hypotheses were formulated.

Method

The research design was a qualitative case study. In case studies, the researchers seek a situation in depth in case to understand its story in every detail (Stake, 1995). Therefore, in this study "determination of the gifted students' nature of science images, creativeness, nature of science metaphors, and nature of science myths" was sought in depth to understand every parameter in detail.

The current research was conducted on 17 gifted students at a school for gifted students in Ankara province in the 2023-2024 academic year. Convenience sampling was employed in the current study. The participants consisted of 17 gifted students enrolled in similar programs at a school for gifted students. In these schools, students are educated through specialized programs rather than being grouped by age. The participants' ages ranged from 13 to 15 years. The criterion for selecting the gifted students was their willingness to participate. Participants were informed in detail that they could withdraw from the study at any time. Ethical approval for the study was obtained.

The gifted students were invited to use visual art to create representations of "how scientists construct scientific knowledge" as part of the data collection procedure. The participants produced their drawings over seven lessons, allowing a suitable duration for scientific research application. To promote clarity and compliance with the standards, students were urged to inquire about their drawings from their peers, a scientific instructor, or an art instructor. The gifted students' drawings are illustrated in Figure 1. From left to right, the codes of the illustrations were as paticipant1 (P1), P2, P3 … P17 respectively.

Figure 1 The gifted students' drawings on how scientists construct scientific knowledge

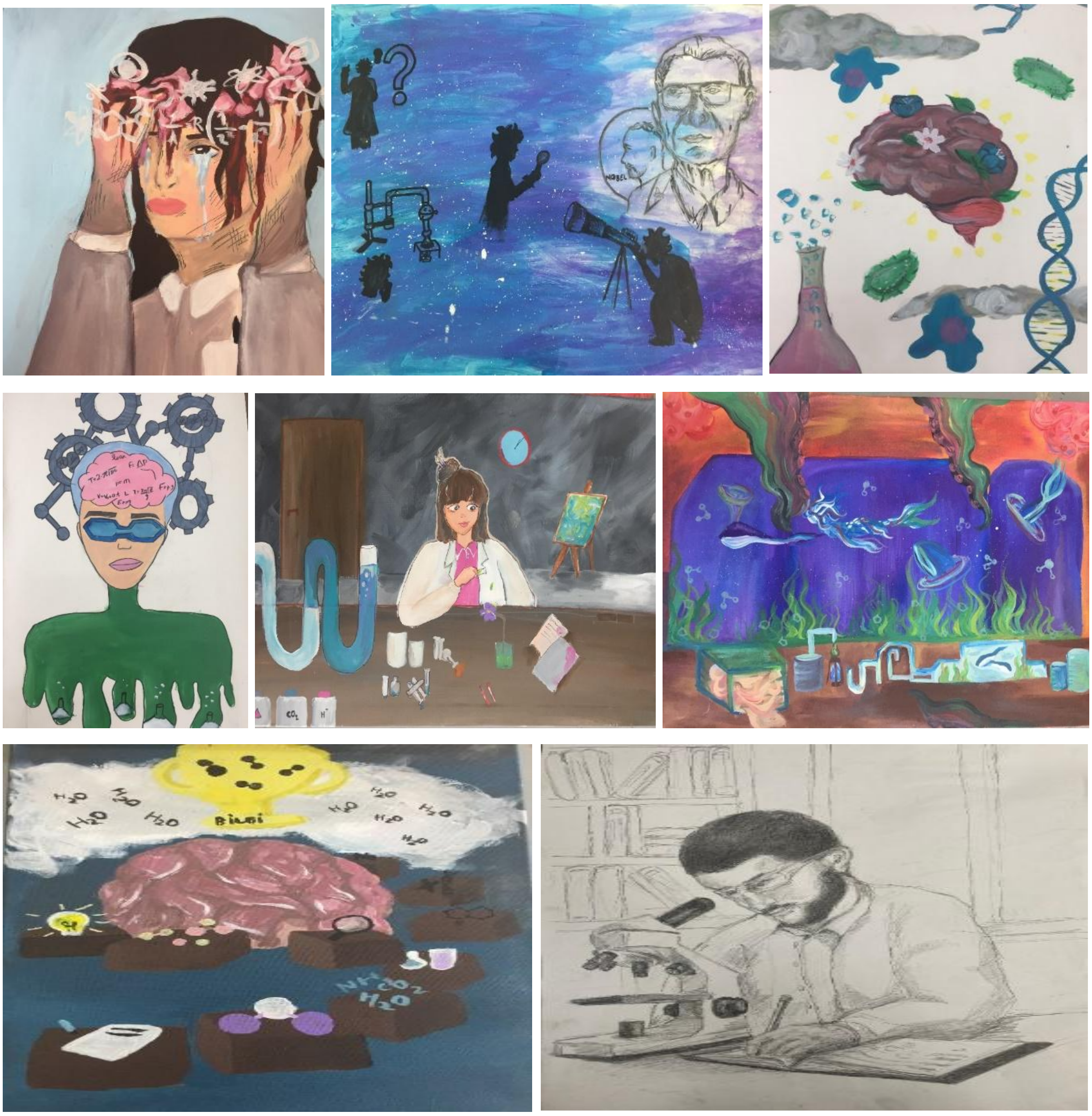

Figure 1 (continue) The gifted students' drawings on how scientists construct scientific knowledge

As noted in the literature, visual messages could be used as data-collecting tools (Bilgin, 2006). Therefore, in the current study, the data collection tools were "gifted students' art sheets illustrating how scientists construct scientific knowledge". Descriptive analysis and content analysis were utilized for the gathered data.

To determine the gifted students' nature of science images, codes, and categories were developed based on content analysis of the data collection tool. Descriptive analysis was used to assess the students' creativity levels in their drawings. The creativity scale developed by Kettler and Bower (2017) was adapted from the literature to construct the relevant codes and categories. Codes and categories were also developed based on content analysis to analyze the students' nature of science metaphors. Established myths from the literature (McComas, 1998) were used as codes to analyze the nature of science myths, and a descriptive analysis was conducted. Finally, the scientifically accurate nature of science images of the gifted students were analyzed using descriptive analysis based on literature codes (Lederman & Lederman, 2004; McComas, 1998).

Findings and Discussions

In this section, the findings on “how scientists construct scientific knowledge” are presented in Table 1. The data collected from the art sheets was analyzed using content analysis. Codes and categories were developed, and frequencies (f) for each code were calculated. In Table 1, the frequency is denoted by the letter "f." The total frequency for each category may not match the number of participants, as some participants either did not draw on the topic or provided more extensive drawings.

As shown in Table 1, the gifted students depicted scientists' fields of work in their drawings, including chemistry (f:12), biology (f:9), physics (f:3), astronomy (f:3), and mathematics (f:2). The students also portrayed scientists as women (f:5), men (f:4), or both together (f:1). In the analysis of the drawings, it was observed that the gifted students’ images of scientists’ work topics included compounds (f:8), viruses (f:4), elements (f:3), bacteria (f:2), plants (f:2), and celestial bodies (f:1). The students indicated that scientists construct knowledge by thinking (f:9), observing (f:5), experimenting (f:5), making mathematical calculations (f:3), or examining documents (f:1). Finally, in their drawings, the gifted students depicted various scientific equipment used by scientists, such as flasks (f:6), magnifying glasses (f:4), tubes (f:3), telescopes (f:3), volumetric flasks (f:2), droppers (f:2), distillation systems (f:2), microscopes (f:2), separatory funnels (f:1), computers (f:1), dyestuffs (f:1), spacecraft (f:1), and maps (f:1). As seen in Table 1, the gifted students' images of scientists and the process of constructing scientific knowledge largely reflected traditional representations.

Table 1 The Findings of How Scientists Construct Scientific Knowledge

Categories	Codes	f
Working disciplines	Chemistry	12
	Biology	9
	Physics	3
	Astronomy	3
	Mathematics	2
Gender of the scientist	Woman	5
	Man	4
	Woman and man	1
Working topics	Compound	8
	Virus	4
	Element	3
	Bacterium	2
	Plant	2
	Celestial body	1
How to construct knowledge	By thinking	9
	By making observation	5
	By making experiments	5
	By making mathematics calculations	3
	By examining documents	1
	By intuition	1
Equipment for making science	Flask	6
	Magnifying glass	4
	Tubes	3
	Telescope	3
	Volumetric flask	2
	Dropper	2
	Distillation system	2
	Microscope	2
	Separatory funnel	1
	Computer	1
	Dyestuff	1
	Spacecraft	1
	Map	1

Secondly, this section presents the gifted students' creativity levels based on their drawings, as analyzed through descriptive analysis. Kettler and Bower's (2017) creativity scale for gifted students was adapted for this analysis. The categories were based on the originality and the expansion of the drawing. Within these categories, the codes ranged from 0 to 3, depending on the development of the drawings. The frequencies of these codes were then provided. The results of the creativity analysis are presented in Table 2. In Table 2, the frequency is denoted by the letter "f", and the participant is denoted by the letter "P".

Table 2 The Findings of Gifted Students' Creativeness Levels

Categories	Codes			
	3	2	1	0
The originality of the drawing	A drawing much more original than the others *f:3* *P8, P9, P11*	A drawing more original than the others *f:14* *P1, P2, P3, P4, P5, P6, P7, P10, P12, P13, P14, P15, P16, P17*	A drawing reflects a bit of regularity	A regular drawing
The expansion of the drawing	A drawing much more detailed than the others *f:3* *P8, P9, P11*	A drawing more detailed than the others *f:14* *P1, P2, P3, P4, P5, P6, P7, P10, P12, P13, P14, P15, P16, P17*	A drawing consists of only a few details	Minimum detailed drawing

As seen in Table 2, the gifted students' drawings' originality was coded under the level 2 theme (f:14), and level 3 theme (f:3). Also the gifted students' drawings expansion was coded under the level 2 theme (f:14), and level 3 theme (f:3). So, it could be said that the gifted students' creativeness was in average levels.

In the third step of this section, the gifted students' metaphors about science were analyzed from their drawings based on content analysis. Codes were constructed and categorized; frequencies were also reported for each code. The gifted students' analyzed metaphors about science are shown in Table 3. In Table 3, the frequency is denoted by the letter "f", and the participant is denoted by the letter "P".

Table 3 The Gifted Students' Metaphors About Science

Category	Codes	F
Metaphor	Science is the brain.	f:9 *P1, P2, P3, P4, P5, P10, P12, P13, P16*
	Science is an eye.	f:2 *P1, P3*
	Science is the heart.	f:1 *P2*
	Doing science is painful.	f:2 *P4, P10*

The gifted students' metaphors as seen in Table 3, were *"Science is the brain."* (f:9), "Science is an eye." (f:2), *"Science is the heart."* (f:1), *"Doing science is painful."* (f:2). According to these findings *"Science is the brain."* is the common metaphor among the research's participant gifted students.

As the final part of the findings, gifted students' myths about the nature of science were analyzed. The myths were analyzed from student drawings based on descriptive analysis.

Codes were constructed based on McComas' (1998) nature of science myths, a category was constructed, and then frequencies were given for each of the codes. The gifted students' nature of science myths are given in Table 4. In Table 4, the frequency is denoted by the letter "f", and the participant is denoted by the letter "P".

Table 4 The gifted students' nature of science myths

Category	Codes	F
Nature of science myth	There is a universal scientific method.	f:6 *P5, P6, P7, P10, P14, P17*
	Scientific knowledge was constructed alone.	f:6 *P6, P7, P10, P13, P14, P17*

Table 4 shows the nature of science myths held by the gifted students, including *"There is a universal scientific method"* (f:6) and *"Scientific knowledge is constructed alone"* (f:6). It can be noted that there was little diversity in the myths held by the participants, as only two myths were analyzed.

Additionally, the gifted students' nature of science knowledge was analyzed based on the data collection tools. The data was analyzed using descriptive analysis. Lederman and Lederman's (2004) and McComas' (1998) studies were used to develop codes for the nature of scientific knowledge. The category was then created, and frequencies for each code were calculated. The results of the analysis of the students' nature of science knowledge are presented in Table 5. In Table 5, the frequency is denoted by the letter "f", and the participant is denoted by the letter "P".

Table 5 The gifted students' nature of science knowledge

Category	Codes	F
Nature of science knowledge	There are so many ways to gather data.	f:11 *P1, P2, P3, P4, P8, P9, P11, P12, P13, P15, P16*
	Scientific knowledge was constructed by a scientific team, not alone.	f:3 *P8, P9, P11*

Table 5 illustrates the perspectives of gifted students regarding the nature of science, with one student stating, *"There are so many ways to gather data"* (f:11). *"Scientific knowledge is constructed by a scientific team, rather than by an individual alone"* (f:3).

Three independent researchers collaborated to code and categorize the data collected from the drawings of gifted students, as the data comprised visual messages. When disagreements arose during the coding process, a new, shared code was created to resolve the issue. The independent analysis by multiple researchers was used to enhance the validity of the research (Guion et al., 2002). Additionally, to ensure the plausibility of the qualitative research, all the gathered data is presented in Figure 1.

Conclusions and Suggestions

At the end of the study, the gifted students' images of scientists depicted them as either women or men, mostly working in the fields of chemistry or biology, researching compounds, elements, bacteria, viruses, or plants. These scientists were shown gathering data through thinking, observation, experimentation, and/or calculations, and using equipment such as flasks, magnifying glasses, tubes, telescopes, volumetric flasks, droppers, distillation systems, and/or microscopes. The findings revealed that the gifted students predominantly held a traditional image of scientists, similar to previous studies (Bayri et al., 2016; Camcı-Erdoğan, 2013a; 2013b; 2018; Ozel & Doğan, 2013; Turgut et al., 2017). This traditional view may be a result of their prior learning experiences. To enhance gifted education, it is advisable to conduct a thorough review of contemporary scientific research, emphasizing modern representations of scientists and their practices. Also in literature, it is emphasized the importance of gifted students to gain a modern nature science perspective as "flexible, interdisciplinary, skill in collaboration, communication across region and culture, and conscious consideration of ethical implications of the work produced." (Gallagher, 2021).

The creativity of the gifted students was analyzed using Kettler and Bower's (2017) creativity scale for gifted students. The originality of their "how to make science" drawings was rated at level 2, while the expansion level of their drawings was also at level 2, on a 0-3 scale. This indicates that their creativity levels were average. This could be attributed to the limited use of visual messages in gifted education. To enhance the creativity of gifted students, it may be helpful to design enrichment environments that incorporate more drawing activities focused on common science concepts, providing students with the opportunity to express themselves and boost their creativity. As in the literature, extracurricular learning experiences were offered to promote their creative thinking (Ngiamsunthorn, 2020).

The gifted students' metaphors for science included "Science is a brain," "Science is an eye," "Science is a heart," and "Doing science is painful." Among these, "Science a brain" was the most common metaphor among the participants in the study. While there have been some studies on gifted students' metaphors about science, particularly in the context of image art, such studies are relatively rare in the literature. For example, there is a study examining gifted students' scientist metaphors, but not specifically science metaphors (Kocak et al., 2016). Therefore, this research makes a unique contribution to the literature in this regard. In literature, it was underlined that determining gifted students' metaphors was important so that by being aware of their metaphors, proper educational environments could be constructed (Özdemir & Kınık-Topalsan, 2022).

The nature of science myths held by the gifted students was identified as "There is a universal scientific method" and "Scientific knowledge is constructed alone." Only two myths were analyzed in this study, which could be due to the limited number of participants (17 gifted students). In future studies, a larger sample of gifted students could be employed, especially if the research adopts a quantitative approach rather than the current qualitative one. Additionally, it is worth noting that the limited diversity like science myths among the participants may be attributed to enrichment studies in gifted education that focus on science-related themes.

The gifted students in the study also expressed views on how to do science, such as "There are so many ways to gather data" and "Scientific knowledge is constructed by a scientific team, not alone." These scientifically accurate perspectives are a valuable contribution to the literature, as the participants not only held myths but also demonstrated true understanding of the nature of science. It is worth noting that, in the literature, studies on gifted students' myths and scientific knowledge about the nature of science, based on image art, are relatively rare. Therefore, the current research again makes an important contribution to the field. Camcı-Erdoğan (2013a, 2013b) examined the images of scientists held by gifted students and discovered a prevalent belief that "Scientists work alone," a finding that is consistent with the results of the current study.

The main suggestion of the current research is that educators and researchers working in the field of gifted education should be aware of gifted students' nature of science knowledge, myths, metaphors, and creativity levels. This awareness will help in constructing the effective nature of science teaching environments, tailored to their prior knowledge and experiences. For instance, by recognizing gifted students' gaps in science knowledge and their misconceptions (e.g., nature of science myths), educators could implement project-based learning experiences focused on realistic, real-life problem-solving. Additionally, Lederman and Lederman (2004) recommended that when designing science curricula, it may be more practical to focus on a few key aspects of the nature of science knowledge rather than attempting to address all aspects at once. Ayverdi et al. (2025) offered in their research, that gifted students developed more positive views of science and scientists, once the gifted students found the science activities both engaging and informative. In addition to all, also in literature Gorgulu and Unlu (2024) mentioned the importance of implementing targeted activities for making gifted students gain a scientific nature of science view.

Compliance with Ethical Standards

Disclosure of potential conflicts of interest

No conflict of interest.

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Credit author statement

All authors took part in writing the article. First author also made editing and reviews as corresponding author.

Research involving Human Participants and/or Animals

The study involves human participants. The ethics committee permissions were obtained with the letter dated 26.05.2023 and numbered: E-50704946-100-298736 of the "Educational Sciences Scientific Research and Publication Ethics Committee of Sivas Cumhuriyet University."

İmge Sanatı Yoluyla Özel Yetenekli Öğrencilerin Bilimin Doğası Algılarının, Yaratıcılıklarının, Bilimin Doğası Metaforlarının ve Mitlerinin Belirlenmesi

Özet:

Bu çalışmada imge sanatı yoluyla özel yetenekli öğrencilerin bilimin doğası algılarının, yaratıcılıklarının, bilimin doğası metaforlarının ve mitlerinin belirlenmesi amaçlanmıştır. İmge sanatı öğrencilerin zihinlerindeki kavram imajlarını analojiler, benzetmeler yoluyla çizimler yaparak açıklamalarına imkan verir. Bu çalışma Ankara ilinde özel yetenekli öğrencilerle öğretim yapan bir kurumda 2023-2024 öğretim yılında 17 özel yetenekli öğrenci ile yürütülmüştür. Çalışma nitel araştırma desenlerinden durum çalışması temelindedir. Veri toplama sürecinde özel yetenekli öğrencilerden "bilim insanlarının nasıl bilimsel bilgi ürettiği" sürecini imge sanatıyla resmetmeleri istenmiştir. Çalışmanın veri toplama aracı özel yetenekli öğrencilerin "bilim insanlarının nasıl bilimsel bilgi ürettiğini" resmettikleri sanat yapraklarıdır. Veriler betimsel analiz ve içerik analizi ile çözümlenmiştir. Çalışmanın sonunda bilimin nasıl yapıldığı ve bilim insanlarına dair özel yetenekli öğrencilerin genellikle geleneksel bir bakış açısına sahip olduğu bulunmuştur. Özel yetenekli öğrencilerin bilimin nasıl yapıldığı çizimlerinin yaratıcılık düzeyleri orijinallik ve ayrıntılandırılmışlık bakımından orta düzeydedir. Ayrıca özel yetenekli öğrencilerin bilimin doğasına dair metaforları da vardır. "Bilim beyindir." çalışma kapsamındaki yaygın metaforlardan biridir. Özel yetenekli öğrencilerin bilimin doğası mitlerine sahip olmalarının yanında bilimin doğası boyutlarına dair de bilimsel olarak doğru algıları vardır. Bu çalışmanın bilimin doğası öğretimi üzerine çalışan araştırmacılara özel yetenekli çocukların ön bilgilerinden haberdar olarak öğretim ortamlarını yapılandırmaları adına bir rehber olması amaçlanmıştır.

Anahtar kelimeler: Özel yetenekli öğrenciler, bilimin doğası bilgisi, yaratıcılık, metafor, mit.

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Research Article

The Connection between Children's Literature and Mathematics: Reflections from Problem Posing Situations of Prospective Mathematics Teachers*

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Abstract – Utilizing interdisciplinary connections in teaching mathematics increases the quality of teaching and makes learning more effective and permanent. In this study, the connection between children's literature and mathematics was discussed and this connection was examined through problem posing. The relevant research was conducted with a case study design, which is one of the qualitative research methods. In this direction, 6-week tasks were carried out intermittently for prospective mathematics teachers regarding the connection between children's literature and mathematics. As a result of these tasks, prospective mathematics teachers were asked to pose as many problems as they could using a visual in a book of children's literature. 66 mathematical problems posed by 27 prospective mathematics teachers were evaluated descriptively with the problem posing evaluation criteria including the themes of "Content", "Mathematical Connection" and "Creativity", and the frequencies for the themes were presented in a table. As a result of the study, it was concluded that the connection between children's literature and mathematics positively affected the mathematical connection skills and creativity of the prospective teachers. At the same time, it was observed that the number of problem-solving strategies used in the problems posed by the prospective teachers was high and the most preferred problem-solving strategy was mathematical reasoning.

Keywords: Children's literature, connection, creativity, mathematics education, problem posing, prospective teachers.

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Introduction

Mathematical connections have an important place in mathematics teaching as a concept that is necessary for individuals to understand their environment, see the connection between relationships in daily life, be aware of the communication between different disciplines and structure mathematics better (Eli et al., 2011; Özgen, 2017). In the various mathematics teaching programs that we use in education and training today, it is clearly emphasized that making connections is one of the processes of learning to do mathematics (Özgen, 2013).

The members of the National Council of Teachers of Mathematics (NCTM, 2000), which develops standards to determine the content of mathematics curriculum, defines mathematics teaching as teaching that encourages students to communicate their mathematical ideas, emphasizes problem-solving and problem-posing skills, develops reasoning, and ensures the training of individuals who can show and use connections within mathematical subjects and between different disciplines. In the general objectives section of the Mathematics Course Curriculum, it is emphasized that students can understand mathematical concepts and establish relationships with each other, and that the relationships they establish can be used both in other disciplines and in daily life, and that mathematical connections are important (Ministry of National Education [MoNE], 2018; 2024). Ma (1999) also expresses mathematical connections as mathematical nodes that bridge important key concepts with mathematical thoughts. It is said that mathematical connections will have a supportive effect on the construction of mathematics teaching on a more solid foundation by hosting positive features such as creating meaning, doing mathematics, establishing a bridge between new information and old information, and ensuring permanent learning by increasing the continuity of many ideas in the mind, and for this reason, it is emphasized that connections are an important building block that can strengthen mathematics teaching in the learning-teaching processes (Ball et al., 2005; Özgen 2017).

The data presented by the Programme for International Student Assessment (PISA) exam results, which allow for the assessment of many mathematical skills along with the ability to make connections, indicate that mathematical literacy and reading skills are not at a sufficient level in Türkiye and are below the average of OECD (Organisation for Economic Co-operation and Development) countries (Özmusul & Kaya, 2014). In this case, the relationship between mathematical literacy, which expresses the usability of mathematics in daily life (Pugalee, 1999), and children's literature, which is considered a powerful tool for the development of reading skills (Whitin, 1992), has begun to be addressed. In addition to developing students' reading skills, children's literature is also seen as a way to relate school mathematics to daily life. Drawing attention to mathematics in literature that covers daily life supports the emergence of mathematics inherent in human thought and communication about life experiences (Haury, 2001). However, it is thought that children's literature books can serve as an effective and important tool in using the daily life context in the process of teaching mathematical concepts (Van de Walle et al., 2016).

Many studies that included the connection between children's literature and mathematics teaching in international literature (Diakiw, 1990; Furner, 2018; Mink & Fraser, 2002; Raymond, 1995; Ward, 2005; Whitin, 1992; Zhang et al., 2023) and national literature (Ayvaz, 2010; Arslan-Başdağ & Dağlıoğlu, 2020; Demirci, 2023; Fırat & Dinçer, 2020; Kuş & Işık-Tertemiz, 2022; Yalçın et al., 2022) have revealed that this connection leads to positive results. When the literature is reviewed, it is seen that the connection between literature and mathematics; it has been observed that it supports understanding mathematical concepts and developing mathematical skills (Durmaz & Miçooğulları, 2021), directing students to think critically (Barnaby, 2015), developing a positive attitude towards mathematics (Van den Heuvel-Panhuizen & Boogaard, 2008) and realizing that mathematics is a part of daily life (Moyer, 2000). In addition, it has been stated that by integrating children's literature into the mathematics teaching process, students can more easily gain abstract thinking and problem-solving skills, which are seen as the most important elements of mathematical thinking (Aslan, 2019; Cankoy, 2011), that it will be useful for understanding the stated problem, which is the first step of the problem-solving stages (White, 2016) and that it is effective in helping to create an interesting problem model (Green, 2013). In this way, young children can develop their verbal and written skills to express themselves by reading storybooks, while at the same time they can have different opportunities to structure mathematical knowledge within themselves and discover new ways of learning (Edelman, 2017; Moyer, 2000).

Problem posing, which is thought to be at the heart of both mathematical and scientific research (Cai, 2003), is expressed as both the generation of new problems based on situations and the reformulation of given problems (Silver, 1994; Singer & Voica, 2015). Solving a problem requires the solver to use some degree of creativity or originality (Lenchner, 1983; Polya, 1957). Problem posing activities, which are closely related to problem solving, can also encourage flexible thinking, develop problem solving skills and sharpen students' understanding of mathematical content (English, 1996; Mallart et al., 2018; Ünlü, 2017;

Zhang et al., 2022). There is widespread agreement in mathematics education that students should be given opportunities to enhance their skills in mathematical problem-posing (Brown & Walter, 2005; NCTM, 2000). Therefore, problem posing, which is considered as a real mathematical task, maintains its important place in NCTM standards (Baumanns & Rott, 2022), and its importance in school mathematics has been emphasized to be widely accepted (Cai et al., 2016; Singer et al., 2013). Since the NCTM revealed that problem posing should be included in mathematics classrooms, the role of teachers in problem posing has become even more important (Lee et al., 2018).

Given the growing emphasis on problem posing within curriculum design and classroom teaching (Cai et al., 2015; Ellerton, 2013), it is crucial for teachers to not only understand students' perspectives on problem posing but also to effectively integrate this approach into their mathematics instruction (Cai et al., 2016). In particular, for teachers to successfully incorporate problem posing into their lessons, they must gain a deeper understanding of the cognitive processes students engage in when formulating problems. By anticipating students' responses to instructional tasks, teachers can plan and implement the most effective teaching strategies, thus optimizing the learning environment (Işık & Kar, 2012; Joaquin, 2023; Korkmaz & Gür, 2006; Xu et al., 2020). Moreover, problem posing serves not only as a tool for assessing student thinking but also as a strategy that enhances learning opportunities for all students (Cai & Hwang, 2020). Research has indicated that such tasks can alleviate students' anxiety, foster a more positive attitude toward mathematics, and contribute to improvements in their comprehension, problem-solving abilities, and relational skills (Barlow & Cates, 2006; Brown & Walter, 2005; Coşkun, 2013; Mersin & Akkaş, 2023; NCTM, 2000; Silver, 1994). Problem posing is considered one of the most effective methods in mathematical thinking and learning processes (Cai & Hwang, 2020). While significant progress has been made in problem-posing research (Cai et al., 2015), studies focusing on prospective teachers creating mathematical problems through the lens of children's literature are limited (Arslan & Kartal, 2023). This gap highlights the originality of the study and its potential to fill a crucial void in the existing literature.

One effective strategy for teachers to develop rich mathematical problems is by grounding scenarios in stories from children's literature. This approach enables educators to foster students' problem-posing abilities by incorporating literature into mathematics instruction (Young & Marroquin, 2006). In addition, integrating children's literature into mathematical reasoning not only enhances the relevance and engagement of mathematics lessons but also provides prospective teachers with an opportunity to cultivate students' creativity and critical thinking skills. This dual benefit underscores the importance of incorporating literary elements into the teaching of mathematics, enriching both cognitive and problem-solving capacities.

In this context, the research problem was formulated as follows:

"How are the reflections of mathematics education practices connected with children's literature on the problem-posing situations of prospective mathematics teachers?"

The study aims to provide valuable insights into how these connections are reflected in the problem-posing tasks of future educators, potentially contributing to the development of innovative teaching methods. Additionally, it emphasizes the importance of adopting an interdisciplinary approach in mathematics instruction, offering students the opportunity to recognize connections between various fields and understand the role of mathematics in real-life contexts. The findings could guide stakeholders involved in developing educational policies and teaching strategies, providing recommendations on how to effectively incorporate children's literature into future mathematics education.

Method

Research Design

Due to the existence of a situation where the researcher collects detailed and in-depth information, this study was conducted with a case study design from qualitative research methods. A case study is a qualitative approach in which the researcher collects detailed and in-depth information about real life or situations with the support of multiple sources of information and describes the situation (Creswell & Poth, 2016). This design, which covers topics including community work, education, social problems and conflicts, has a very important role in facilitating the meaning of complex situations (Yin, 2009). Since the aim of this study was to examine in detail the reflections of mathematical tasks connected with children's literature on the problem-posing of prospective teachers, a case study design was considered appropriate.

Participants

The study group of this research consists of 42 prospective mathematics teachers enrolled in the "Connections in Mathematics Education" course in the Primary School Mathematics Teaching program at a state university in Bursa during the spring semester of the

2022-2023 academic year. In the later stages of the research, based on the scope and nature of the collected data, prospective teachers who actively participated in the process were selected and the study was conducted in detail with 27 prospective mathematics teachers. In addition to this situation, it is known that only eight of the 27 prospective mathematics teachers took the "Problem Solving in Mathematics" course before these tasks. The prospective teachers who participated in the research were determined on a voluntary basis and were included in the process with the explicit consent of the participants. The identities of the participants were kept confidential throughout the research period and each participant was given codes as "S1", "S2", "S3" to ensure anonymity. The demographic characteristics of the prospective teachers in the study group are provided in Table 1.

Table 1 Demographic Characteristics of the Prospective Teachers in the Study Group

Grade Level	Age	Female	Male	Total
First-year undergraduate student	-	-	-	-
Second-year undergraduate student	19	-	1	9
	20	5	-	
	21	3	-	
Third-year undergraduate student	20	3	-	15
	21	6	2	
	22	2	1	
	23	1	1	
Fourth-year undergraduate student	21	1	-	2
	22	-	1	
Total		21	6	27

Data Collection

The present study, mathematics prospective teachers participated in mathematics tasks integrated with children's literature as part of the "Connections in Mathematics Education" course. Since the content of the course covers various aspects of mathematics teaching, the implementation process was planned and conducted within a six-week training program, which was spaced over time. The main components of this training program include the role of children's literature in mathematics teaching, the effective use of children's literature works in line with teaching goals, and the selection of appropriate children's literature books. Throughout the training process, various children's literature works, addressing different cognitive developmental levels of each age group and containing a variety of content and themes, were used in tasks. Additionally, this process was meticulously planned to ensure that the prospective teachers could learn by integrating mathematical concepts with children's literature in a hands-on manner, and was structured in harmony with various topics of the course. The selection of books was made in a way that reflected this alignment. The educational process is presented in Figure 1.

In this study, certain sections of the books "I Solve These Problems Quickly" and "Jayden's Rescue", which are thought to integrate children's literature and mathematics more strongly, were carefully examined during the course process and the problems in these books were solved by prospective mathematics teachers. During this process, special attention was paid to how the mathematical concepts presented in the books were integrated with children's literature, and efforts were made to ensure that the prospective teachers understood these connections. Later, in accordance with the course's aim to relate mathematics to daily life, specific sections of the books "Vicious Circles and Other Savage Shapes" and "Math Curse" were read, and tasks from these books were carried out. These books were carefully chosen for their ability to concretize mathematical concepts within daily life contexts and help the prospective teachers see how mathematics could be applied in real-life situations.

In the final weeks of the process, books without direct mathematical content were intentionally selected. This conscious decision was made to help the prospective teachers develop their problem-posing skills using books that did not contain mathematical situations, as well as to creatively explore the relationship between these types of books and mathematical concepts. Thus, the prospective teachers were provided with the opportunity to assess their mathematical thinking skills and problem-posing abilities through children's literature.

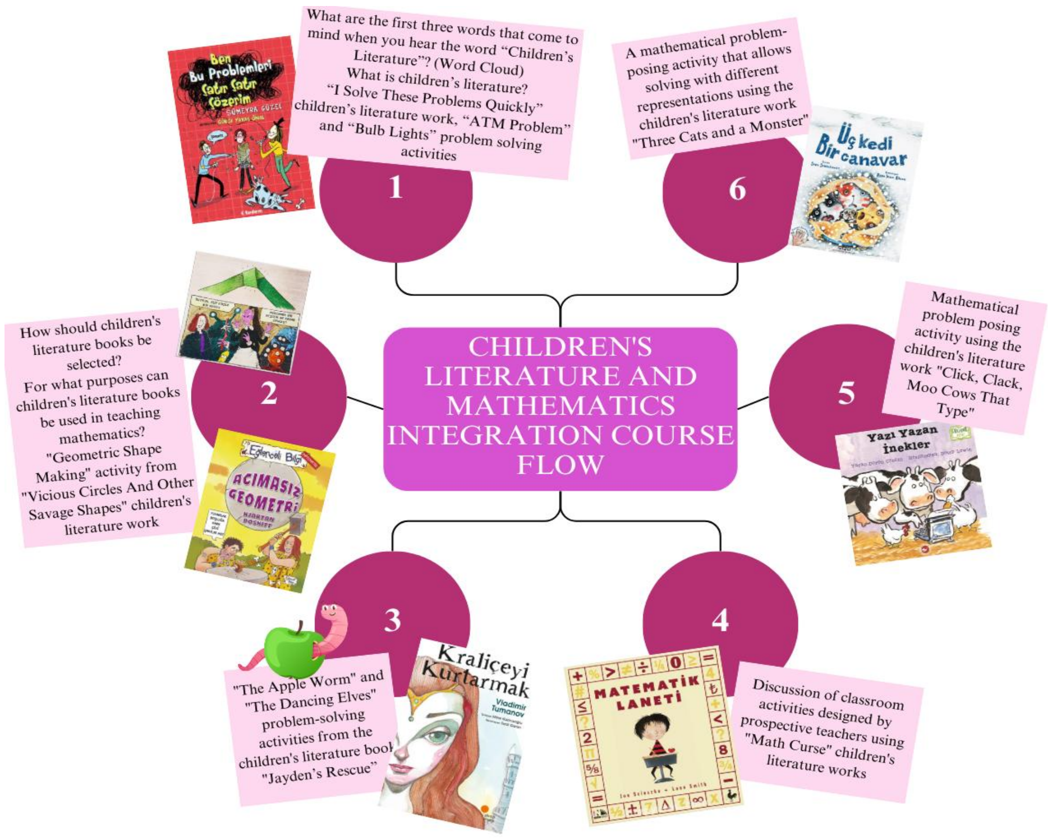

Figure 1 Children's Literature and Mathematics Integration Course Flow

As part of the tasks, the participants were asked to create as many mathematical problems as possible based on an image from a selected children's literature book. They were also expected to explain the features they considered while shaping the problems they created. This task enabled the participants to engage in a creative problem-solving process by relating mathematical concepts to children's literature works. The image used for the task considered in this study is presented in Figure 2.

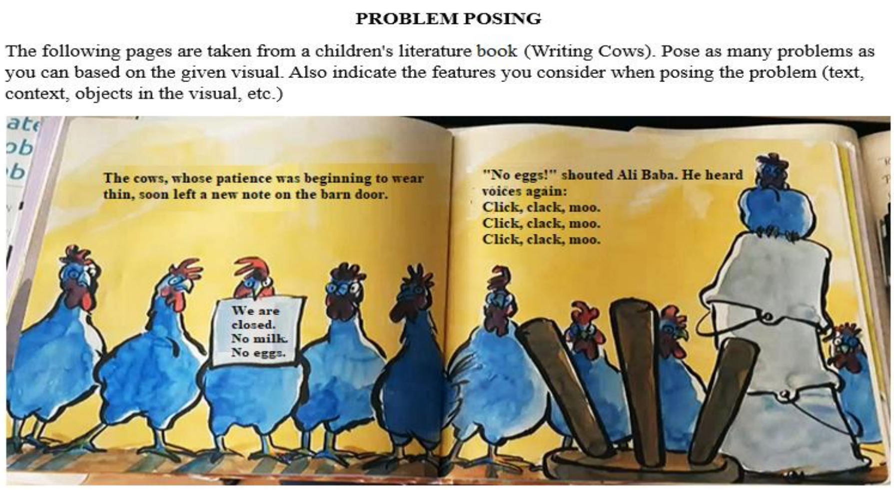

Figure 2 Data Collection Tool

This research was conducted concurrently with the master's thesis by one of the researchers, where the prospective teachers underwent the same training; however, the research questions and data collected vary. In this study, the link between children's literature and mathematics is explored through the problems posed by prospective mathematics teachers.

Data Analysis

Descriptive analysis aims to organize, interpret, and present data to the reader (Baltacı, 2019). This approach allows data to be categorized according to specific themes (Kitzinger, 1995). Thus, data can be structured and presented based on the themes that arise from the questions within the data collection tool (Yıldırım & Şimşek, 2021). In this context, the mathematical problems created by prospective teachers within the framework of integrating children's literature and mathematics were subjected to descriptive analysis and thoroughly examined according to criteria determined by the researchers and expert opinions. The analysis focused on three main criteria: "Content", "Mathematical Connection", and "Creativity". The content criterion was further examined with the subcategories of "Learning Area", "Mathematical Problem-Solving Strategies" and "Context".

The learning area reveals which mathematical topics the prospective teachers chose to create problems, allowing for an evaluation of their subject knowledge and their ability to apply this knowledge. The learning areas were categorized according to the learning areas defined by the Ministry of National Education (MoNE, 2018). Mathematical problem-solving strategies indicate how the candidates prefer to solve the problems they encounter and which methods and tools they use, providing insights into the depth of their problem-solving abilities. Context refers to the life situations addressed by the created problems and the contexts chosen by the prospective teachers were classified according to the four main categories defined by the OECD (2003). These categories—personal, occupational, social, and scientific—help us understand how well prospective teachers can relate their mathematical thinking skills to real-life situations. Mathematical connection is an important criterion that assesses the candidates' ability to make meaningful connections between mathematics, daily life and other disciplines, offering insights into the complexity of their mathematical thinking processes. Finally, the creativity criterion highlights how candidates go beyond traditional solution methods, showcasing their ability to think innovatively and creatively. This serves as an indicator of how creative and innovative prospective teachers are in the process of problem creation and solving. All of these criteria allowed for a multidimensional analysis of the problem-creation processes of prospective teachers and provided a more comprehensive evaluation of the effectiveness of the methods used in education. The "Evaluation Criteria for Posing Mathematical Problems" are presented in Figure 3.

Themes	Codes	Analysis Detail
CONTENT	Mathematical problem solving strategy	Which problem solving strategy(ies) does the problem posed require in its solution? Drawing a diagram, Solving a simpler related problem, Finding a pattern, Making an organized list, Mathematical reasoning, Writing an equation, Working backwards Strategy types are limited to the strategy types preferred by prospective teachers.
	Learning Area	Which mathematical learning area is the problem set up for? Learning areas preferred by prospective teachers are categorized according to the learning areas determined by the Ministry of National Education (2018). Numbers and Operations, Algebra, Geometry and Measurement, Data Processing, Probability.
	Context	Which context was used when posing the problem? Context is the vital situation in which the problems are dressed (Altun, 2020). The contexts used by the prospective teachers are categorized according to the context types determined by the OECD (2003). The OECD (2003) considers real-world contexts in four categories. Personal: Problems classified in the personal context category focus on the activities of the person himself, his family, or his peer group (OECD, 2003). Occupational: Problems classified in the occupational context category focus on the world of work but must be accessible to the individual who will face the problem (OECD, 2003). Social: It may include things such as voting systems, public transportation, government, public policies, demography, advertisements, national statistics, and economics (OECD, 2003). Scientific: Problems classified in the scientific category may include areas such as weather, climate, ecology, medicine, space science, genetics, measurement, and the world of mathematics itself (OECD, 2003).
MATHEMATICAL CONNECTION	Connections Within Mathematics	Which mathematical topics or concepts have been associated with in the problem? Percentage, Integer, Algebra, Divisibility, Fraction, Probability. The specified concepts are limited to the concepts that prospective teachers use in problem-posing situations.
	Daily Life Connections	Daily Life Relation How is the daily life relation addressed in the problem? Exchange, Budget, Profit, Gift, Salary, Special Day, Raffle, Exchange. The specified concepts are limited to the concepts used by prospective teachers in problem posing situations.
	Interdisciplinary Connections	Have interdisciplinary connections been used in the problems posed?
CREATIVITY	Convergent vs. divergent thinking	Is the problem posed convergent or divergent within the group it is in (compared to other problems posed)? While new ideas are thought to be generated through divergent thinking within the scope of creativity, convergent thinking is generally associated with traditional ideas (Cropley, 2006).
	Fluency	How many problems did the prospective teachers pose for the given situation? What is the fluency score of the prospective teachers? 1-2-3 ….
	Flexibility	Are the problems posed by prospective teachers' problems that require the use of different problem-solving strategies?

Figure 3 Evaluation Criteria for Posing Mathematical Problems

The problems posed by the prospective mathematics teachers were coded independently by the researchers, adhering to the analysis details given above. A Microsoft Excel document was created for the data obtained from the 66 problems. Frequency, which is a descriptive statistic, was used in the analysis of the data obtained from the problem-posing situation, and the results were tabulated in an understandable and systematic way using frequency (f) values.

Validity and Reliability

Validity and reliability are two criteria widely used in the credibility of study results, which are considered to be one of the most important criteria of scientific research (Yıldırım & Şimşek, 2021). In qualitative research, it is critical to report the data collected in detail and explain how the researcher reached the results in order to produce valid results. In this direction, in order to contribute to the validity of qualitative research, that is, to confirm the accuracy of the results, receiving expert support at every stage, such as selecting the tools to collect data in the research, preparing these tools or interpreting the findings obtained, can have an increasing effect on the validity of the research (Denzin & Lincoln, 2008). In this context, another researcher who is an expert in the field of mathematics education was consulted regarding the "Evaluation Criteria for Posing Mathematical Problems" used in the evaluation of the mathematical problems posed by the prospective teachers.

For reliability, which is expressed as the repeatability of the results of the research in qualitative research, it can be stated that the study is reliable by taking into account the detailed explanation of the data collection process and data analysis (Miles & Huberman, 1994), supporting the research with various documents (Yin, 2009). In this context, the reliability formula recommended by Miles and Huberman (1994) was preferred for the reliability of the findings obtained from the mathematical problems posed by the prospective mathematics teachers using children's literature. Expert support was received to examine the problems posed and the percentage of agreement between the researcher and the expert for the problems examined was calculated. The formula is as follows;

$$\text{Reliability} : \text{Agreement Percentage} = \frac{\text{Number of Agreements}}{\text{Number of Agreements} + \text{Number of Disagreements}} \,.\, 100$$

The percentage of agreement between the researcher and the expert in the analysis of the posed problems was calculated as 91%. This value is shown as a sufficient level for the results to be considered reliable (Miles & Huberman, 1994). For the 9% of cases where the inter-rater agreement was not achieved, final decisions were made as a result of discussions between the researchers. During this process, both parts conducted a more in-depth analysis, taking into account different perspectives, and reached a consensus. As a result, decisions regarding the evaluation of the problems were based on a solid foundation of reliability and validity, thereby enhancing the robustness of the findings.

Results

The findings of the problems posed by the prospective teachers regarding the code of "Mathematical Problem Solving Strategy" are given in Table 2 and Table 3.

Table 2 Frequencies of Situations Requiring Strategy Use in Solving Problems Posed

The solution to the problem posed requires the use of strategy	The solution to the problem posed does not require the use of strategy	Total
46	20	66

When the posed problems were examined, it was determined that 46 out of 66 problems required the use of at least one problem-solving strategy. Table 3 presents detailed findings on the strategies required for addressing problems that involve the application of strategies.

Table 3 Frequencies of Problems Requiring Strategy Use in Their Solutions Regarding the Code "Mathematical Problem Solving Strategy"

Code	DD	SSRP	FP	MOL	MR	WE	WB	GC	Total
Mathematical problem solving strategy*	12	2	6	1	30	14	1	7	73

*Limited to the types of strategies preferred by prospective teachers. If the problem posed includes more than one strategy, each strategy is reported with separate frequencies.
DD: Drawing a Diagram
SSRP: Solving a Simpler Related Problem
FP: Finding a Pattern
MOL: Making an Organized list
MR: Mathematical Reasoning
WE: Writing an Equation
WB: Working backwards
GC: Guess and Check

It is seen that the most preferred problem solving strategy in the problems posed by the prospective mathematics teachers is the "Mathematical Reasoning" strategy (f=30). Then, the strategies "Writing an Equation" (f=14) and "Drawing a Diagram" (f=12) were preferred. It was noticed that only one problem was posed for the use of the "Making an Organized List" and "Working Backwards" problem solving strategies. When we look at the problems posed in general, it is seen that eight different problem solving strategies are used. Different examples of the problems posed by the prospective teachers in terms of problem solving strategies are presented in Figure 4.

S20	S23
There are 4 cows on Ali Baba's farm and the total amount of milk given by each cow in the last 4 days is noted as follows. The 1st cow gave (x+3) liters more milk than the second cow. The 3rd cow gave (2y+17) liters more milk than the 1st cow. The 4th cow gave (3x-2) liters more milk than the 1st cow. The second cow gave a total of x liters of milk in the last 4 days because she was sick. Based on the information above, how much milk could Ali Baba collect from his cows in the last 4 days?	Of the three buckets that can hold 10 kg, 7 kg and 3 kg, one is full of 10 kg of milk. Can you divide the 10 kg of milk into two equal parts using these buckets (without using any other measuring tools)?

Figure 4 Different Examples of the Problems Posed by the Prospective Teachers in Terms of Problem Solving Strategies

While the prospective mathematics teacher with code S20 posed a problem that required the use of the writing an equation problem-solving strategy, prospective mathematics teacher with code S23 posed a problem that required the use of the mathematical reasoning problem-solving strategy.

The findings of the problems posed by prospective mathematics teachers regarding the code of “Context” are given in Table 4.

Table 4 Frequencies Regarding the Code “Context” in the Problems Posed

Code	Personal	Social	Scientific	Occupational	No context
Context	14	1	-	43	8

When looking at Table 4, it is seen that the context most used by the prospective teachers in the problems they posed is the “Occupational” context (f=43). The second most used context is the “Personal” context (f=14). It was determined that only one problem was posed for the “Social” context and that there was no problem posed for the “Scientific” context.

The findings of the problems posed by the prospective teachers regarding the code of “Learning Area” are given in Table 5.

Table 5 Frequencies Regarding the Code of “Learning Area” in the Problems posed

Code	Numbers and operations	Algebra	Geometry and measurement	Data processing	Probability
Learning area*	56	15	5	4	-

* If the problem posed includes more than one learning area, each learning area is reported with separate frequencies.

As seen in the table, the most preferred learning area in the problems posed by the prospective teachers was the “Numbers and Operations” learning area (f=56). No problem was encountered regarding the “Probability” learning area.

The findings regarding the “Connections Within Mathematics” code of the problems posed by the prospective teachers are given in Table 6.

Table 6 Frequencies Regarding the Code of “Connections Within Mathematics” in the Problems Posed

Code	Fraction	Pattern	Algebra	Percent	Graph	Average	Geometric shape	Area	Volume	Parity	Number line	Dozen	Absolute value	Ratio	Cluster	Table	Total
Connections within mathematics*	8	5	5	4	4	2	2	2	1	1	1	1	1	1	1	1	40

* If the problem involves more than one connection within mathematics, each learning area it contains is reported with separate frequencies.

It is seen that the mathematical concept that prospective mathematics teachers mostly included by making connections in the posed problems is “Fraction” (f=8). It is followed by “Pattern” (f=5), “Algebra” (f=5), “Percentage” (f=4) and “Graph” (f=4). Example situations are given in Figure 5.

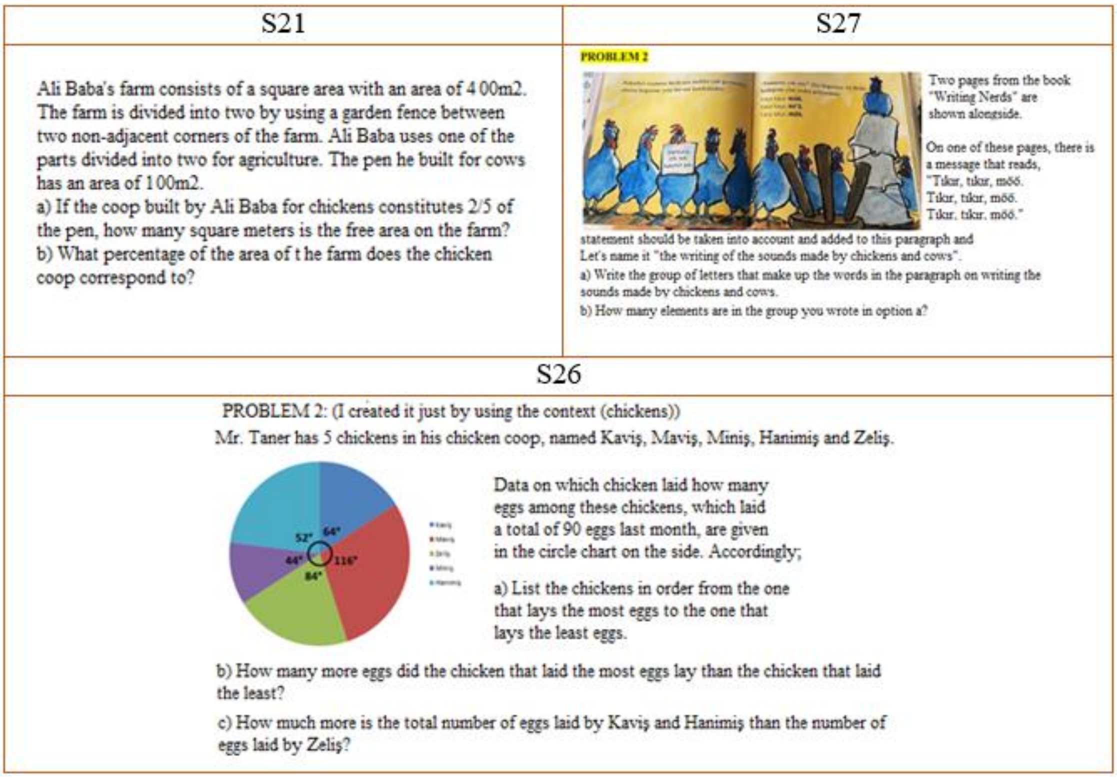

Figure 5 Different Examples of the Problems Posed by the Prospective Teachers in Terms of Connections within Mathematics

When the table showing the problems posed by the prospective teachers is examined, it is seen that the prospective teacher with code S26 made a connection with the concept of angle in his problem, the prospective teacher with code S27 made a connection with the concept of sets, and the prospective teacher with code S21 made a connection with the concepts of fraction, area, and percentage.

The findings regarding the code of "Daily Life Connections" of the problems posed by the prospective teachers are given in Table 7.

Table 7 Frequencies Regarding the Code of "Daily Life Connections" in the Problems Posed

Code	Shopping	Product quantity	Number of animals	Food	Living space	Time	Total
Daily life connections	16	13	9	5	2	1	46

*If the problem involves more than one daily life connections, each learning area it contains is included in separate frequencies.

It is seen that the situation that is most frequently included in the daily life connections of the prospective mathematics teachers in the problems posed is "Shopping" (f=16). "Product Quantity" (f=13), "Number of Animals" (f=9), and "Food" (f=5) follow this order. Example situations are given in Figure 6.

S1	S13
PROBLEM 2: Ali Baba's Eggs Each chicken in Ali Baba's chicken coop gives one egg a day.  The older brother collects the eggs for a week and sells all of these eggs at the market on Sunday for 0.75 cents each. Considering that he earns a total of 105 TL from eggs, how many chickens does Ali Baba have in how many chicken coops?	Problem: The minimum area required for every 5 chickens is 6 and the maximum area is 11 m². 100 chickens on Ali Baba's farm live comfortably in large enough coops. Over time, Ali Baba began to increase the number of chickens in the chicken coop. Although the chickens were disturbed by this situation as their space was limited, they did not make a sound because they still had enough space. When the number of chickens in the coop reached 165, they no longer fit in the coop. Accordingly, what is the maximum size of the chicken coop in?

Figure 6 Different Examples of the Problems Posed by the Prospective Teachers in Terms of Daily Life Connections

When the situations in which prospective mathematics teachers included daily life context in the problems they posed were examined, it was determined that the participant coded S1 used the "Shopping" context, and the participant coded S13 used "Product Quantity" context.

The findings regarding the code of "Interdisciplinary Connections" in the problems posed by prospective teachers are given in Table 8.

Table 8 Frequencies Regarding the Code of "Interdisciplinary Connections" in the Problems Posed

Code	Literature			Music	Total
	Poem	Story	Riddle		
Interdisciplinary connections*	2	1	1	1	5

*If the problem involves more than one interdisciplinary connections, each learning area it contains is included in separate frequencies.

When the problems posed were examined, it was determined that there were only five problems that made interdisciplinary connections. In four of these five problems, a connection with literature was used, and in one, a connection with music was used. Example situations are given in Figure 7.

S13

Question 1: When Ali Baba wakes up in the morning and goes to the barn, he sees that the chickens and cows left a note on the door.

Ali Baba's relations with chickens and cows have been bad for a while due to an argument over feed. He wants the chickens and cows' feed to be changed. Ali Baba does not want to change it because the feed fee will increase. The feed fee Ali Baba pays for the chickens and cows on his farm is 3000 TL per week, and the daily income he earns from eggs and milk is 1000 TL. If he changes the feed, the fee he will pay increases to 4000 TL. Ali Baba wants to find middle ground with chickens and cows. He slips a note under the door in which he writes that he wants to talk to the barn. After the chickens and cows talk and decide among themselves, they send a chicken representative out to talk to Ali Baba. As an agreement, they say that they will only provide eggs and milk on a certain number of days a week. When Ali Baba calculates his weekly earnings, he sees that he has made a loss and is forced to accept the request for a feed change. (Ali Baba spends the income he earns from eggs and milk for the feed expenses of chickens and cows.)

a) How many days can the chickens and cows determine as a certain number of days?

b) By what percentage does Ali Baba's weekly income from eggs and milk decrease after the feed change?

Explanation: While writing the question, I used the note visual, the text on the page, and the general context. I tried to make a story appropriate to the text.

S22

Problem 2:

Grandpa Ali's chickens lay eggs as he pleases.
Chickens lay one egg for 3 days, and on the 4th day they lie down without stopping.
Grandfather Ali came at the beginning of the month and said, "Give me eggs."
At the end of the month, he collected 230 eggs and distributed the whole thing to the neighbor.
If he owns it for a month, he has 30 days. How many chickens does Grandfather Ali have in total?

Figure 7 Different Examples of the Problems Posed by the Prospective Teachers in Terms of Interdisciplinary Connections

When the table above is examined, it is seen that the prospective teacher with code S13 aimed to make a story suitable for the problem and the prospective teacher with code S22 wrote the problem in a literary language as a poem.

When the problems posed by the prospective teachers were examined within the scope of the theme of "Creativity", it was determined that 40 out of 66 problems contained divergent thinking. In the analysis of the problems posed regarding the fluency code, it was seen that there were ten prospective teachers with a fluency score of one, eight prospective teachers with a fluency score of two, and nine of them with a fluency score of three or more. It was also determined that 21 out of the 66 problems posed were flexible. Examples regarding the theme of creativity are given in Figure 8.

S19	S21
PROBLEM 4 A group of chickens is arranged in a square shape in a large area. Arranging in a square shape means that the number of chickens next to each other is equal to the number of rows. Then, on the rooster's command, the same chickens are arranged in a rectangular shape, and in this case the number of rows increases by 5. If chickens are arranged in a row with 50 chickens, how many rows will be formed in total?	Except for 4 of the 3-legged stools on Ali Baba's farm, the stools are upside down. When the stools are upright, 2 chickens are placed on each stool, while when the stool is upside down, one chicken is placed on each leg of the stool. There are 3 chickens on this farm. Accordingly;  a) If all the chickens find a place for themselves on the stools, how many stools are there in this farm? b) If 3 chickens were placed on a flat stool on the farm, how many stools would remain idle? c) What is the absolute value of the difference between the number of feet of chickens and the number of feet of stools?

Figure 8 Different Examples of the Problems Posed by the Prospective Teachers in Terms of Creativity

When the given figure is examined, it is seen that participants coded S19 and S21 included connections with new ideas in the problems they posed.

Conclusions and Suggestions

This study aims to examine the reflections of mathematics education practices connected with children's literature on the problem-posing situations of prospective mathematics teachers. At the end of the practices, the prospective teachers were asked to pose as many problems as possible using an illustration from a children's literature book. These problems were then analyzed by the researchers within the framework of three main themes: "Content," "Mathematical Connection," and "Creativity."

In this study, it was observed that prospective teachers tended to focus on problems that required specific strategies during the problem-posing process, effectively using a total of eight distinct problem-solving strategies. This finding aligns with Ünlü's (2017) research, which highlighted that prospective mathematics teachers can pose problems effectively by employing appropriate problem-solving strategies when needed. The variety of strategies used by the participants can be attributed to their academic progress, particularly as third-year undergraduate students who have been exposed to problem-solving courses. This suggests that the problem-solving and problem-posing skills of prospective teachers are strengthened through the knowledge and experience gained during their undergraduate education. Knowledge and experience are crucial factors in shaping teachers' instructional practices (Barlow & Cates, 2006), and the courses the participants took during their undergraduate studies were key in shaping their problem-posing knowledge (Lee et al., 2018). Therefore, it can be argued that teacher education programs should place greater emphasis on developing problem-solving skills, as doing so would allow prospective teachers to deepen these abilities and enhance their problem-posing practices. This finding underscores the importance of incorporating a stronger focus on problem-solving and problem-posing within teacher education programs to support the professional growth of future educators.

The findings of this study indicate that the most frequently observed problem-solving strategy employed by prospective teachers in their constructed problems is the "Reasoning Strategy". Reasoning skills hold a crucial place as one of the fundamental components of mathematical literacy processes (Pugalee, 1999). These skills enable students to engage actively in mathematical reasoning and establish mathematical relationships, thereby contributing to a deeper understanding of problem-solving processes (NCTM, 2000). Furthermore, children's literature emerges as a powerful tool in enhancing mathematical literacy and strengthening reading skills (Whitin, 1992). By connecting real-life experiences to mathematical concepts, children's literature facilitates a more concrete and meaningful comprehension of these ideas (Haury, 2001; Van de Walle et al., 2016). In this context, the findings of our study highlight that connecting mathematics with children's literature supports the mathematical literacy skills of prospective mathematics teachers and promotes the use of reasoning strategies in the problems they construct. This result underscores the potential of employing mathematics applications linked to children's literature as an effective pedagogical approach for prospective teachers to transfer mathematical literacy and reasoning skills to their future students.

When the constructed problems were analyzed within the "Learning Area" theme, it was found that prospective teachers predominantly created problems related to the "Numbers and Operations" domain. This finding aligns with the results of Joaquin's (2024) study, which investigated the problem-posing processes of mathematics teachers and prospective teachers. Joaquin reported that while participants were capable of posing problems in various mathematical topics such as numbers, algebra, geometry, measurement, and data, they tended to follow established routines and predominantly focused on the "Numbers and Operations" domain. The prevalence of problems related to the "Numbers and Operations" domain in the present study can be attributed to the content of the 2018 Mathematics Curriculum, where this domain constitutes 49.5% of the program. It is anticipated that this trend may shift in future studies due to the influence of the updated mathematics curriculum. For instance, an examination of the "Turkish Century Education Model" (2024) reveals that the weight of themes corresponding to the "Numbers and Operations" domain has been reduced to 30.25%, demonstrating a more balanced distribution across other domains.

It has been observed that candidates relate mathematical concepts in various ways within the problems they create. Specifically, in the theme of connections within mathematics, candidates used 16 different concepts, with the most frequently preferred being the concepts of "Fraction" and "Pattern". Similarly, the problems created by candidates to relate mathematics to daily life have also yielded significant findings. Teacher candidates particularly preferred concepts related to everyday life, such as "Shopping" and "Product Quantity". Özgen (2013), in his study examining the connecting skills of prospective mathematics teachers during the problem-solving process, noted that relating mathematics to itself was more commonly used compared to other types of connections. Similarly, Coşkun (2013) found that the most common types of connection used by teachers in the classroom were making connections between concepts and making connections with daily life. These findings align with the results of the present study, which revealed that teacher candidates tend to use mathematics in concrete and familiar contexts, aiming to establish connections that students could more easily understand. On the other hand, one reason for the increased emphasis on connections in the problems could be the characteristics of the problem-creation tasks presented. In the present study, teacher candidates were shown a visual without numerical values. Zhang et al. (2022) identified that participants used more elements and relationships in tasks without numbers, as opposed to tasks involving numerical problem creation. In light of these results, considering that problem-posing activities interact with mathematical connection skills (Mersin & Akkaş, 2023), it is recommended that more problem-posing activities be organized so that prospective teachers can develop their connection skills more effectively. It is believed that such activities will make a substantial contribution to the reinforcement of prospective teachers' mathematical thinking processes, enhance their comprehension of problem-solving strategies, and foster the development of their ability to establish connections.

Although the problems posed by prospective mathematics teachers have shown positive results in terms of connecting mathematics within itself and with daily life, there are deficiencies in interdisciplinary connections. Only 5 of the 27 pre-service teachers who participated in the study included interdisciplinary connections in the problems they posed. This situation shows that prospective teachers have limited competence in establishing interdisciplinary connections. Özgen (2017) similarly stated that prospective teachers' skills in making connections between mathematics and other disciplines are generally not at a sufficient level. Özgen emphasizes that prospective teachers should participate in interdisciplinary connection practices with more theoretical and practical studies. In this study, it was observed that the activities carried out within the scope of the connection course in mathematics teaching had a limited focus on interdisciplinary connections. However, these findings show that prospective teachers can receive additional training and guidance support to include problems that include interdisciplinary connections. Addressing the issue of interdisciplinary connections more can increase the experiences of prospective teachers in this area. In particular, the inclusion of this process in the activities may encourage candidates to use interdisciplinary connections more frequently and correctly. In addition, it may be clearly stated that teacher candidates are expected to make interdisciplinary connections in the problems they pose, and how they handle this connection may be examined in more detail. In this way, teacher candidates' interdisciplinary thinking skills can be systematically developed and mathematics teaching can be enriched by establishing a stronger connection with other disciplines.

Another significant finding from the research is that divergent thinking was more prominently evident in the problems posed by prospective teachers. This suggests that the problem-posing tasks implemented within the scope of the study encouraged prospective teachers to engage in creative and innovative thinking. However, this finding contrasts with the results of a study by Korkmaz and Hür (2006), where it was observed that prospective teachers rarely included creative problems in their work. Similarly, Işık and Kar (2012) also noted a lack of creative thinking and connectional skills in the problems posed by prospective teachers. In this regard, the context's distinct impact on creativity should also be considered. Singer and Voica (2015) emphasized the importance of context in fostering creative thinking, while Haury (2001) suggested that the integration of mathematics and literature aims to create a meaningful context for students. The connection between children’s literature and mathematics has proven to be an effective method for supporting prospective teachers' creative thinking processes and enhancing their divergent thinking skills. This study also highlights the positive contribution of linking children’s literature with mathematics to prospective teachers’ problem-posing abilities. In light of these findings, it is recommended that interdisciplinary tasks, such as those connecting children’s literature with mathematics, be incorporated into teacher education programs and that such tasks be further encouraged to help develop prospective teachers’ creative thinking skills.

As a result, this study reveals that the integration of children’s literature and mathematics has a significant effect on the use of reasoning skills of prospective teachers, diversification of mathematical connection skills and development of divergent thinking skills. In this context, enriching mathematics teaching with interdisciplinary connections will strengthen teachers’ pedagogical approaches and add depth to students’ learning processes. Incorporating children’s literature into classroom environments by connecting it with mathematical content may have the potential to develop students’ reasoning skills.

Compliance with Ethical Standards

Disclosure of potential conflicts of interest

The authors declare that this study and no processes involved in conducting the study have the potential for conflicts of interest.

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Research involving Human Participants and/or Animals

This study was carried out taking into account ethical rules. The participants were informed about the study and asked to sign a consent form based on a voluntary basis. The study was approved with the decision number 80 taken at the meeting numbered 11 and dated 23.12.2022, by the Board of Directors of the Institute of Educational Sciences at Bursa Uludağ University, from which ethical approval was obtained. The data of the study were collected in the second semester of the 2022-2023 academic year.

Çocuk Edebiyatı ve Matematik İlişkilendirmesi: Matematik Öğretmen Adaylarının Problem Kurma Durumlarından Yansımalar

Özet:

Matematik öğretiminde disiplinler arası ilişkilendirmeden yararlanmak öğretimin niteliğini arttırmakta, öğrenmeyi daha etkili ve kalıcı hale getirmektedir. Bu çalışmada çocuk edebiyatı ile matematik ilişkilendirmesi ele alınmış, bu ilişkilendirme problem kurma üzerinden incelenmiştir. İlgili araştırma nitel araştırma yöntemlerinden durum çalışması deseni ile yürütülmüştür. Bu doğrultuda matematik öğretmen adaylarına çocuk edebiyatı ve matematik ilişkilendirmesine yönelik aralıklı olacak şekilde 6 haftalık uygulamalar gerçekleştirilmiştir. Bu uygulamalar sonucunda matematik öğretmen adaylarından bir çocuk edebiyatı eserinde yer alan görselden yararlanarak kurabildikleri kadar problem kurmaları istenmiştir. 27 matematik öğretmen adayı tarafından kurulan 66 matematiksel problem "İçerik", "Matematiksel İlişkilendirme" ve "Yaratıcılık" temalarını içeren "Problem Kurmayı Değerlendirme Kriterleri" ile betimsel olarak değerlendirilmiş, temalara yönelik frekanslar tablo halinde sunulmuştur. Çalışma sonucunda çocuk edebiyatı ile matematik ilişkilendirmesinin öğretmen adaylarının matematiksel ilişkilendirme becerilerini ve yaratıcılıklarını olumlu anlamda etkilediği sonuçlarına ulaşılmıştır. Aynı zamanda öğretmen adaylarının kurdukları problemlerde problem çözme stratejilerinin kullanımının sayıca fazla olduğu ve en fazla tercih edilen problem çözme stratejisinin matematiksel muhakeme yapma olduğu görülmüştür.

Anahtar kelimeler: Çocuk edebiyatı, ilişkilendirme, matematik eğitimi, öğretmen adayları, problem kurma, yaratıcılık.

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Research Article

Investigation of Metacognitive Strategy Tendencies of Students in Science Course within the Scope of Support and Training Courses

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Abstract –Support and training courses (STCs) within the scope of non-formal education, it is aimed to increase students' course success; however, the direction in which students' perceptions of motivational components change in this process is not taken into account. The present study is dedicated to examining the longitudinal trends of students' perceptions of metacognitive learning strategies (MLS) within the context of science lessons during the summer term. A total of 622 students (51.6% female; 48.4% male) from four different secondary schools were involved in the research, which utilized the relational screening model. The findings indicate a significant longitudinal increase in students' tendencies to use MLS. Additionally, the intergroup analysis comparing female and male students revealed no significant difference in MLS scores between the two groups. The rise in students' MLS scores without any instructional intervention indicates that choice-based STCs increase students' active engagement in learning tasks and encourages motivational processes related to the course. This underscores students' active control of cognitive strategies during learning and upon completion of tasks. The results show that students need to benefit more from non-formal and informal learning environments for science classes. Expanding the inclusiveness of STCs by including students with high learning losses, declining interest in science courses, and socioeconomic disadvantages may increase homogeneity among students regarding academic competencies. Therefore, policymakers should consider integrating metacognition and associated learning strategies into routine science education by devising processes that facilitate this integration in curricula and teacher education.

Keywords: Metacognition, out-of-school education, science education, science teaching, middle school students.

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Introduction

In the changing world and working life, the knowledge and skills, values, and attitudes that need to adapt to intercultural contexts have led to multidimensional competencies gaining more space in education plans and policies (Organization for Economic Cooperation and Development [OECD], 2018a). In education, science lessons have become a part of social goals, beyond the demands of developing technology and a scientifically qualified workforce, consistent with the predictions of international competencies. One of the most important developments in learning sciences that has significantly influenced science education research is the transition from seeing learning as an individual process to understanding that knowledge and knowing are situated in social and cultural contexts (Pellegrino, 2020). In parallel, science education today is evolving towards producing a new generation of citizens who are scientifically literate and thus better prepared to function in a world increasingly influenced by science and technology.

Science courses are critical in meeting the needs of 21st-century competencies that are expected to be indispensable in the changing world and working life in the future. Indeed, in today's world where access to information is accelerating, individuals are expected to be able to organize and use the information they have accessed and reflect it in multiple tasks. The global competencies and basic skills represented in the lists of 21st-century competencies intersect with the basic principles and ideas of science education that people need to understand and apply in different areas (Voogt & Roblin, 2012). Thuneberg et al. (2022) emphasize seven competence areas, emphasizing the importance of viewing these competences as overarching principles guiding subject-specific teaching. These areas include: (a) learning to think and learn, (b) cultural competence, (c) daily life management competence, (d) multiliteracy, (e) information and communication technology competence, (f) work-life competence, and (g) participation, inclusion and sustainability. In parallel with this, in our country, it is emphasized in the core curriculum (framework curriculum) that it is necessary to encourage students' multifaceted scientific literacy in science education (Ministry of National Education-MoNE, 2024). It can be said that the basic objectives on which the curriculum in practice in our country is based include elements such as cognitive abilities, personal attitudes, communication skills, social values, social skills, and dimensions of self-efficacy. These objectives do not specifically target any subject discipline; they are expected to be acquired as a whole during the education process. The specific objectives in the science curriculum are listed as field-specific skills (a) scientific process skills, (b) life skills (analytical thinking, decision making, creative thinking, entrepreneurship, communication, and teamwork), and (c) engineering and design skills (MoNE, 2018). The objectives in the science curriculum, unlike the general objectives of education, require a context, and this context inevitably includes science content and conceptual structuring related to the science course.

In a world that is becoming increasingly interconnected, where economic productivity and educational achievement are closely linked and competitive, there is a growing emphasis on standards-based science education (DeBoer, 2011). The "OECD Learning Framework 2030" (OECD, 2018b), which is a pioneer of this trend and is effective in setting new criteria and targets in curriculum standards, creates significant changes in the curriculum reforms of various countries. Many countries are redoubling their efforts to establish higher standards in order to maintain a competitive edge in the global arena and achieve their desired educational objectives. The driving forces behind this global movement are the Programme for International Student Assessment (PISA), the Trends in International Mathematics and Science Survey (TIMSS), and the associated student performance reports, which shed light on the relative performance of students worldwide. The results of both PISA and TIMSS serve as crucial tools for policymakers to consider when seeking to enhance science education within their respective nations. Simultaneously, as noted by Apple (2000) and Carter (2005), these results also provide opportunities for increased accountability, oversight, and regulation.

The impact of student success in science courses under the STEM umbrella on future science courses and career choices is a significant consideration (Ainley & Ainley, 2011; Vedder-Weiss & Fortus, 2018). Science education is increasingly important on national and international levels, but there are several issues that affect students' success, perceptions, and practices in science education. One of these concerns is the use and effectiveness of textbooks. To help students learn, countries need to develop high-quality teaching materials or textbooks that are aligned with curriculum standards. Textbooks that lack personal interest and appeal to students can make it harder to achieve the intended outcomes. In particular, due to the abstract concepts and scientific language in science textbooks, science may be perceived as boring for students. Indeed, Li and Wang (2024) and Harris et al. (2014) argue that the use of high-quality teaching materials can improve students' performance in science.

Another issue that effects science learning is related to teacher competence. In a review focusing on learning sciences and science education research (Songer & Kali, 2022), it is reported that current teacher competence is incompatible with today's knowledge-based and innovative society and is increasingly criticized. Teachers are often considered the primary source of knowledge and are responsible for conveying content to students (Jesaani, 2015). However, public exams, such as the high school entrance exam, can limit the freedom and authority of teachers in choosing and presenting content, putting pressure on them to cover all the content in a limited time at the expense of students' learning. The successful implementation of science education reforms in Türkiye is contingent on addressing various challenges at the policy and implementation levels. One of these steps is the establishment of support and training courses (STCs) financed by the government and associated with out-of-school learning. Launched by the Ministry of National Education in the 2014-2015 academic year, STCs aims to enhance the academic achievement of secondary and high school students. These non-formal learning environments offer structured course activities based on student participation and course selection, fostering an environment for holistic development and interaction with peers.

Out-of-school learning encompasses various activities in different open learning environments, such as museums, nature parks, art exhibitions, aquariums, science centers, accommodation and offer integrative pedagogy opportunities to achieve targeted outcomes. Out-of-school learning can be designed as a summer school to improve academic skills and reduce learning losses, or it can have appearances that include enriched options and support the development of students' skills in language, art and sports (Koop, 2010). STC applications carried out in our country mostly consist of accelerated contents that complement the gains foreseen in official programs. However, since STCs offers students the opportunity to choose courses freely, it has some similarities with the learning activities referred to as out-of-school learning in the literature. For example, according to the MoNE (2024) STCs directive, students can apply for courses in certain fields (e.g., mathematics, science, Turkish), as well as courses such as sports, music and visual arts within the scope of summer school courses. Conversely, the fact that the activities envisaged by STCs are carried out in schools or course centers suggests a lack of real-life experiences that can be triggered in different learning contexts.

Previous studies on STCs have primarily explored teachers' attitudes towards courses (Aküzüm & Saraçoğlu, 2018), teachers' perspectives on challenges encountered in courses (Bozbayındır & Kara, 2017; Sarıca, 2018), and students' viewpoints (Çağrı Biber et al., 2017; İncirci et al., 2017). However, there is a noticeable gap in the research regarding the changes in students' perceived motivational processes towards science learning in the STC process over time. The cognitive and motivational processes experienced by students in this context are equally significant as the STCs practices and encountered difficulties. Because, research (e.g., Thuneberg et al., 2022) has shown that out-of-school learning activities encourage students to develop confidence in their own abilities, abstract thinking, complex reasoning, and promote metacognitive learning that reflects learner autonomy. Bannert et al. (2015) found that students achieved positive results by using their metacognitive prompts in computer-based learning environments without any instructional intervention. With the updated science curriculum placing greater emphasis on integrating conceptual knowledge with real-world experiences and learning from informal and non-formal environments, it is essential to investigate how students' motivational perceptions in these settings have evolved. On the other hand, it is emphasized in the literature that middle school students' motivation to learn science decreases as their grade levels advance (Liou et al., 2020). Therefore, examining motivation, a crucial factor in students' engagement with learning tasks, and its underlying mechanisms in science learning environments within the framework of STC is crucial for achieving the expected educational outcomes.

The influence of metacognition, a motivational factor, on the process of learning and teaching has emerged as a focal point in educational research. Metacognition pertains to the mechanisms involved in acquiring the ability to learn (Flavell, 1979). Flavell et al. (2002) differentiate between two essential constituents of metacognition: metacognitive knowledge and metacognitive self-regulation. Whitebread et al. (2009) further expound on the metacognitive elements, delineating them as planning (the selection of strategies and procedures and the endeavor to employ them in tackling the present problem), monitoring (sustained awareness of task performance and the attainment of desired goals), evaluation (appraisal of learning processes and learning outcomes), and self-regulation/control (management of cognitive activities during learning). This study has embraced the self-regulation aspect of metacognition, which encompasses the abilities and processes employed to steer, control, and regulate cognition and learning, in line with the conceptualizations of Flavell et al. (2002) and Whitebread et al. (2009). The strategies encapsulated by metacognition pertain to the processes of reasoning, learning, and problem-solving. Metacognitive learning strategies entail individuals actively overseeing and regulating cognitive strategies during and after the learning process (Magaji & Umar, 2016). Metacognitive learning strategies are essential for students to achieve their academic goals. These strategies, encompassing thinking, learning, and problem-solving approaches, have been linked to improved performance (Fooladvand et al., 2017; Zohar & Barzilai, 2013). Previous research has highlighted the positive correlation between the use of metacognitive learning strategies and motivation (Atay, 2014; Rashid & Rana, 2019). Furthermore, the literature underscores the significance of these strategies in students' academic progress (Afrashteh & Rezaei, 2022; Teng, 2020; Xiao & Zhao, 2024). Winne and Azevedo (2014) emphasized that metacognition plays an important role in all cognitive tasks and should be integrated in science education practices. Considering the importance of metacognition for learning environments, it follows that students should be encouraged to use these strategies.

The literature predominantly focuses on investigating metacognitive learning strategies (MLS) and their correlation with motivation among students in formal educational settings. However, there is a dearth of research exploring the motivational processes experienced by students during informal learning activities, such as STCs, which are characterized by student autonomy and are conducted outside the formal education environment. Recognizing this research gap, the present study aims to longitudinally examine students' perceptions of metacognitive learning strategies in the context of science lessons during the summer term STC. Longitudinal data collection is crucial for evaluating hypotheses that cannot be adequately addressed with only cross-sectional or dichotomous data (Preacher et al., 2008). Given that data will be gathered at three different time points, it is important to acknowledge the potential emergence of complex relationships. Therefore, efforts have been made to delineate the directionality of the effects based on prior research findings in order to mitigate this complexity.

Another rationale that guided this research was that administrators, teachers, and parents viewed STCs as a way to motivate students and prevent student achievement from declining. Although practices integrated with curricula are implemented in short-term course environments in Türkiye, the learning experience created by these practices differs from the formal education context. Expecting long-term educational outcomes, which are associated with formal education, from STCs may lead to inaccurate conclusions due to their short-term nature. Therefore, it is critical to enrich the understanding of the effects of the STCs context on students' cognitive appraisals, motivational perceptions, and academic outcomes. It is expected that the results of the current study will inform future studies to improve science teaching practices and will also encourage studies to increase the effectiveness of out-of-school learning contexts.

Purpose of the Study

The aim of this study is to analyze the long-term trends in summer term STC students' perceptions of MLS in science lessons. To achieve this, we have formulated the following questions:

- How do summer term STC students' perceptions of learning strategies in science lessons change over time, and to what extent?
- Do the changes in students' perceptions of learning strategies in science lessons within the scope of STC differ between male and female students over time?

Methods

Research Model

This research was conducted based on the relational screening model because it makes it possible to reach the opinions of large masses. According to Karasar (2005), in relational screening models, differences between groups are examined according to the status of the determined variables. In this model, there is a possibility that the data may not reflect the participants' genuine views or may mislead the participants by making them state an opinion that aligns closely with their own (Fraenkel & Wallen, 2006).

Population and Sample

The study encompasses all students enrolled in science courses within the framework of STC at secondary schools in the Artuklu district of Mardin province during the 2022-2023 academic year. The sample for the study was drawn from students studying science courses within the scope of STC at 4 secondary schools. The selection of schools for the study was guided by criterion sampling, a purposeful sampling method. According to Patton (2002), purposeful sampling allows for a detailed examination of situations containing comprehensive information. Criterion sampling involves the examination of events and facts that meet specific criteria determined by the researcher (Yıldırım & Şimşek, 2013). The criteria for selecting the sample for this study are as follows: enrollment in secondary school and attendance in the 8th-grade science course within the scope of STC summer courses. To estimate the minimum sample size, an a priori power analysis was conducted using G*Power version 3.1.9.7 (Faul et al., 2007). The results indicated that with a significance level of $\alpha = .05$, the sample size required to obtain a medium effect and achieve power at the .95 level was $N = 42$. Therefore, it can be said that the sample gathered for this study reflects the ratio required by the recommended sample size. Descriptive information about the sample is provided in Table 1.

Table 1 Participant Characteristics

Variables	T1		T2		T3	
	n	%	n	%	n	%
Gender						
Female	321	51.6	310	51.2	308	51.8
Male	301	48.4	295	48.8	287	48.2
School						
1st school	142	22.8	141	23.3	139	23.4
2nd school	150	24.1	148	24.5	143	24.0
3rd school	151	24.3	145	24.0	140	23.5
4th school	179	28.8	171	28.2	173	29.1
Total	622	100.0	605	100.0	595	100.0

According to Table 1, 622 individuals (321 females [51.6%], 301 males [48.4%]) participated in the study at time point T1, 605 individuals (310 females [51.2%], 295 males [48.8%]) at time point T2, and 595 individuals (308 females [51.8%], 287 males [48.2%]) at time point T3. When the student distribution across schools was examined between time points T1 and T3, 139-142 students participated from the first school, 143-150 students from the second school, 140-151 students from the third school, and 173-179 students from the fourth school. At time point T1, 622 students completed the scales, at time point T2, 605 students completed the scales, and at time point T3, 595 students completed the scales. The final sample size analyzed was 95% (595/622). Therefore, there was a 5% loss of participants. The age range of the participants spanned from 13 to 16 years, with an average age of 14.01 years (standard deviation = 3.33).

Procedure

The data collection process commenced following the approval of the Fırat University ethics committee (ethics committee reference number: 2022/9684) and the authorization of the provincial directorate of national education. The research was guided by ethical principles set out by the British Psychological Society (2021), including: (a) respect, (b) competence, (c) responsibility and (d) integrity. Prior to participating in the study, students were required to obtain parental consent and participant approval. It was clearly communicated to the students that they had the option to abstain from responding to the surveys without facing any repercussions at any stage before, during, or after the data collection. Students were informed that their data would be anonymous. The traditional paper and pencil data collection method was implemented during regular course hours. The surveys were administered during nonscience class hours to minimize potential teacher and student expectation biases. Prior to commencing the survey, the researcher provided participants with detailed information regarding the study's objectives and procedures. Participants were explicitly informed that the surveys did not pertain to their personal preferences regarding their teachers or their general teaching styles. Instead, participants were asked to evaluate each statement independently based on its content and context. Throughout the questionnaire completion process, students were encouraged to signal at any time and silently ask questions if they encountered difficulties in understanding the items. The three data collection phases (see Figure 1) were conducted in the first week of the STCs (July), the first week of August, and the last week of August. Each survey took approximately 10 minutes for students to complete. The first step of data collection (week one) was carried out at the beginning of the STC sessions. In the first week, data were collected before the presentation of the course content began. In this way, the possible effects of the STC process on the students' cognitive processes were tried to be reduced. The second step of data collection coincided with the fifth week of the course calendar. In the process until this week of the accelerated course program, students had covered four of the seven units in the course program. The last measurement was carried out in the eighth week, after the end of the course. Thus, the effects of STC on the students' MLS levels were measured longitudinally through three consecutive measurements.

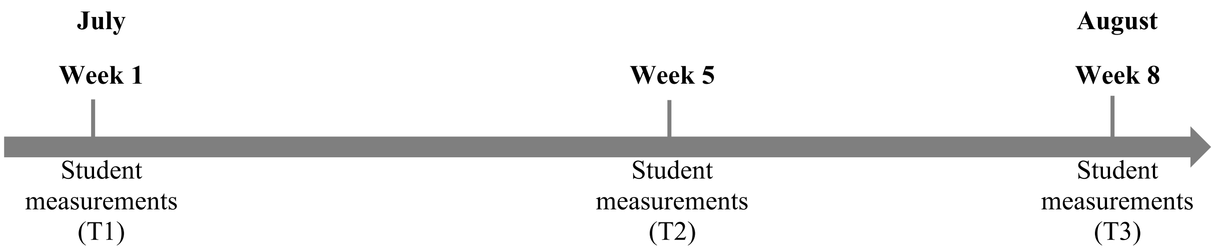

Figure 1 Timeline and Three Data Collection Points

Data Collection Tool

The study assessed students' utilization of learning strategies using the Motivation and Learning Strategies Scale, initially developed by Pintrich and Smith (1993) and later adapted to Turkish by Karadeniz et al. (2008). This scale comprises two subscales: Motivation (24 items) and Learning Strategies (45 items). Pintrich and Smith (1993) asserted that the scale has a modular structure allowing implementers to use the subscales according to their specific purposes. In this study, the Learning Strategies subscale and the associated Cognitive Self-Regulation (Metacognition) scale (10 items) were employed. Karadeniz et al. (2008) reported that the scale, scored on a Likert scale from 1 (Absolutely wrong for me) to 5 (Absolutely right for me), encompasses 9 factors based on the findings of the confirmatory factor analysis (X^2 = 3288.17; df = 948; GFI = .89; AGFI = .87; CFI = .89; NNFI = .88; SRMR = .04; RMSEA = .05) confirming the predefined factors. Additionally, a satisfactory Cronbach's alpha coefficient (.85) was obtained for the scale in a previous study (Deniz, 2023), while the current study yielded a Cronbach's alpha coefficient of .82.

Data Analysis

Before commencing the data analysis, the dataset underwent a thorough examination to identify and address any missing data. It was observed that there were 12, 9, and 15 missing values in the first, second, and third measurements, respectively. Following the guidance of Tabachnick and Fidell (2013), the missing values were imputed with the mean of the series. Subsequently, the equivalence of the groups in terms of variables was assessed using a t-test. The analysis of the measurements obtained at three-time points was conducted using a mixed design ANOVA, which allowed for the examination of the effects of both between-group variables (e.g., gender: female/male) and time-dependent variables (within-groups) (Patton, 2020). To ascertain the reliability of the scale, Cronbach's alpha coefficient was employed. The results were interpreted at the predetermined alpha significance level of .05. Notably, the Z values fell within the range of ±3, indicating the absence of extreme values. Furthermore, the skewness and kurtosis values, as presented in Table 1, were within the range of ±1.96. The Levene test results affirmed the equality of error variances. Additionally, the results of the test of sphericity indicated that variance differences between all related group combinations were assumed to be equal, as the produced results were at the $p>.05$ level.

Results

Descriptive Statistics

Means, standard deviations, and correlations between study variables are presented in Table 2.

Table 2 Descriptive Statistics of Study Variables

Variables	M	S. d	Skew.	Kurt.	1	2	3
MLS (T1)	2.30	.83	.60	.02	1		
MLS (T2)	3.09	.92	.08	.29	.34**	1	
MLS (T3)	4.22	.47	.66	.16	.23**	.41**	1

*p<.05
**p<.01

In accordance with the findings presented in Table 2, it is observed that the variables fall within the ±1.96 skewness-kurtosis value range. Furthermore, the pairwise correlations indicate significant relationships among the variables measured at three distinct time points, with none of these correlations surpassing the recommended 0.9 cut-off value as suggested by Hair et al. (2014).

Moreover, an examination of the study variable at time point T1 involved a comparison based on gender and school groups. The outcomes of the t-test analysis can be found in Table 3, while the ANOVA results are provided in Table 4.

Table 3 The Results of the T-Test Analysis Indicate the Equivalence of Gender with Respect to the Study Variables

Variables	Groups	Group statistics			Levene test		t-test		
		n	M	S. d.	F	p	t	df	p
MLS (T1)	Female	321	2.27	.81	1.12	.28	.63	575	.52
	Male	301	2.32	.85					

Based on the t-test analysis findings, there is no statistically significant disparity between males and females with regard to MLS measured at the T1 time point. As there is no discernible distinction between the groups, the outcomes derived can be extrapolated to the study cohort. ANOVA analysis was employed to ascertain if there are variations among the school groups in relation to the study variables.

Table 4 The ANOVA Results Indicate the Equivalence of School Groups in Terms of Study Variables

Variables	ANOVA					Post-hoc (Tukey HSD)				
	S. s.	df	M. s.	F	p	Schools	School order	M. dif.	Std. e.	p
MLS (T1)	3.87	3	1.29	1.85	.13	1	2	-.08	.09	.84
							3	-.13	.10	.50
							4	-.22	.09	.10
						2	3	-.05	.09	.93
							4	-.14	.09	.45
						3	4	-.08	.09	.82

As per the ANOVA results outlined in Table 4, it is evident that the data derived from MLS at time point T1 does not exhibit a significant variance across the four schools. This conclusion is further supported by the follow-up Tukey HSD analysis. Hence, it can be posited that all participants in the initial time period hold similar perceptions regarding MLS.

Mixed Design ANOVA Results

In conducting mixed design ANOVA analysis, it is imperative to ensure that the assumption of sphericity is satisfied. According to this assumption, the differences in variance scores across any two conditions must be equivalent (Pallant, 2020). To assess this assumption, Mauchly's Test of Sphericity, available in SPSS, was employed. The test result ($X^2_{(2)}$ = 44.80, p>.05) indicated that the assumption of sphericity (ε = .92) was upheld. Additionally, it is essential to address the assumption of homogeneity of variances.

In the analysis, Levene's test was conducted for each level of the repeated measures variable. The results indicated that the test was not significant at all three time levels (*p* = .30, p = .10, *p* = .20), suggesting that the assumption of homogeneity of variances was not violated.

The mixed design ANOVA yielded significant results pertaining to the variations in students' perceptions of metacognitive learning strategies across the time points T1, T2, and T3, as well as the changes in scores for two distinct groups (male/female) over time.

Table 5 Utilizing a Mixed Design ANOVA to Evaluate the Time x Gender Interaction and between Time Points

Source		Tip III S.s.	df	M. s.	F	p	η^2
Time	Sphericity Assumed	1057.03	2	528.51	907.27	.00	.61
	Lower-bound	1057.03	1.00	1057.03	907.27	.00	.61
Time * Gender	Sphericity Assumed	.97	2	.48	.83	.43	.00
	Lower-bound	.97	1.00	.97	.83	.36	.00
Error (Time)	Sphericity Assumed	665.25	1142	.58			
	Lower-bound	665.25	571.00	.16			

Based on the findings presented in Table 5, the interaction between time and gender does not yield statistically significant results, as indicated by a p-value greater than .05. This suggests that there is no significant difference in MLS scores between male and female students over time. Furthermore, the main effect of time is supported by a p-value of .00, signifying statistical significance. Therefore, it can be inferred that there is a substantial effect associated with time, indicating a change in MLS scores across different time periods. The effect size for the observed difference between time periods is .61, which, according to Cohen (1988), corresponds to a medium-level effect.

The statistical analysis in Table 6 indicates that the intergroup effect (p = .82) is not statistically significant. This suggests that there is no discernible difference between the MLS scores of female and male participants. Therefore, the gender of the student does not appear to significantly influence the perception of metacognitive learning strategies.

Table 6 Mixed Design ANOVA Results Reflecting the Main Effect of Variables between Groups

Source	Tip III S. s.	df	M. s.	F	p	η2
Intercept	5787.22	1	5787.22	28387.39	.00	.98
Gender						
Error	.01	1	.01	.05	.82	.00
	116.40	571	.20			

The statistical analysis in Table 6 indicates that the intergroup effect (p = .82) is not statistically significant. This suggests that there is no discernible difference between the MLS scores of female and male participants. Therefore, the gender of the student does not appear to significantly influence the perception of metacognitive learning strategies.

Pairwise comparisons between time periods reflecting within-group effects are presented in the table below and in Figure 2, along with the Bonferroni correction.

Table 7 Pairwise Comparison Between Time Periods

(I) Time	(J) Time	Mean difference (I-J)	Std. e.	p
1	2	-.79*	.05	.00
	3	-1.92*	.04	.00
2	1	.79*	.05	.00
	3	-1.13*	.04	.00
3	1	1.92*	.04	.00
	2	1.13*	.04	.00

To make the information in Table 7 more visible, information including post-hoc comparisons between all time points from T1 to T3 can be seen in Figure 2.

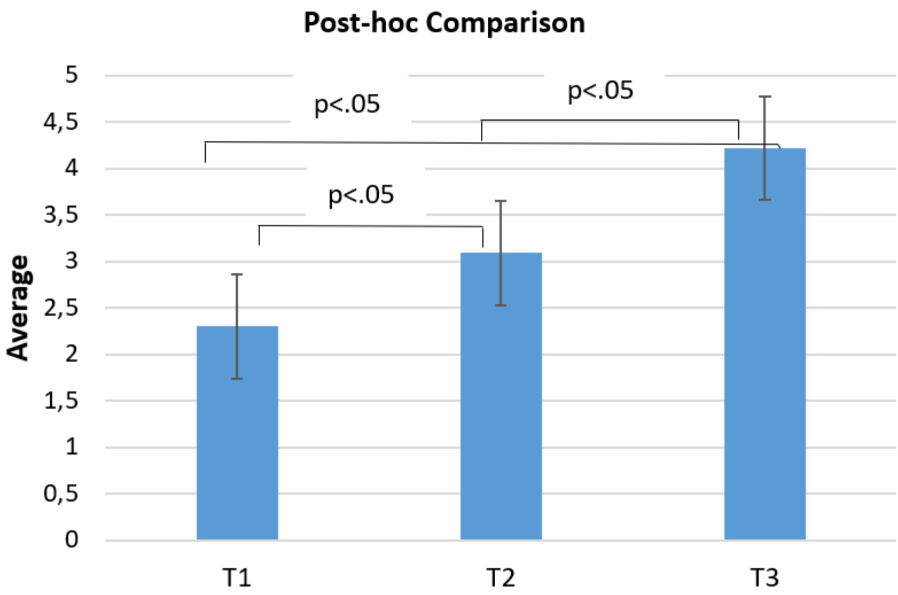

Figure 2 Post-Hoc Comparisons between Time Points

The findings in Table 7 and Figure 2, which stem from the post-hoc analysis, indicate a notable disparity at the p = .00 significance level across time periods 1-2, 1-3, and 2-3. Additionally, Figure 3 visually represents the association between time periods and the gender x time interaction.

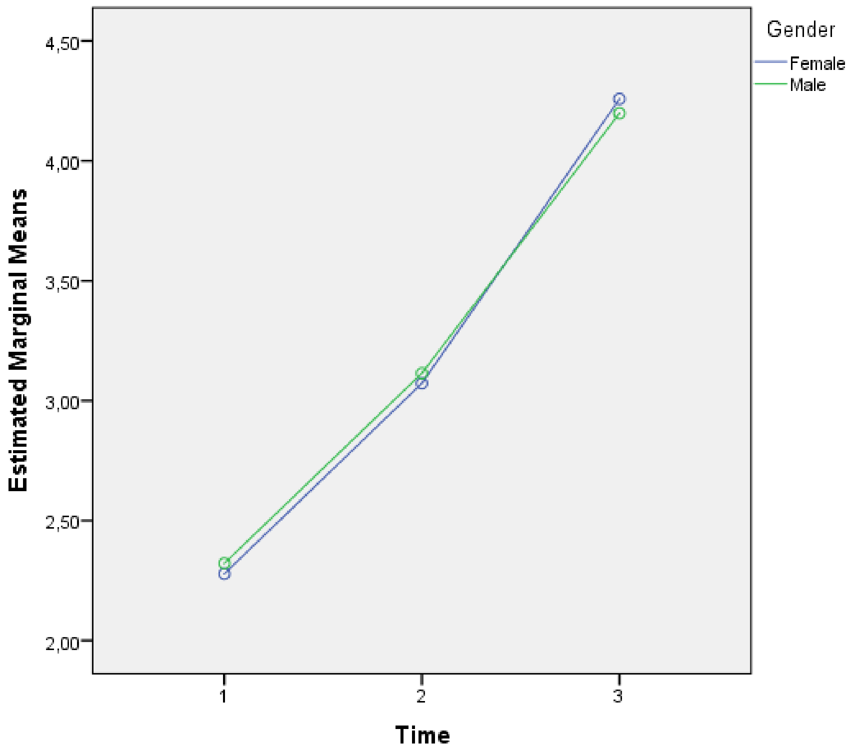

Figure 3 MLS Scores of Students in Time Periods

The data depicted in the graph concerning the time periods and gender x time interaction indicates that the disparity between time periods 1-3 is more pronounced than the variance between time periods 1-2 and 2-3. Furthermore, the gender x time interaction demonstrates a parallel trend, signifying the absence of a significant effect, aligning with the outcomes delineated in Table 6.

The present study employed a mixed design ANOVA to examine the impact of students' perceptions of metacognitive learning strategies (MLS) with respect to time, gender, and their interaction. The interaction of time and gender yielded a non-significant effect, $F(2, 1142) = .83$, $p = .43$, $\eta 2 = .00$, indicating no substantial difference in MLS scores based on gender. However, the main effect of time was found to be significant, $F(2, 1142) = 907.27$, $p = .00$, $\eta 2 = .61$, suggesting notable changes in students' MLS scores across different time periods.

Discussion

The concept of metacognition has emerged as a focal point in the realm of science education owing to its significant influence on cognitive processes and learning outcomes. In the domain of science education research, metacognition is frequently incorporated into studies that address the fundamental objectives of science education, rather than being studied in isolation. This indicates a growing emphasis on the development of metacognition within science education. This study sought to investigate the longitudinal utilization of metacognitive learning strategies among middle school students enrolled in a science course as part of the summer STC program. Specifically, the study aimed to ascertain whether there were disparities in the employment of metacognitive learning strategies between male and female students. The findings revealed noteworthy variations in students' employment of metacognitive learning strategies over time, indicating a consistent increase in the use of such strategies from the initial time point (T1) to the final time point (T3). This suggests that students increasingly engage in deep learning processes, such as directing, controlling, and regulating cognition and learning, which are indicative of metacognitive learning strategies, within the context of science courses offered as part of the STC program.

The existing literature on metacognitive awareness in middle school students has often focused on the impact of various variables unrelated to the current study, such as grade level, note-taking habits, experimental work, and their application in daily life (Bağçeci et al., 2011; Oğuz & Kutlu Kalender, 2018; Öztürk & Serin, 2020). Limited research has investigated metacognitive learning processes and strategies within learning environments based on course selection and voluntary participation, which is the primary focus of this study. Notably, Aydın and Kılıç-Mocan (2022) conducted a study on the impact of science education on the metacognitive awareness levels of middle school students, demonstrating that voluntary participation in a science project significantly enhanced their metacognitive awareness. Similarly, Mudd (2010) revealed in his study, "Student Choice as a Motivational Strategy to Increase the Success of Middle School Students," that students exhibited higher motivation levels when given the opportunity to make choices. Furthermore, Birdsell et al. (2009) presented four options to middle school students -group selection, curriculum selection, assignment selection, and assessment selection- finding that providing choices led to increased self-motivation. In the study conducted by Frye (2010), it was revealed that the summer school course program for academic courses had significant effects on students' perceptions of motivation, effort levels, and learning responsibility behaviors, which are closely related to metacognition. Thuneberg et al. (2022) demonstrated the positive effects of out-of-school learning on MLS, abstract thinking, and complex reasoning, reflecting learner autonomy. Finally, in a study conducted in a computer-based learning environment (Bannert et al., 2015), it was concluded that students used the MLS autonomously without any instructional intervention. Consistent with these findings, the present study suggests that choice-based activities or learning tasks can enhance students' motivation and active participation in the course.

Researchers in various disciplines (e.g., English) who focus on the effects of metacognitive knowledge and strategies on learning environments suggest that they facilitate the development of student autonomy, are associated with perceptions of competence, and show positive correlations with task performance (Teng, 2020; Xiao & Zhao, 2024). Considering the importance of metacognitive knowledge and strategies for learning environments, it follows that students should be encouraged to use these strategies. STCs, which is effective in reinforcing out-of-school learning, are a good alternative to fill this gap. Therefore, it is important for teachers to direct students to STCs and for educational administrators to support the process with functional mechanisms.

The ongoing debate surrounding metacognition centers on its domain specificity and generality. Various factors contribute to the complexity of this debate, including the age of the students, the nature of the task, the specific metacognitive component under consideration, and the level and focus of analysis (Neuenhaus et al., 2011; Veenman, 2012). Nevertheless, research indicates that metacognition evolves within specific domains and tasks and can gradually be applied to multiple domains (Van der Stel & Veenman, 2013).

In contrast, several impediments hinder the integration of metacognition into standard scientific practices. Notably, educators' disciplinary expertise and ongoing professional growth can significantly influence the implementation of metacognitive strategies within educational settings. The contention put forth by knowledgeable educators regarding the dearth of suitable learning resources and time allocations (Zohar & Barzilai, 2013) suggests the presence of a disparity between theory and practice in this domain.

The issue at hand is influenced by both internal and external factors, particularly in the context of student-teacher dynamics. Within the middle school milieu, numerous students grapple with a lack of impetus to excel academically, which is evidenced through diminished test scores, non-participation in classroom activities, incomplete assignments, and a general disinterest in assuming the role of independent learners. Existing literature presents a multitude of rationales for the apparent dearth of motivation among students, attributing most of these reasons to intrinsic and extrinsic motivational factors (Liou et al., 2020; Ryan & Deci, 2020). Individuals lacking intrinsic motivation may manifest signs of boredom, a dearth of personal goals and interests, or a perception of being unchallenged in accordance with their skill level. Conversely, educators can also contribute to low motivation in students by demonstrating a lack of enthusiasm during lessons, imposing limited choices upon students, or failing to establish rapport with them (Ben-Eliyahu & Linnenbrink-Garcia, 2015; Böheim et al., 2021; Phillips & Lindsay, 2006). As per Birdsell et al. (2009), when students are afforded choices in learning tasks such as activities, lesson topics, assessments, and homework, they exhibit higher levels of initiative and engagement in the educational process. Consequently, the overall ambiance of the learning environment and student attitudes can be positively impacted.

The current study aimed to investigate whether there are differences in MLS scores based on gender. The findings revealed a non-significant effect of gender on students' perceptions of MLS, indicating that being a female or male student does not lead to significant differences in MLS scores. This result is consistent with previous research by Aydın and Kılıç-Mocan (2022) and Kandal and Baş (2021), suggesting that gender does not significantly impact MLS. However, contrasting results from Oğuz, Kutlu Kalender (2018), and Öztürk and Serin (2020) indicated that gender does create significant differences in the metacognition variable. The inconsistent results regarding metacognition may stem from variations in its conceptualization and the use of different measurement scales. Furthermore, the diversity in samples and contexts across studies may contribute to these inconsistencies.

Therefore, it is essential to establish refined definitions of metacognition to alleviate conceptual ambiguity and to explicitly state the adopted definition or conceptual framework in future studies.

Conclusion and Recommendations

The focus on metacognitive learning strategies as a motivational component within the context of science lessons is of significant importance. This study aims to demonstrate the potential contribution of choice-based science learning to the utilization of metacognitive learning strategies, highlighting the importance of empowering students to take responsibility for their own learning processes. By shifting the traditional role of the teacher as the primary responsible party, students are encouraged to assume accountability for their individual learning journeys. Furthermore, the encouragement of metacognition, which is integral to the development of students' scientific thinking and questioning skills (Ben-David & Zohar, 2009; Cooper & Sandi-Urena, 2009), through self-regulation, represents a key objective in science education. Given the significant impact of metacognition on learning outcomes, future studies could attempt to determine the benefits of metacognitive learning strategies across learning contexts. Notably, a comprehensive review of studies involving students across different age groups and diverse fields of study revealed that metacognitive skills accounted for 40% of the variance in learning outcomes (Veenman, 2011). As such, it is recommended that educators devote attention to the field of metacognition, recognizing it as a fertile area for potential academic advancement.

The current study points to the increasing importance of out-of-school learning in student outcomes, including MLS. However, despite the increasing importance of metacognition in science education, attempts to implement it in classroom settings are rare. Therefore, in order for metacognition and related learning strategies to find a place in routine science education, policy makers need to prepare processes that will facilitate this in curriculum and teacher education. Expanding the inclusiveness of courses to include students with high learning loss, declining interest in science, and socioeconomic disadvantages may increase homogeneity among students in terms of academic competencies. Students can be encouraged to participate in STCs by providing transportation, free and discounted lunch, and offering enrichment classes such as physical education and art that students are interested in. This can help prevent learning loss among students and increase their success in science classes.

The more time a student spends in school, the more knowledge they can acquire. Miller (2007) reports that summer vacations create many problems for students. These include learning loss, spending much of the first semester of the new school year reviewing the curriculum from the previous year, loss of motivation, and time away from school due to lack of supervision. Therefore, schools should attract students’ attention with enriched programs that will enable continuous learning beyond the official work calendar. In this way, the negative effects of being away from the school context on academic success can be reduced. Considering the fact that students have much lower levels of academic skills than they should have in the transition from middle school to high school, it can be said that policy makers should add more accessible and functional applications such as STCs to their agendas.

This study was conducted in official state secondary schools where MoNE-financed STC science course summer term programs were implemented. Determining the MLS levels that are effective in developing students' science literacy skills and reducing learning losses is important in terms of revealing the effects of non-compulsory STC education contexts on student outcomes. Considering the prevalence of courses run through private educational institutions outside of official STC courses in Türkiye, it can be said that the components affecting MLS should be clarified, integrated into the curriculum components of science courses and other disciplines, and associated with educational outcomes.

The study at hand is concerned with the implications of science education research findings. An inquiry into whether the outcomes of this research can be extrapolated to other disciplines will be undertaken. The uncertainty surrounding this matter may be attributed to the intricate relationship between the generalizability and specificity of the field. Nonetheless, research on metacognition in the realm of science education, which delves into elucidating metacognitive learning strategies and fostering deep learning through guidance, control, and organization, is believed to possess cross-disciplinary applicability (Veenman, 2011; Veenman & Van der Stel, 2013). The findings of this study may shed light on previously overlooked performance indicators associated with metacognition. Furthermore, it is posited that science education activities encompassing metacognitive planning, evaluation, and control/regulation may be rendered more accessible, thereby presenting a promising avenue for further exploration. It is advisable to emphasize the significance of metacognitive knowledge/awareness. Metacognitive knowledge and metacognitive self-regulation are interconnected facets of metacognition. The development of metacognitive self-regulation is influenced by metacognitive knowledge, and vice versa (Efklides, 2008). Research has consistently demonstrated the substantial benefits of cultivating metacognitive knowledge/awareness in enhancing students' scientific thinking, questioning, and problem-solving abilities (Kaberman & Dori, 2009; Zohar & Ben David, 2008). Consequently, it is recommended that forthcoming studies on metacognition encompass diverse aspects of metacognition and assess the efficacy of experimental designs that encompass both metacognitive knowledge and metacognitive self-regulation.

This study was conducted by within the scope of a two-month course program due to the limitations of the research environment. The participants were 8th grade students. This short period, during which students make great efforts to prepare for the high school entrance exam and benefit from additional courses, is open to the effects of mediating variables affecting the cognitive processes of the students. For example, the steady increase in students' MLS levels may reflect the effects of mediating variables. Therefore, the results should be interpreted with caution. Repeated application in longer-term and extended contexts would be beneficial in enriching insights into metacognitive learning strategies and other components.

In conclusion, this study adds to the existing body of literature by shedding light on the impact of student choice as a motivational strategy in influencing metacognitive teaching strategies, which serve as a predictor of academic success.

Compliance with Ethical Standards

Disclosure of potential conflicts of interest

The author has no conflicts of interest to declare.

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CRediT author statement

Since the research was conducted by a single author, no specific roles were assigned.

Research involving Human Participants and/or Animals

This study was carried out taking ethical rules into account. The study was approvad by the Fırat University Social Sciences Ethics Committee (2022-9684).

Destekleme ve Yetiştirme Kursları Kapsamındaki Fen Dersine İlişkin Öğrencilerin Üstbilişsel Strateji Eğilimlerinin İncelenmesi

Özet:

Yaygın eğitim kapsamındaki destekleme ve yetiştirme kurslarında (DYK) öğrencilerin ders başarısının artırılması hedeflenmektedir; ancak, bu süreçte öğrencilerin motivasyonel bileşenlere ilişkin algılarının ne yönde değiştiği dikkate alınmamaktadır. Bu ihtiyaca yönelen bu araştırma, yaz dönemi DYK kapsamındaki öğrencilerin fen dersi bağlamındaki motivasyonel bir bileşen olan üstbiliş öğrenme stratejilerine (ÜÖS) ilişkin algılarının boylamsal eğilimlerine odaklanmıştır. İlişkisel tarama modelinde yürütülen bu araştırmaya, dört farklı ortaokuldan toplamda 622 öğrenci (%51.6 kadın; %48.4 erkek) katılmıştır. Ulaşılan sonuçlara göre, öğrencilerin ÜÖS kullanma eğilimleri, boylamsal olarak anlamlı düzeyde artmıştır. Buna ek olarak, kadın ve erkek öğrencileri yansıtan gruplar arası sonuç, iki grubun ÜÖS puanları arasında anlamlı bir farklılık oluşmadığını yansıtmaktadır. Öğrencilerin herhangi bir öğretimsel müdahale olmadan ÜÖS puanlarının artması, seçime dayalı DYK'nın öğrencilerin öğrenme görevlerine aktif katılımını artırdığı ve derse yönelik motivasyonel süreçleri teşvik ettiğini göstermektedir. Bu da öğrencilerin öğrenme sırasında ve sonunda bilişsel stratejileri aktif olarak kontrol ettikleri anlamına gelmektedir. Sonuçlar, öğrencilerin fen dersine yönelik yaygın ve informal öğrenme ortamlarından daha fazla yararlanmalarının gerektiğini göstermektedir. Kursların kapsayıcılığının, öğrenme kayıpları yüksek olan, fen dersine karşı ilgi düzeylerinde gerileme olan ve sosyoekonomik dezavantajlara sahip olan öğrenciler dahil edilerek genişletilmesi, öğrenciler arasında akademik yeterlikler açısından homojenliği artırabilir. Dolayısıyla, üstbiliş ve buna bağlı öğrenme stratejilerinin rutin fen eğitiminde yer edinebilmesi için, politika yapıcıların öğretim programlarında ve öğretmen eğitiminde bunu kolaylaştıracak süreçleri hazırlamaları gerekmektedir.

Anahtar kelimeler: Üstbiliş, okul dışı eğitim, fen eğitimi, fen öğretimi, ortaokul öğrencileri.

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Research Article

Teaching Multiplication Through the Japanese Multiplication Method: An Action Research Study*

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Abstract –The Japanese multiplication method (JAMED) is defined as drawing diagonal lines from left to right, followed by crossing them with diagonal lines from right to left, and then counting the intersection points to determine the multiplication result. This study aimed to teach multiplication to third-grade students who struggled to learn the operation using traditional methods, by employing the JAMED method, and to evaluate the process. We utilized the technical/scientific/collaborative model, a type of action research, in this study. The research was conducted with four third-grade students who were unable to learn multiplication through traditional methods, in a primary school located in Hani district of Diyarbakir province. We collected data using several tools: the 3rd Grade Multiplication Success Test developed by the researchers, Pre- and Post-Implementation Teacher Interview Forms, Post-Implementation Student Interview Forms, Researcher Diary, Audio Recordings taken during the Teaching Process, Lesson-End Assessment Activity Sheets, and related Rubrics. For the analysis of the qualitative data obtained, we employed content analysis and descriptive analysis. The findings indicated that the JAMED method positively impacted the development of multiplication skills and the transformation of negative affective traits towards multiplication into positive ones. However, students faced difficulties with marking intersection points, counting dots, grouping, adding carry-over numbers, drawing diagonal lines, shifting digits, and transferring results obtained with JAMED to traditional methods. We also identified potential disadvantages of JAMED, such as overshadowing other subjects and time limitations.

Keywords: Multiplication, JAMED, Japanese multiplication method, arithmetic operations, cross-line method.

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Introduction

Mathematics is an abstract tool that solves problems by utilizing concepts of shape, size, and counting. It plays a crucial role in every aspect of life (Niswarni, 2012; Purnama & Afriansyah, 2016; Rohmah & Suriarso, 2018; Ulwiyah & Ragelia, 2020). This discipline is fundamental in developing skills such as analysis, evaluation, and problem-solving. Given its role as a powerful means of communication and its pervasive presence in daily life, it is essential that mathematics be taught from an early age (Lolang, 2019; Simbolon & Sapri, 2022).

In elementary education, mathematics is taught to help individuals acquire various mathematical concepts and to enable them to understand and use arithmetic operations. Among the arithmetic operations introduced at the elementary level, multiplication is particularly significant because it forms the foundation of mathematics and supports other topics (Prahmana et al., 2012; West, 2011).

Multiplication is one of the four basic operations required to solve mathematical problems. Multiplication serves as an essential tool in problem-solving and establishes a solid foundation for reasoning, algebraic thinking, and advanced mathematics. Mastering multiplication is viewed as prerequisite skill that facilitates the learning of other mathematical concepts. Therefore, multiplication is considered a topic that must be taught and reinforced from the early years of elementary education (Adawiyah & Kowiyah, 2021; Firdaus, 2018; Halyadi et al., 2016; Kamini, 2013; West, 2011).

According to the Mathematics Curriculum in Türkiye, the teaching of multiplication begins in the second grade, and as the grade level increases, the topics related to multiplication expand and become more complex. A student who starts the process by learning that multiplication is repeated addition can perform more complex multiplication operations involving multi-digit numbers by the time they graduate from primary school (Ministry of National Education [MNE], 2018; 2024).

Studies have shown that techniques such as magic fingers, dot marking, concrete-semi-concrete-abstract, self-monitoring, read-write-compare, hide-copy-paste, Vedic, and VOFT (Video-Oyun-Flaş Kart-Test [Video-Game-Flash Card-Test]) are effective in teaching multiplication. Additionally, the use of visualization, games, realistic mathematics education, and computer-assisted software has been found to be effective (Albay, 2020; Akgün, 2022; Alıncak, 2019; Aydemir, 2017; bin Syed Ismail & Sivasubramniam, 2010; Chang et al., 2008;

Duyen & Loc, 2021; Hartatik & Rahayu, 2018; Kouhi & Rahmani, 2022; Küçüközyiğit & Özdemir, 2017; Özlü & Yıkmış, 2019; Saygılı & Ergen, 2016; Sertdemir, 2021; Sidekli et al., 2013; Thai & Yasin, 2016). Consequently, the use of different methods and techniques in teaching multiplication is both important and necessary.

One alternative method for teaching multiplication is the Japanese Multiplication (JAMED) method. The JAMED method is described as a way of calculating the results of numbers to be multiplied. Using this method, students can develop their multiplication skills in a balanced manner without the need for memorization (Hemi et al., 2021; West, 2011). The JAMED method is known as a learning innovation created by Professor Fujisawa Rikitarou from the University of Tokyo. In Indonesia, JAMED is known as the Cross Line Multiplication Method, a geometry-based approach involving two parallel, right diagonal, and left diagonal auxiliary lines. The method involves drawing right diagonal lines over left diagonal lines, counting the points where these lines intersect, and writing the product at the intersection points. As an algorithm, JAMED uses a group of lines to represent numbers, teaching multiplication to children through these patterns. The JAMED method facilitates the understanding and performance of multiplication for primary school students without relying on memorization techniques (Alim et al., 2022; Fuadah et al., 2019; Grain & Kumar, 2018). Figure 1 illustrates how multiplication is performed using the JAMED method.

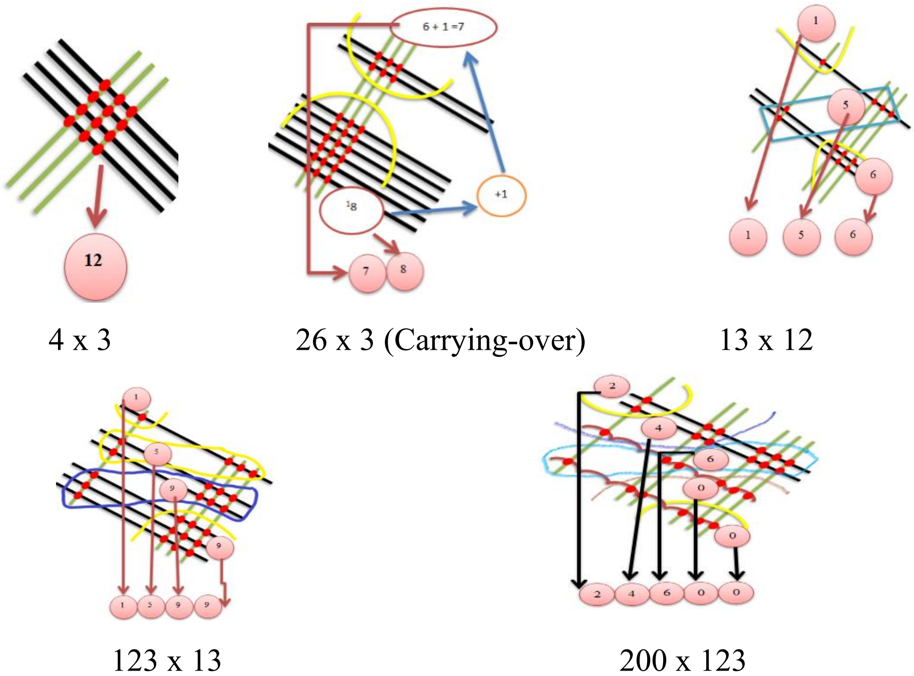

Figure 1 Multiplication Representations with JAMED for Numbers with Different Digit Counts

JAMED is a geometric-based method that enables students to learn multiplication solely through counting skills, without requiring any prior knowledge of addition operations or multiplication tables (Grain & Kumar, 2018). This method frees elementary-level students from the limitations and difficulties of rote learning by allowing them to visualize mathematics (Abari & Tyovenda, 2022; Fuadah et al., 2019). In this method, students can visualize each factor through lines and the product as points, or they can easily comprehend multiplication elements represented in this way. Moreover, by simply changing the orientation of the paper, students can observe the commutative property of multiplication. According to Dumagat et al. (2024), JAMED helps students construct and acquire knowledge through exploration and reflective thinking, facilitating active and hands-on learning. JAMED enables the concretization of highly abstract mathematical concepts by encouraging students to draw lines and create visual representations.

A review of the literature highlights numerous studies on the use of the JAMED method in mathematics education. Abari and Tyovenda (2022) demonstrated that JAMED is more effective than traditional methods in improving mathematics achievement and retention among elementary school students in Benue State, Nigeria, regardless of gender. Similarly, research conducted in Indonesia with elementary school students indicates that JAMED significantly enhances multiplication skills (Mustafa et al., 2021; Pertiwi et al., 2023), positively impacts learning outcomes (Cahyani & Lestari, 2024), and effectively teaches mathematical representation skills compared to rote learning methods (Fuadah et al., 2019). Furthermore, studies have shown that JAMED has a large effect size on conceptual understanding of multiplication (Hidayah, 2016), promotes active participation and easier comprehension of multiplication concepts (Nitasari, 2020), and simplifies students' understanding of the "concept of multiplication" (Fasya et al., 2023). In the context of the Philippines, Dumagat et al. (2024) similarly revealed that JAMED is more effective than traditional methods in improving the multiplication skills of elementary school students. In addition to its effectiveness in general settings, JAMED has been found to assist elementary school students with learning disabilities in Malaysia in developing fundamental multiplication skills (Mun & Abdullah, 2023).

Despite its proven benefits, JAMED is not included in the current Mathematics Curriculum in Türkiye (MoNE, 2024), and no studies on its implementation have been conducted in this context. Instead, the curriculum relies on the conventional long multiplication method. However, research has identified significant challenges with this approach. Students often make errors such as incorrect carrying, multiplying only digits in the ones place, calculation errors, using addition instead of multiplication, and misunderstanding the effects of "0" and "1." Additional issues include misapplying operation sequences, writing results incorrectly, and lacking knowledge of shortcut multiplication techniques (Attisha & Yazdani, 1984; Doğan, 2002; Gürsel, 2000; Kilian et al., 1980; Kubanç & Varol, 2017; Üçüncü, 2010). On the one hand, studies reporting positive findings on the teaching of multiplication through methods such as JAMED, and on the other hand, the challenges faced in traditional multiplication methods, raise the question of whether JAMED could serve as an alternative solution. Therefore, this study aims to explore the potential of the JAMED method in teaching multiplication to students who have struggled to learn through traditional approaches. To this end, the study seeks to address the following research questions:

1. What are the teacher's perspectives on the process of teaching multiplication using traditional methods?
2. What are the views of the teacher, students, and researcher regarding the process of teaching multiplication using the JAMED method?
3. How effectively do students apply the steps of the JAMED method for multiplication?
4. What changes are observed in the multiplication success test scores of students after learning multiplication with the JAMED method?

Method

Research Model

In this study, we employed the technical/scientific/collaborative model, one of the types of action research. Action research is recognized as a research method that involves systematically and scientifically collecting data to understand the current situation and developing practices based on that data. In action research, the researcher actively participates in the research process. Although action research falls within the category of qualitative research, it utilizes both qualitative and quantitative research methods and techniques (Büyüköztürk et al, 2021; Kuzu, 2009).

Study Group

We conducted the research in a primary school located in the Hani district of Diyarbakir, Türkiye. The study began by identifying a teacher who had students in her classroom experiencing difficulties with multiplication and who was willing to voluntarily participate in the research to address this issue. The teacher, who is 30 years old, has completed her fifth year in the teaching profession. At the time the study was conducted, she was teaching students whom they had been educating since the first grade.We used criterion sampling, one of the purposive sampling methods to determine the students. The criteria for selecting students in this study included being in the third grade and struggling to learn multiplication using traditional methods. To identify the students, we administered an achievement test developed by the researcher and research advisor and conducted interviews with classroom teachers. Based on the analyses of the test results and interviews, students who met the criterion of obtaining the lowest scores on the achievement test were selected for the study. The selected students and their parents were informed about the research processes, and informed consent was obtained from them, confirming their voluntary participation in the study. We assigned pseudonyms—Ada, Songül, Ferit, and Seyran—to the students included in the study. The teacher provided the following descriptions of the students, as presented in Table 1.

Table 1 Descriptions of the Students

Student	Teacher's description
Ada:	"*Her reading skills are the weakest among her peers. She struggles the most with reading in the class. She exhibits learned helplessness. Although her parents are supportive, she lacks motivation and effort, which prevents her from progressing. She struggles not only in mathematics but in all subjects. However, she is social and enjoys talking. I believe her academic performance will improve if she advances her reading skills. I think her struggles in all subjects stem from her reading difficulties.*"
Ferit:	"*He is interested in everything except the lessons. He loves to talk and share his experiences. He shows no interest in any subject and often forgets his books and notebooks. He doesn't make any effort. Although his reading skills are good, he struggles to regulate his breathing. Even after discussing this with his family, no progress was made. His parents believe that he doesn't study enough.*"
Songül	"*She shows more interest in art than in other subjects. She enjoys colors and drawing and is aware of color harmony. However, she is not engaged in her lessons. Her reading and writing skills are at a low level, and she doesn't make an effort to improve. This lack of effort is reflected in all subjects, not just mathematics. She exhibits learned helplessness and doesn't practice reading and writing at home. As a result, she is failing in all subjects. Although she performs better in addition and subtraction, she is still behind her peers. Her family is uninvolved and insufficiently supportive.*"
Seyran	"*Seyran is a curious and talkative child but often misses classes and does not participate regularly. She can perform addition and subtraction but has weak reading skills, although her reading has improved recently. She now reads books and asks me if her reading has improved. I believe Seyran has the potential to progress and that, with time, she will learn multiplication. She enjoys extracurricular activities such as playing games, jumping rope, and physical education*."

In the study, in addition to teacher and student data, researcher data were also utilized. The researcher graduated from the department of primary school teaching in 2018 and has completed their fourth year in the teaching profession. At the time the study was conducted, the researcher was serving as an assistant principal and was pursuing a master's degree program in primary education.

Action Committee Meetings

To ensure the effective implementation of the study, we formed an action committee before beginning the implementation process. The committee, comprising the advisor, researcher, and classroom teacher, met at the start of the process, after each action plan was implemented, and at the conclusion of the study to assess progress and address emerging issues.

Initially, the committee gathered to discuss the research process and decided that the JAMED method was appropriate for addressing the research problem, recommending that data be collected in this direction. The committee also concluded that it would be beneficial to interview the teacher about the students before starting the implementation. The interview provided insights into the teacher's previous experience with traditional multiplication teaching methods. However, the committee found the interview data insufficient and decided to conduct a second interview. After reviewing the pre-implementation achievement test results, the committee selected the students to be included in the study.

Before starting the research, we conducted a pilot implementation. We found that students had difficulty drawing diagonal lines. To address this issue, we decided to use grid paper to make drawing diagonal lines easier in our first action committee meeting. Following the first action plan, the committee met to evaluate the week. It was reported that grid paper had been distributed to the students, and the issue of not being able to draw diagonal lines was resolved. However, a new issue emerged the following week. The committee observed that the complexity of grid paper increased when the number of steps and numerical values increased, leading to the decision to discontinue the use of grid paper. After the second action plan, the committee convened to review the week’s activities. It was decided that, for a student who experienced difficulties with carrying, remedial instruction in addition was to be provided until the next action plan date. After the third action plan, the researcher reported that the remedial instruction was insufficient, as the student continued to struggle with carrying. The researcher suggested that the student should add dots to the lines representing the carried number, which successfully resolved the issue. However, the researcher also noted that students had difficulty grouping by place value, and the committee recommended marking each group with different colored pencils. After the fourth action plan, the researcher reported no problems, and the meeting was adjourned. However, after the fifth action plan, the teacher raised a concern, stating that reverting to the traditional method after using JAMED might negatively impact the students. As a result, the committee decided to extend the action research by one more week. The committee suggested combining the JAMED method with traditional multiplication for the sixth action plan, creating a lesson plan where each multiplication step is performed using the JAMED method and recorded in the corresponding place in the traditional method.

Data Collection

We collected the data for this study using several instruments, including the 3rd Grade Multiplication Achievement Test developed by us, pre- and post-implementation teacher interview forms, post-implementation student interview forms, a researcher's diary, audio recordings from the teaching process, lesson-end assessment activity sheets, and rubrics related to these activity sheets.

The content of the 3rd Grade Multiplication Achievement Test includes learning objectives of multiplication from the 2nd and 3rd grades. We reviewed these learning objectives and selected those suitable for teaching using the JAMED method. Based on this selection, we created a draft achievement test form consisting of 25 items. To determine the content validity of the test, we used Lawshe's (1975) technique. We formed an expert group consisting of eight members—five from elementary education and three from mathematics education. These experts evaluated the items using three criteria: essential, useful but not essential, and not necessary for performance. After gathering the experts' feedback, we calculated the content validity ratios (CVR) and content validity indices (CVI) for each item. We calculated the content validity ratios by subtracting "1" from the value obtained by dividing the number of experts who labeled the item as 'essential' by half the total number of experts. Items with a CVR of 0 or lower were removed from the test, which led to the exclusion of items 5 (CVR = -0.25), 7 (CVR = 0), 9 (CVR = 0), and 10 (CVR = 0). The average CVI value for the remaining items in the test was found to be 0.93, which is above the critical CVR value of 0.75 for eight experts. Therefore, we concluded that all remaining items had sufficient content validity.

After establishing content validity, we administered the 21-item version of the test to 504 third-grade students in Diyarbakir to calculate item difficulty and discrimination indices and to conduct an Exploratory Factor Analysis (EFA) for construct validity. The item discrimination indices ranged from 0.11 to 0.85, while the difficulty indices varied between 0.55 and 0.95. We removed item 1, which had a discrimination index below 0.30 (0.11). The average difficulty level of the test was calculated as 0.72, indicating that the test is relatively easy (Büyüköztürk, 2020). This ease was expected since the pilot study was conducted with students who had previously learned these skills. Given that this study is an action research project and the test's purpose is to identify students who struggle even with easier questions, we decided to use the test within this research.

As a result of EFA, the Kaiser-Meyer-Olkin (KMO) value was 0.93, and Bartlett's test was significant ($p < 0.05$). The EFA results indicated that the achievement test could be grouped under a single factor. The total variance explained by the 20-item test was 42%, which is sufficient for a single-factor structure (Bayram, 2015). All items in the test had factor loadings above 0.30 (ranging from 0.44 to 0.77), suggesting that none of the items needed to be removed (Pallant, 2007). These findings indicate that the data were appropriate for factor analysis and that the sample size was adequate (Seçer, 2013).

We assessed the reliability of the measurements conducted for the EFA using Cronbach's α coefficient, given that the test items had more than two response options (three-choice items) (Uyanah & Nsikhe, 2023). The reliability coefficient for the achievement test was calculated as 0.92, indicating that the measurements were reliable (Sipahi et al., 2010).

We designed the Pre-Action Teacher Interview Form to gather insights into the multiplication teaching process using traditional methods. We aimed to understand the challenges faced, the reasons behind these challenges, students' attitudes and perceptions toward multiplication, and the errors students made while solving multiplication problems.

After each action plan, we used the Post-Action Teacher Interview Form to collect the teacher's reflections on the JAMED method. Similarly, we employed the Post-Action Student Interview Form to capture students' thoughts on the JAMED method following each action plan.

We kept a research diary to record our observations after each action plan. We maintained the diary in an unstructured format, making occasional notes during the action plan implementation and reflecting on the assessment after the lesson ended. We also documented any observations shared by teachers and students regarding the effects of the JAMED method both inside and outside the classroom between the conclusion of one action plan and the implementation of the next.

We administered lesson-end assessment activities to students after each action plan. We designed these activities to align with the day's action plan outcomes. We shared the activities with the teacher before each action plan and made necessary revisions. For instance, we prepared a three-question activity sheet for the first action plan and presented it to the teacher, who suggested adding a question to assess the representation of the number "0" in JAMED. Consequently, we replaced the "6x3" question with "6x0". After the lesson, we asked students to complete the activities and collected the completed activity sheets.

We assessed the collected activity sheets using an analytic rubric, which allowed for detailed evaluation of each step in the process or skill being measured (Haladyna, 1997). We developed separate rubrics for each assessment activity in the action plans to gather detailed information about students' performance in the multiplication process using the JAMED method.

To ensure the validity and reliability of the rubrics, we followed several steps. We referred to Kutlu et al. (2010) for guidelines on creating reliable rubrics. According to their recommendations, criteria should be clear and unambiguous, non-overlapping, descriptively defined, accurately reflect grading, and have enough levels to distinguish performance differences. After preparing the rubrics with these features, we increased their validity by seeking expert opinions. We consulted seven experts, including three in mathematics education and four in elementary education. We asked the experts to evaluate the rubric based on the criteria, descriptive definitions, and grading accuracy. Based on their feedback, we made several changes. For example, we revised the description for the "0" score from "inability to draw lines as many as the factor" to "inability to draw lines." Similarly, we split the original criterion "*Left a small space between lines and drew diagonal lines as many as the units digit on the righ*t" into two separate criteria: "*Did not leave a space where necessary*" and "*Drew as many diagonal lines as the units digit on the right*."

After each action plan, both the teacher and researcher individually scored each student using the rubric. To facilitate scoring, each rubric included the criteria, their descriptive definitions, and the corresponding scores. Table 2 provides an example of the rubric and descriptive definitions used for scoring the multiplication of two single-digit numbers using the JAMED method.

Table 2 Rubric for the Multiplication of Two Single-Digit Numbers Using the JAMED

	0 (Inadequate)	1 (Partially adequate)	2 (Adequate)
1. Drew diagonal lines from the right for the first factor.	Did not draw lines	Drew lines unevenly, too many or too few, or did not draw the correct number of lines	Drew lines correctly and as many as the factors
2. Drew diagonal lines from the left intersecting with the diagonal lines from the right for the other factor.	Did not draw lines	Drew lines unevenly, too many or too few, or did not draw the correct number of lines	Drew lines correctly and as many as the factors
3. Drew curved lines for the factor with a zero value.	Did not draw curved lines for the zero value	Drew curved lines incorrectly for the zero value	Drew curved lines correctly for the zero value.
4. Marked the intersection points of the lines.	Did not mark intersection points	Marked intersection points incorrectly	Marked intersection points correctly
5. Counted the marked intersection points.	Did not count intersection points	Counted intersection points incorrectly	Counted points correctly
6. Wrote the multiplication result.	Did not write the multiplication result	Wrote the multiplication result incorrectly	Wrote the multiplication result correctly.

Data Analysis

We employed content analysis and descriptive analysis to analyze the qualitative data obtained from the research. Content analysis is a qualitative research method that involves examining documents, texts, and records to obtain objective and reliable information (Metin & Ünal, 2022). Descriptive analysis involves the in-depth examination and organization of qualitative and quantitative research on a specific topic (Ültay et al., 2021). We analyzed interviews, diaries, and dialogues using content analysis, while documents were analyzed through descriptive analysis. We used MS Office Excel software to calculate data from the success test, summing the points given for each correct answer (5 points).

Validity and Reliability

To ensure internal validity and reliability in the study, we also addressed and attempted to block the researcher's biases related to the phenomena under investigation (Merriam, 2015). The researcher's bias was their belief in the JAMED method's effectiveness for teaching multiplication and their role as an assistant principal at the school where the research was conducted. To account for the potential influence of the researcher's beliefs on the diaries, we utilized semi-structured interviews and document data to obtain diverse perspectives. We informed both students and teachers at the beginning of the interviews that they could express their thoughts impartially and without hesitation, emphasizing the value of negative feedback for the study. One indicator of the effectiveness of this strategy was the identification of themes related to both the advantages and disadvantages of the JAMED method in the research findings.

We ensured the internal validity of the data through data source triangulation and the internal validity and reliability through analyst triangulation (Patton, 2014). In this context, we conducted interviews with teachers and students, maintained diaries, collected documents related to student activities, evaluated these documents using scoring rubrics, and recorded researcher-student dialogues during action implementations. In other words, we enriched the data obtained from the research through interviews with various individuals and documents from the process. We supported findings in the presentation by corroborating the same category with different data sources. For instance, the "willingness" category under the affective theme in the process findings of the second action plan is an example. The researcher's statement, "*Students constantly raised their hands to come to the board and solve multiplication problems,*" and the dialogue, "***Researcher****: Yes, children, the multiplication of a two-digit number by a single-digit number is done like this in the Japanese multiplication method. Now, let's do another example.* ***Seyran****: Teacher, let's do it too*," demonstrate data collection from two different sources for the same category. Additionally, we used other data sources to uncover themes and categories not apparent from a single source. For example, the theme of cognitive features, which did not emerge from interviews or diaries, along with the categories of guidance and process explanation, were obtained through recording classroom dialogues. Interviews and diaries were coded by the researcher and the advisor, while activity documents were coded and analyzed by the researcher and teacher using scoring rubrics. We calculated the reliability of these codes using Miles and Huberman's (1994) reliability formula [Reliability = Agreement/(Agreement + Disagreement)]. The reliability for teacher interview data was 85%, for student interview data was 92%, and for researcher diary data was 83%. Inter-coder reliability for the assessments conducted with scoring rubrics was 98.3% (728/740). Since these percentages exceed 70%, we can assert that the inter-coder reliability ratio is sufficient and that the coding meets the minimum reliability criteria.

In qualitative research, the use of the audit trail technique is also essential for ensuring research reliability. This involves explaining how data were collected, how categories were created, and how decisions were made (Merriam, 2015). In this study, we collected qualitative data between March 14, 2023, and May 9, 2023. We conducted semi-structured interviews with the teacher before the implementation. After selecting students based on success test data, we communicated the process to them and explained the actions to be taken during the implementation. Weekly, we conducted semi-structured interviews using teacher and student interview forms at the end of each action plan. Additionally, throughout the process, the researcher maintained their diary. Weekly interviews were recorded and transcribed. We analyzed and coded the transcribed interviews and the researcher's diary data.

Initially, two coders separately coded the data. We then compared these codes to identify agreements and disagreements. In cases where the two coders disagreed, we followed the researcher's decisions due to their greater familiarity with the research processes; however, all such cases were recorded as disagreements. For example, while scoring the rubric for the first activity of the first action plan, the researcher awarded a "1" point for Ada under the criterion "Marked the intersection points of the lines" by noting that the points were not distinct, while the teacher awarded a "0" point, believing that the marking was incomplete.

From the codes obtained by the coders, we derived categories, and from the categories, we developed themes. For instance, in the pre-action interview with the teacher, we found statements such as:

"*Children generally have a failure mindset. They realize they cannot perform addition and subtraction, and then they think, 'If I can't do addition and subtraction, I can't do multiplication either' (**cannot-do prejudice**). As a result, they develop prejudices such as 'I cannot grasp multiplication' (**cannot-grasp prejudice**) and 'I can't do it' (**cannot-do prejudice**). … Since children cannot perform rhythmic counting and do not understand the concept of multiples in multiplication, they develop a prejudice against multiplication (**prejudice due to lack of knowledge**)*."

From these statements, we obtained three codes: "cannot-grasp prejudice," "cannot-do prejudice," and "prejudice due to lack of knowledge." These codes were categorized under the "prejudice" category, which was then combined with themes of fear and anxiety, lack of self-confidence, and learned helplessness under the "affective characteristics" theme.

To ensure the external validity of the study, we employed sample diversity and rich, thick descriptions (Creswell, 2007; Merriam, 2015). To achieve sample diversity, we included one student with the lowest score among boys, despite the fact that all four students with the lowest scores from the success test were girls. In terms of rich, thick descriptions, the findings were supported by direct quotations from teachers, students, and the researcher, as well as visuals of activities solved by the children. Additionally, after providing pseudonyms for each participant in the study group section, we presented detailed information based on the teachers' views.

Role of the Researcher

Akgün (2008) has stated that action research can be conducted not only by teachers but also by academics and researchers. Based on this, in this study, the implementation process was directly managed by one of the researchers. Her role as both the assistant principal of the school where the study was conducted and a graduate student created a sense of responsibility for resolving the issues students faced with multiplication. As a result, all action plans in the study were implemented by us in collaboration with and under the observation of the teacher.

A review of the literature reveals similar studies where action plans were managed by researchers (Anagün, 2008; Türkkan, 2008; Şekerci, 2018). Therefore, the researcher's position, qualifications, personal values, and experience with the research topic were considered influential factors at each stage of the process. We conducted detailed research on the problems related to multiplication and its teaching, as communicated by the teacher, and concluded that the JAMED method could address these issues. Consequently, we decided to use action research as qualitative research method for this study.

As the assistant principal of her own school, the researcher was able to maintain continuous communication with students. She worked to earn their trust by interacting with them during breaks and informed them that they could visit her with any concerns related to the action process.

Findings

Findings on the Process of Teaching Multiplication Using the Traditional Method and JAMED

The themes and categories derived from opinions on the multiplication process conducted with the traditional method before the action research, the multiplication teaching process carried out using JAMED during the intervention (1st-5th weeks), and the process where these two methods were combined (6th week) are presented in Table 3.

Table 3 Perspectives on Teaching Multiplication Using the Traditional Method and JAMED

		Traditional multiplication	JAMED					
			1	2	3	4	5	6
Perspectives	Difficult	✓						
	Necessary	✓						
Issues	Carrying Over	✓		✓				
	Shifting digits	✓						✓
	Failing to Complete the Multiplication Process	✓						
	Inability to Solve Problems	✓						
	Marking Intersection Points		✓	✓				
	Speed		✓	✓				
	Counting Dots		✓	✓		✓		✓
	Grouping				✓		✓	
	Transferring JAMED Results to the Traditional Method							✓
Causes of Issues	Lack of Prerequisite Knowledge	✓						
	Unfamiliarity with Rhythmic Counting	✓						
	Lack of Understanding of Multiples	✓						
	Unfamiliarity with the Multiplication Table	✓						
	Inability to Grasp the Logic of Multiplication	✓						
	Aesthetic Concerns		✓	✓				
	Line (Spacing, Size, and Shape)		✓		✓	✓	✓	✓
	Hastiness		✓	✓	✓	✓		
	Lack of Knowledge of Addition			✓				
	Inability to Express Data Numerically						✓	
	Confusion							✓
	Sequential steps							✓
Affective Traits	Prejudice	✓						
	Fear and Anxiety	✓						
	Lack of Confidence	✓						
	Learned Helplessness	✓						
	Low Motivation	✓				✓		
	Perseverance		✓	✓	✓			
	Enjoyment		✓	✓				
	Affection		✓	✓	✓	✓	✓	✓
	Interest		✓					
	Confidence		✓	✓	✓	✓	✓	✓
	Sense of Success		✓			✓		✓
	Enthusiasm			✓				
Cognitive Traits	Suitability for Developmental Stage		✓					
	Ability to Guide			✓				
	Ability to Convey the Problem-Solving Process			✓				
	Learning the Concept of Place Values				✓			
	Learning the Concept of Carrying Over				✓	✓		
	Transfer				✓	✓	✓	✓
	Problem-Solving						✓	
	Traditional Multiplication							✓
	Synthesis with Traditional Multiplication							✓
Advantages	Compensation					✓		
	Widespread Impact					✓		
Disadvantages	Overshadowing Other Subjects				✓			
	Curriculum Differences				✓			
Limitations	Time					✓		✓

***Pre-action research*:** In this study, the first step involved gathering the classroom teacher's perspectives on the students' process of learning multiplication using the traditional method. During the interviews conducted before the JAMED implementation, the teacher mentioned that students found multiplication difficult but necessary. The teacher also noted that students faced issues such as carrying over, shifting digits, failing to complete the multiplication process, and being unable to solve problems. The teacher attributed these problems to a lack of prerequisite knowledge, as well as difficulties in understanding rhythmic counting, the concept of multiples, the multiplication table, and the logic of multiplication. According to the teacher, students experienced prejudice, fear and anxiety, lack of confidence, lack of motivation, and learned helplessness when it came to multiplication. Some of the teacher's views related to these themes are provided below.

> **Perspective-Necessary:** *"Students tried to learn multiplication at the beginning of the process because they knew they could use it in their daily lives."* (Classroom Teacher)
> **Affective Traits - Prejudice:** *"Children developed a prejudice against multiplication because they could not perform rhythmic counting and did not understand the concept of multiples in multiplication."* (Classroom Teacher)
> **Issues - Carrying Over:** "*Students couldn't grasp the concept of carrying over during multiplication, which led to addition errors. They didn't understand that the carried number should be added after multiplying the other numbers. They kept writing the carry repeatedly."* (Classroom Teacher)
> **Causes of Issues - Lack of Understanding of Multiples:** "*Students couldn't grasp the concept of multiples. For example, when we say five times six, they couldn't add five sixes together. This made learning multiplication difficult."* (Classroom Teacher)

***First action plan process*:** Feedback on the implementation of the first action plan related to JAMED indicates that after their initial experiences with this method, students developed perseverance, enjoyment, affection, interest, confidence, and a sense of achievement. During the first week, opinions also emerged about the suitability of this method for students' developmental stages. However, it was observed that students struggled with marking intersection points, achieving the appropriate speed, and counting points due to aesthetic concerns, inability to draw lines correctly, and hasty behavior. Some of the opinions on these issues are provided below:

> **Affective Traits - Interest:** *"Students enjoy drawing. Since the Japanese multiplication method is similar to drawing, it facilitated their learning and increased their interest in the lesson."* (Classroom Teacher)
> **Cognitive Traits - Suitability for Developmental Stage:** *"Since it is a fun drawing activity, children in this developmental stage can project it onto paper as they can think concretely, and I believe this method is more suitable and effective for their age group.*" (Classroom Teacher)
> **Issues - Marking Intersection Points:** *"I drew the points too close together, which led to mistakes in marking.*" (Ada)

> **Causes of Issues - Aesthetic Concerns:** *"Although I initially considered the reason to be a lack of understanding of the method, I found out that the student first solved the problem with a pencil using the Japanese multiplication method, then erased it and solved it with a different pencil. When I asked about this, the student said it was 'to make it look nicer.'"* (Researcher)

***Second action plan process*:** Following the implementation of the second action plan, students continued to exhibit positive affective traits such as perseverance, enjoyment, affection, confidence, and enthusiasm towards JAMED. However, students faced issues with carrying over, marking intersection points, speed, and counting dots due to aesthetic concerns, hastiness, and lack of knowledge of addition. Despite these challenges, it was observed that students were able to guide the researcher in solving a multiplication problem using JAMED and effectively convey their own problem-solving processes.

> **Affective Traits - Enjoyment:** "*It was very nice. We all had fun. We did the Japanese multiplication by drawing lines; I think it was very nice. It required carrying over. It felt easier*." (Songül)
> **Affective Traits - Enthusiasm:** "*Students were constantly raising their hands to come to the board and express their desire to solve multiplication problems*." (Researcher)
> **Cognitive Trait - Ability to Guide: Researcher**: "*After this example, may I take you to the board? Let's have you solve this example for me."* **All Students***: "For the tens place, draw two diagonal lines from the right. One, two."* ***Researcher****: "What should I do now?"* **All Students***: "Leave a bit of space and then draw three more lines."* **Researche***r: "What should I do now?"* **Ferit***: "Now we will make the dots, but first we will separate them."* ***Researcher:*** *"Well done, let's separate them into units and tens."* **All Students***: "Now we will count the dots."* **Researche***r: "Where should I start counting?"* **All Students***: "We will start from the bottom."* ***Teacher and All Students****: "One, two… nine. Then we moved to the next place."* **Researcher***: "We counted all of them; what should I do now?"* **Students***: "We will write the result."* **Researcher***: "Where do I start writing?"* **Students***: "Start with six, then nine."* **Seyran***: "The answer is 69.*"
> **Issues - Speed:** "*Songül drew the lines with great care and beautifully using the crayon today. However, this caused her to solve the problems after her peers, even though she completed the multiplication correctly*." (Researcher)
> **Issues - Carrying Over:** "*Ada initially did not grasp the concept of carrying over. Although she improved with more examples, she struggled significantly with adding the carry to the next place. Later, I instructed her to add dots to the higher place value instead of adding the carry, and this allowed her to perform the multiplication with carrying over*." (Researcher)
> **Causes of Issues - Lack of Knowledge of Addition:** "*I couldn't perform addition. That's why I couldn't manage the carry.*" (Ada)

***Third action plan process*:** Observations and experiences from the implementation of the third action plan indicate that students continued to exhibit positive affective traits such as perseverance, affection, and confidence while learning multiplication with JAMED. They learned the concepts of place values and carrying over and were able to transfer their learning outcomes. However, students encountered issues with grouping due to difficulties in drawing lines correctly and hasty behavior. Additionally, the use of JAMED has revealed disadvantages such as overshadowing other subjects and curriculum differences. Some perspectives related to these observations are provided below:

> **Affective Traits - Perseverance:** "*In the first minutes of the lesson and in subsequent observations, I see that the students' efforts and enthusiasm while trying to learn multiplication remained consistent*." (Teacher)
> **Cognitive Traits - Learning Place Values:** "*Our lesson was very good. I really liked drawing the diagonal lines and separating them. I liked it because I learned the tens and units place values.*" (Ferit)
> **Issues - Grouping:** "*This week, grouping by place values was done. Although students initially found it strange, they learned as they practiced, but they struggled with grouping in some cases*." (Researcher)
> **Causes of Issues - Lines:** "*It was fine, but I solve problems more easily when I leave a bit more space and draw larger lines.*" (Ferit)
> **Disadvantages - Overshadowing Other Subjects:** "*They want to participate in that lesson because it seems fun. Also, as their success increased, their interest in the method for that lesson grew, and they wanted to attend that lesson rather than mine*." (Teacher)
> **Disadvantages - Curriculum Differences:** "*Children can perform multiplication here because we cover the classic method and include all operations, such as multiplication and division. For example, we solve problems related to currency and weight measurements. I think they are currently inadequate in this context. I wonder what they will do when these topics are finished, and there is no multiplication involved. Will they be able to apply what they learned or will they immediately revert to the shortcut method? I am not sure. Currently, we are working with the traditional method. Since students are applying this method, they might struggle when we revert to the traditional method in the future*." (Teacher)

***Fourth action plan process*:** In the implementation of the fourth action plan, an ongoing issue has been counting the dots. This problem is attributed to students' hasty behavior, lack of attention to the required spacing, size, and shape of lines, and low motivation. Despite these challenges, students continue to demonstrate feelings of affection, confidence, and success towards JAMED. They have reinforced their understanding of the carrying concept learned in the previous week and have applied their knowledge in various contexts. The observations indicate that while JAMED has limitations in terms of time, it is advantageous in attracting other students, creating a widespread impact, and compensating students' readiness deficiencies. Some views related to this are presented below:

> **Affective Traits - Confidence:** "*Three-digit numbers seemed easier. One and two-digit numbers are good, but three-digit numbers are even better. I feel that I can now perform multiplication. When my teacher asks about multiplication, I can do it now. When my teacher asks for multiplication, I solve it using this method.*" (Seyran)
> **Affective Traits - Low Motivation:** "Comparing with others, *Ferit appeared to lose interest in learning. He wanted to finish the activity quickly to play games with his friends. Therefore, he tried to complete it hastily.*" (Researcher)

> **Advantages - Widespread Impact:** "*They constantly want to attend our teacher's (researcher) class. Other students in my class are also curious about this method and want to participate in the lesson*." (Teacher)
> **Advantages - Compensation:** "*In the classic method, students need to know rhythmic counting and multiplication tables. However, with this method, there are shapes and very basic rhythmic counting, which makes it easier for them. This method has become easier for them*." (Teacher)
> **Cognitive Traits - Learning the Carrying Concept:** "*I had mistakes with carrying, but then we solved them. I no longer miss carrying. It is easier to do carrying. I can solve problems with JAMED.*" (Ada)
> **Issues - Counting Dots:** "...he wanted to finish quickly to play games with his friends. Therefore, he tried to complete it hastily, which led to some mistakes in counting and marking dots." (Researcher)
> **Limitation - Time:** "I think the only issue might be time. Our students are taking exams and racing against time. The multiplication process here might delay their results." (Teacher)

***Fifth action plan process*:** In the implementation of the fifth action plan, it was observed that students sometimes struggled with grouping due to issues with lines and were unable to express data numerically. However, students exhibited a confident and affectionate approach towards performing multiplication with JAMED. They were able to learn problem-solving this week and transfer their knowledge to more advanced multiplication tasks.

> **Affective Traits - Affection:** "*Our students really loved the multiplication process. They constantly wanted to do it. When our teacher (researcher) said that this would be the last week, I could see the sadness in the students. They wanted to continue*." (Teacher)
> **Cognitive Traits - Problem Solving:** "*It was very nice and easy. I couldn't solve problems before, but now I can.*" (Songül)
> **Cognitive Traits - Transfer:** "*It would have been better if we could go up to ten-digit numbers. Now I can do four-digit numbers myself.*" (Songül)
> **Issues - Inability to Express Data Numerically:** " *Students showed me their solutions. They had solved the problems correctly, but sometimes they struggled because they did not understand certain aspects. For instance, there was a problem with an expression like 'in one week,' where they could not multiply by 7. Otherwise, they were generally good.*" (Teacher)

***Sixth action plan process*:** In the implementation of the sixth action plan, which combined JAMED with the traditional multiplication method, students experienced feelings of affection, confidence, and success. They were able to transfer their knowledge, learn the classical multiplication method, and integrate it with JAMED. However, time was still mentioned as a limitation this week, and students struggled due to reasons such as the lines, their confusion regarding the integration of the two methods, and issues with the sequential steps. As a result, they made some errors in shifting digits, counting dots, and transferring JAMED results to the traditional method. The following views reflect these issues:

Affective Traits - Sense of Success: "*I could do a few with the previous method. It improved a bit with the Japanese method.*" (Ferit)
Cognitive Traits - Synthesis with Traditional Multiplication: "*It seemed like they struggled with the traditional multiplication at the beginning of the lesson. When I observed later, the students had mastered it and were able to perform it. They were happy. They could do carrying, shifting digits, and addition. They couldn't finish the multiplication previously, but now they found the result.*" (Teacher)
Issues - Transferring JAMED Results to the Traditional Method: Seyran: *"Teacher, I did this (with JAMED), where should I write it now?"* **Researcher**: *"(In traditional multiplication), the result of the unit place multiplication should be written in the unit place, right?"*
Reasons for Issues - Confusion: "*I noticed initial confusion among the students. They seemed to struggle with classical multiplication at the beginning of the lesson*." (Teacher)
Reasons for Issues - Sequential Steps: "*They struggled with the multiplication of two two-digit numbers. I think this is due to the progression through steps. Initially, they confused where to write the results after each step*." (Teacher)

Findings Related to Assessment

At the end of the instructional process, three activities were presented to assess students' understanding of the topic, and these activities were scored using rubrics.

First action plan assessment: The rubric assessment of the activities conducted at the end of the first action plan, where students learned to multiply two single-digit numbers, is presented in Table 4.

As shown in Table 4, the students generally struggled with drawing lines correctly from the right side for the first factor during the first activity. While Songül, Ferit, and Seyran received high scores in multiplying two single-digit numbers using the JAMED method, Ada received a relatively low score. In the second activity, Ada continued to have difficulty drawing lines from the right side for the first factor. However, all students, including Ada, were generally successful in multiplying a single-digit number by zero. In the third activity, Ada, Songül, and Seyran achieved high scores, while Ferit received a lower score compared to the others.

Table 4 Results of the First Action Plan Activity Assessment

	First activity				Second activity				Third Activity			
Criteria	A	So	F	Se	A	So	F	Se	A	So	F	Se
1. Drew diagonal lines from the right for the first factor.	1	1	1	2	1	2	2	2	2	2	2	2
2. Drew diagonal lines from the left intersecting with the diagonal lines from the right for the other factor.	1	2	1	2	-	-	-	-	2	2	2	2
3. Drew curved lines for the factor with a zero value.					2	2	2	2	-	-	-	-
4. Marked the intersection points of the lines.	1	2	2	2	-	-	-	-	2	2	1	2
5. Counted the marked intersection points.	1	2	2	2	-	-	-	-	2	2	2	2
6. Wrote down the product.	2	2	2	2	2	2	2	2	2	2	2	2
Total point	6	9	8	10	5	6	6	6	10	10	9	10

Figure 2-4 illustrates some of the students' assessment activities:

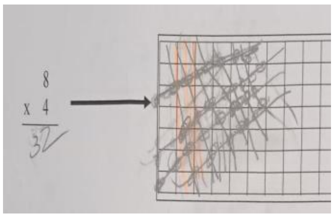

Figure 2 Ada (First Activity)

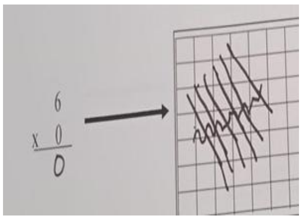

Figure 3 Seyran (Second Activity)

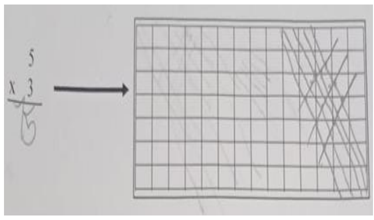

Figure 4 Ferit (Third Activity)

As illustrated in Figure 2-4, Ada was considered "partially adequate" in the first activity for drawing crooked lines for the first factor from the right side and "adequate" for correctly writing the product result. In the second activity, Seyran successfully drew lines from the right side, earning sufficient points for the first criterion, and also met the criteria for "drawing curved lines for the factor with zero" and "writing the product result," thus receiving "adequate" scores. In the third activity, Ferit did not clearly mark the intersection points of the lines, earning a "partially adequate" score for the criterion "marked the intersection points of the lines," but received "adequate" scores for all other criteria. This indicates that students were generally able to use the JAMED method at a partially adequate or adequate level for multiplying two single-digit numbers.

***Second action plan assessment*:** The rubric assessment of the activities conducted at the end of the second action plan, where students learned to multiply a two-digit number by a single-digit number, is presented in Table 5.

According to Table 5, Ada, Songül, and Ferit scored full points in all activities for multiplying a two-digit number by a single-digit number using the JAMED method. However, Seyran scored lower than the others in the first and third activities.

Table 5 Results of the Second Action Plan Activity Assessment

Criteria	First activity				Second activity				Third activity			
	A	So	F	Se	A	So	F	Se	A	So	F	Se
1.Drew diagonal lines from the right equal to the number in the tens place of the two-digit factor.	2	2	2	2	2	2	2	2	2	2	2	2
2.Left a space for the ones place of the two-digit factor on the same line.	2	2	2	2	2	2	2	2	2	2	2	2
3.Drew diagonal lines from the right equal to the number in the ones place of the two-digit factor.	2	2	2	2	2	2	2	2	2	2	2	1
4.Drew diagonal lines from the left that intersected with the diagonal lines from the right, corresponding to the one-digit factor.	2	2	2	2	2	2	2	2	2	2	2	2
5.Drew curved lines for the factor containing the zero value.	-	-	-	-	2	2	2	2	-	-	-	-
6.Marked the intersection points of the lines.	2	2	2	1	2	2	2	2	2	2	2	1
7.Marked the points on the lines according to place values if they appeared.	2	2	2	2	2	2	2	2	2	2	2	1
8. Began counting points from the units place and continued sequentially through the tens, hundreds, and thousands places if applicable.	2	2	2	2	2	2	2	2	2	2	2	2
9.Carried over the first digit of the two-digit count of intersection points to the next higher place value.	2	2	2	2	-	-	-	-	2	2	2	2
10.Wrote the resulting values from left to right starting from the beginning and obtained the final product.	2	2	2	2	2	2	2	2	2	2	2	0
Total point	18	18	18	17	18	18	18	18	18	18	18	13

Figure 3-6 depicts some of the students' assessment activities:

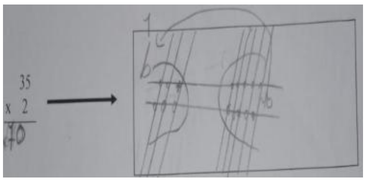

Figure 5 Songül
(First Activity)

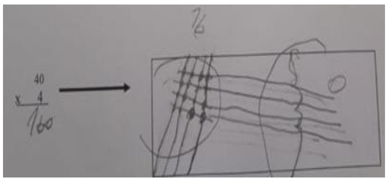

Figure 6 Ferit
(Second Activity)

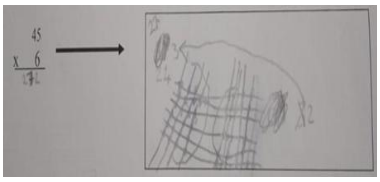

Figure 7 Seyran
(Third Activity)

As seen in Figure 5-7, Songül met all the criteria in the first activity and was considered "adequate." In the second visual, Ferit successfully drew curved lines for the factor with zero, understood that there should be no marking on the curved lines, and correctly identified the product as zero, thus meeting the "drew curved lines for the factor with zero" criterion. In the third activity, Seyran was evaluated as "partially sufficient" in the criterion "drew diagonal lines to the right based on the number in the ones place of the two-digit factor" because the lines were uneven and lacked clarity. Additionally, Seyran did not clearly mark the intersection points, leading to a "partially sufficient" assessment in the criterion "marked the intersection points of the lines". She did not write the product result correctly, leading to no points for the criterion "wrote the calculated value from left to right starting from the first digit and obtained the product result." The inability to earn sufficient points in these criteria caused Seyran to receive the lowest score in the test, despite having scored high in the first and second activities.

***Third action plan assessment*:** The rubric assessment of the activities conducted at the end of the third action plan, where students learned to multiply to multiply two two-digit numbers, is presented in Table 6.

Table 6 Results of the Third Action Plan Activity Assessment

Criteria	First activity				Second activity				Third activity			
	A	So	F	Se	A	So	F	Se	A	So	F	Se
1. Drew diagonal lines from the right corresponding to the number in the tens place of the first factor.	2	2	2	2	2	2	2	2	2	2	2	2
2. Left a space for the units place of the first factor on the same line.	2	2	2	2	2	2	2	2	2	2	2	2
3. Drew diagonal lines from the left corresponding to the number in the tens place of the second factor.	2	2	2	2	2	2	2	2	2	2	2	2
4. Left a space for the units place of the second factor on the same line.	2	2	2	2	2	2	2	2	2	2	2	2
5. Drew diagonal lines from the left corresponding to the number in the units place of the second factor.	2	2	2	2	-	-	-	-	2	2	2	2
6. Drew curved lines for factors that include zero.	-	-	-	-	2	2	2	2	-	-	-	-
7. Marked the intersection points of the lines.	2	2	2	2	2	2	2	2	2	2	2	2
8. Marked the points on the lines according to their place values if they appeared.	2	2	2	2	2	2	2	2	2	2	2	1
9. Began counting points from the units place and continued sequentially through the tens, hundreds, and thousands places if applicable.	2	2	2	2	2	2	2	2	2	2	2	2
10. Carried over the first digit of the two-digit count of intersection points to the next higher place value.	2	2	1	2	-	-	-	-	2	2	2	2
11. Wrote the resulting values from left to right starting from the beginning and obtained the final product.	2	2	0	2	2	2	2	2	2	2	2	2
Total point	22	22	19	22	20	20	20	20	22	22	22	21

As shown in Table 6, Ada, Songül, and Seyran met all the criteria and scored full points in the first activity, while Ferit received the lowest score in the test. Although all students scored full points in the second activity, Seyran received a lower score than the others in the third activity due to being "partially adequate" in only one criterion. Figure 8-10 presents an overview of some of the students' assessment activities:

As seen in Figure 8-10, Ferit incorrectly carried over the first digit in the tens place for the criterion " carried over the first digit of the two-digit intersection point count to the next higher place value," earning a "partially adequate" score, and was marked "inadequate" for "wrote the calculated value from left to right starting from the first digit and obtained the product result" as he did not obtain the correct product. In the second activity, Seyran correctly applied the JAMED method, marked the intersection points, grouped the points, and wrote the product result accurately.

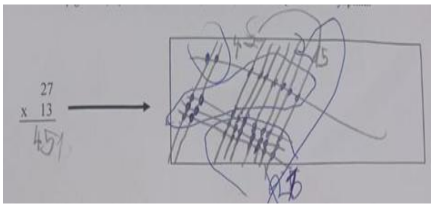

Figure 8 Ferit
(First activity)

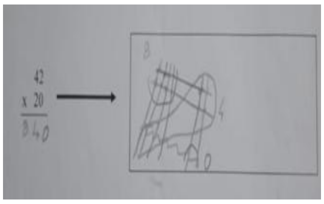

Figure 9 Seyran
(Second activity)

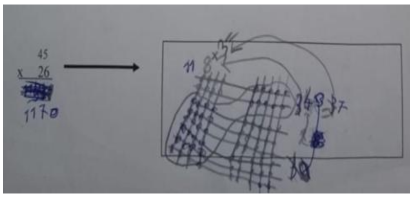

Figure 10 Seyran
(Third activity)

However, in the third activity, she did not group the points in the hundreds and units places, resulting in a "partially adequate" score for the criterion "marked the points on the lines according to place value if they exist." This caused Seyran to score one point lower than the other students on the test.

***Fourth action plan assessment*:** The rubric assessment of the activities conducted at the end of the fourth action plan, where students learned to multiply a three-digit number by a single-digit number, is presented in Table 7.

Table 7 Results of the Fourth Action Plan Activity Assessment

Criteria	First activity				Second activity				Third Activity			
	A	So	F	Se	A	So	F	Se	A	So	F	Se
1. Drew diagonal lines from the right corresponding to the number in the hundreds place of the three-digit factor.	2	2	2	2	2	2	2	2	2	2	2	2
2. Left a space for the tens place of the three-digit factor on the same line.	2	2	2	2	2	2	2	2	2	2	2	2
3. Drew diagonal lines from the right corresponding to the number in the tens place of the three-digit factor.	2	2	2	2	-	-	-	-	-	-	-	-
4. Left a space for the units place of the three-digit factor on the same line.	2	2	2	2	2	2	2	2	2	2	2	2
5. Drew diagonal lines from the right corresponding to the number in the units place of the three-digit factor.	2	2	2	2	2	2	2	2	2	2	2	2
6. Drew diagonal lines from the left intersecting the diagonal lines from the right according to the value of the single-digit factor.	2	2	2	2	2	2	2	2	2	2	2	2
7. Drew curved lines for factors that include zero	-	-	-	-	2	2	2	2	2	2	2	2
8. Marked the intersection points of the lines.	2	2	2	2	2	2	2	2	2	2	2	2
9. Marked the points on the lines according to their place values if they appeared.	2	2	2	2	2	2	2	2	2	2	2	2
10. Counted the points in the formed groups.	2	2	2	2	2	2	2	2	2	2	2	2
11. Sent the digit in the tens place to the next higher place value if the number of points in the group was two-digit.	2	2	2	2	2	2	2	2	2	2	2	2
12. Wrote the number of points in each group and then listed them from left to right to obtain the final product.	2	2	2	2	2	2	2	2	2	2	2	2
Total Point	22	22	22	22	22	22	22	22	22	22	22	22

As shown in Table 7, all students performed at an "adequate" level across all criteria in the activities conducted during the fourth week. Figure 10-12 provides examples of some of the students' assessment activities.:

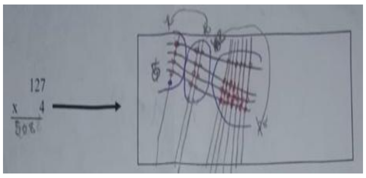

Figure 10 Ada
(First Activity)

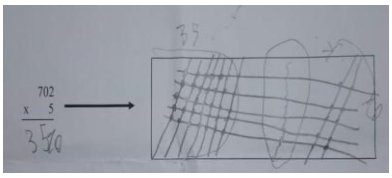

Figure 11 Ferit
(Second Activity)

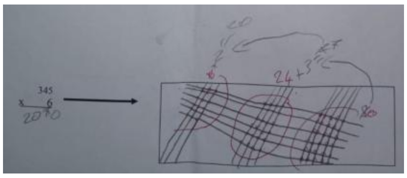

Figure 12 Songül
(Third Activity)

The visuals in Figures 10-12 showing the multiplication of a three-digit number by a single-digit number using the JAMED method by Ada, Songül, and Ferit show that the students understood how to draw diagonal lines, mark intersection points, group the points, carry over to the next place value, and draw curved lines for the zero value. Therefore, all students were considered "adequate" in all criteria and received the highest possible score on the test.

***Fifth action plan assessment*:** At the end of the fifth action plan, where students learned to use JAMED for problem-solving, four problems were presented to them. The first problem required multiplying two single-digit numbers, the second required multiplying a two-digit number by a single-digit number, the third required multiplying two two-digit numbers, and the fourth required multiplying a three-digit number by a single-digit number. The students' solutions to these problems using JAMED were evaluated based on the rubric criteria used in the first four action plans, as shown in Tables 3, 4, 5, and 6. All students were evaluated as "adequate" in meeting the criteria for the first three problems using JAMED. In the fourth problem, Ferit and Seyran again received full points, while Ada and Songül scored 20 out of 22 points due to criteria 10 and 12 in Table 6. Figure 13-16 illustrates several examples of the students' assessment activities.:

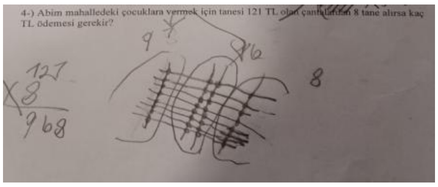

Figure 13 Ferit (First Activity)

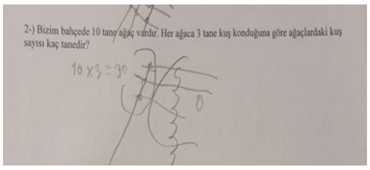

Figure 14 Seyran (Second Activity)

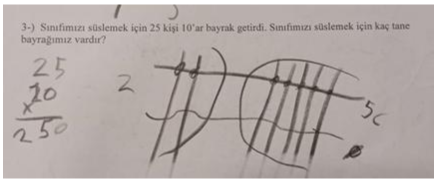

Figure 15 Songül (Third Activity)

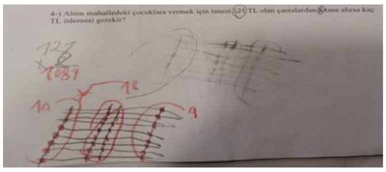

Figure 16 Ada (Fourth Activity)

Figure 13-16 shows that Ferit successfully used the JAMED method to solve the problem in the first activity by meeting the relevant criteria. In the second activity, Seyran demonstrated an understanding of place value, left space between digits, drew curved lines for the zero value, and successfully met the criteria for grouping. In the third activity, Songül met the criteria for solving problems that required multiplying two two-digit numbers, earning the highest score on the test. However, in the fourth activity, Ada incorrectly counted the intersection points in the groups and failed to obtain the correct product result despite performing the relevant operations. These results suggest that students were largely successful in using the Japanese multiplication method (JAMED) to solve problems requiring the multiplication of numbers with different digits.

Sixth action plan assessment: The sixth action plan focused on how to apply the JAMED method in the process of using the traditional multiplication method. This action plan was designed to combine the traditional method with the JAMED when solving multiplication problems. Table 8 presents the rubric for the multiplication of two two-digit numbers:

Table 8 Results of the Sixth Action Plan Activity Assessment

Criteria	A	So	F	Se
1. Drew diagonal lines from the right according to the units digit of the first factor.	2	2	2	2
2. Drew diagonal lines from the left that intersected the diagonal lines from the right according to the units digit of the second factor.	2	2	2	2
3. Drew curved lines for factors containing zero.	-	-	-	-
4. Marked the intersection points of the lines for the first operation.	2	2	2	2
5. Counted the intersection points for the first operation.	2	2	2	2
6. If the number of points was two-digit, wrote the tens digit as a carry-over.	2	2	2	2
7. Wrote the product result of the first operation in the units place.	2	2	2	2
8. Drew diagonal lines from the right according to the tens digit of the first factor.	2	2	2	2
9. Drew diagonal lines from the left that intersected the diagonal lines from the right according to the units digit of the second factor.	2	2	2	2
10. Marked the intersection points of the lines for the second operation.	2	2	2	2
11. Counted the intersection points for the second operation.	2	2	2	2
12. Added the number of points from the second operation if there was a carry-over.	2	2	2	2
13. Wrote the product result of the second operation in the tens place.	2	2	2	2
14. Drew diagonal lines from the right according to the units digit of the first factor.	2	2	2	2
15. Drew diagonal lines that intersected the diagonal lines from the right according to the tens digit of the second factor.	2	2	2	2
16. Marked the intersection points of the lines for the third operation.	2	2	2	2
17. Counted the intersection points for the third operation.	2	2	2	2
18. Wrote the product result of the third operation by shifting the digits.	2	2	2	2
19. Drew diagonal lines from the right according to the tens digit of the first factor.	2	2	2	2
20. Drew diagonal lines from the left that intersected the diagonal lines from the right according to the tens digit of the second factor.	2	2	2	2
21. Marked the intersection points of the lines for the fourth operation.	2	2	2	2
22. Counted the intersection points for the fourth operation.	2	2	2	2
23. Wrote the product result of the fourth operation in the tens place.	2	2	2	2
24. Added the results to obtain the final product.	2	2	2	2
Total point	46	46	46	46

As seen in Table 8, Ada, Songül, Ferit, and Seyran successfully used the JAMED method while performing multiplication using the traditional method for multiplying two two-digit numbers. Figure 17 contains the visual of the assessment activity for Songül.

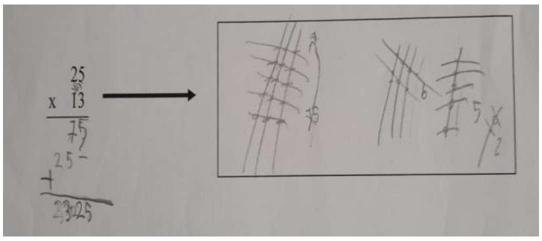

Figure 17 Assessment Activity Visual for Songül

As seen in the visual, Songül successfully used the JAMED method for multiplying two single-digit numbers, then applied the results to the traditional method for multiplying two two-digit numbers, performing well in the multiplication process. Songül effectively used skills such as carrying over, shifting place value, finding the product result, and completing the multiplication process by using the JAMED method. This indicates that students can benefit from JAMED, even during the traditional multiplication process, particularly when they have not memorized the multiplication table.

Findings Related to the Achievement Test

At the end of the implementation process, the Grade 3 Multiplication Achievement Test, initially administered at the beginning of the process, was re-administered. The code names and pre- and post-test scores of the students involved in the study are shown in Table 9.

Table 9 Initial and Final Test Results of the Grade 3 Multiplication Achievement Test

Student		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Point
Ada	İT	0	5	5	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
	ST	5	5	5	5	5	5	5	5	5	5	5	5	5	5	0	5	5	5	5	0	90
Ferit	İT	5	5	5	5	5	5	5	5	5	5	0	0	0	0	0	5	5	0	5	0	65
	ST	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	0	95
Seyran	İT	0	5	0	0	0	0	5	0	5	0	0	0	0	0	0	0	0	0	5	0	20
	ST	5	5	5	5	5	5	5	5	5	5	5	5	5	0	5	5	5	5	5	5	95
Songül	İT	0	5	0	0	5	5	5	0	5	5	0	0	0	0	5	5	5	5	0	0	50
	ST	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	100

In Table 9, correct answers were awarded "5" points, while incorrect answers received "0" points. Comparing the initial and final test scores, Ada increased her score from 15 to 90, Ferit from 65 to 95, Seyran from 20 to 95, and Songül from 50 to 100. This demonstrates that students successfully completed the implementation process and effectively learned multiplication using the JAMED method. It also suggests that JAMED can serve as a helpful method for students who struggle with learning multiplication.

Discussion, Conclusion, and Suggestions

Based on the findings of the current study, third-grade primary school students began the multiplication instruction process with JAMED with some negative affective inputs, including prejudice, fear, anxiety, lack of confidence, reluctance to learn, and learned helplessness. A review of the literature reveals that other students also exhibit high levels of anxiety towards mathematics in general (Süren, 2019). This study found that third-grade students perceived multiplication as both difficult and necessary. Similarly, Kubanç (2012) observed that third-grade students experienced significant difficulties with multiplication.

Interviews with teachers revealed that students encountered difficulties with carry-over, shifting digits, concluding multiplication processes and problem-solving when using traditional methods. Cox (1975) supports this finding by noting that students frequently make errors in multiplication. Additionally, other studies have identified similar issues with carry-over, shifting digits, incomplete multiplication processes, and problem-solving (Attisha Yazdani, 1984; Damayanti et al., 2021; Doğan, 2022; Gürsel, 2000; İspir & Gürsel, 2018; Kilian et al., 1980; Ma et al., 2015; Soylu Makas, 2017; Taraghi et al., 2015; Üçüncü, 2010; Yorulmaz & Önal, 2017).

One of the identified reasons for these errors was a lack of prerequisite knowledge. Doğan (2022) notes that insufficient understanding of the information required for multiplication impedes grasping the logic of multiplication. Additionally, a failure to understand the concept of grouping and the logic of multiplication was also identified as a cause of errors. This lack of understanding suggests that students struggled with the conceptualization of multiplication. Similarly, Özdemir Baki (2023) found that second-grade students had difficulty understanding the concepts related to multiplication. Furthermore, Doruk and Doruk (2019) highlighted that students held conceptions of multiplication that were inconsistent with its conceptual understanding, Masroni and Nusantara (2016) noted that students did not grasp the rules of multiplication, and Soylu and Soylu (2006) found that students did not fully develop the concepts related to multiplication.

The study also revealed that the inability to perform rhythmic counting was a significant factor contributing to errors in multiplication using traditional methods. Yorulmaz and Önal (2017) supported this finding by demonstrating that rhythmic counting skills affect multiplication learning. The findings indicate that not knowing the multiplication table also triggers errors in multiplication. Ma et al. (2020) and Üçüncü (2010) reinforced this by noting that a lack of knowledge of the multiplication table hinders the teaching of multiplication.

According to the findings of this study, the classroom teacher reported that students began the multiplication process with traditional methods exhibiting affective characteristics such as prejudice, fear, anxiety, lack of confidence, learned helplessness, and low motivation. However, after instruction with JAMED, these negative emotions were replaced by perseverance, enjoyment, and enthusiasm. Similarly, Alptekin (2019) implemented the Discover-Copy-Compare (DCC) technique to teach multiplication to students with low math achievement and found that the students did not struggle with multiplication, were happy, and enjoyed the multiplication process. This study, like the current one, demonstrates that teaching multiplication using different methods can foster positive feelings towards the subject.

The results of the current study indicate that the JAMED method helped students experience a sense of achievement in multiplication and thus enhance their self-confidence. Bakan (2017) showed that the use of the dot-marking technique in teaching multiplication also improved students' multiplication success and self-confidence. The success and confidence outcomes associated with the dot-marking technique, which is based on counting dots like JAMED, suggest that students can develop their multiplication skills through visual methods. Results similar to JAMED’s reduction of anxiety and fear and enhancement of self-confidence were also found in Karbeyaz’s (2018) study using multiple intelligence-based activities. This similarity may be related to JAMED incorporating multiple intelligence-based activities, at least visual and logical ones.

The action process conducted in this study showed that JAMED increased students' affection and interest in multiplication. Similarly, Abari and Tyovenda (2022) and Suherdi and Mujib (2020) found that teaching multiplication with the JAMED method increased students’ interest in math and made them happy while solving problems. These findings suggest that the reluctance and avoidance of solving problems observed in other studies (Ekici & Demir, 2018) may change with the JAMED method.

The results of the study indicate that JAMED is well-suited for student development, allowing students to guide others through the multiplication process and verbally convey how they solve multiplication problems. Cevizci (2018) used the Russian peasant multiplication method with unit cubes and found improvements in students’ conceptual and procedural knowledge of multiplication. This result aligns with JAMED, as the study found that students understood the abstract concept of multiplication by making it concrete with lines. Thus, third-grade students, who are likely in the concrete operational stage, learned multiplication and were able to articulate how they solved the problems through JAMED.

The findings of this study demonstrate that JAMED helps students not only learn to solve multiplication problems involving place value and carry-over but also transfer multiplication skills to different contexts and advancing topics independently. Additionally, integrating the JAMED method with traditional multiplication methods has prevented students from repeating previous errors, such as carry-over, shifting digits, and incomplete multiplication processes. As a result, students have been able to perform multiplication using both JAMED and traditional methods.

Assessment activities examined using rubric scales over six weeks showed that students could effectively apply almost all steps of JAMED for multiplying two single-digit numbers, a two-digit number by a single-digit number, two two-digit numbers, and a three-digit number by a single-digit number. This finding suggests that JAMED could be a suitable tool for teaching multiplication. A review of the literature also reveals other studies where this method has improved students' multiplication skills (Fuadah et al., 2019; Grain & Kumar, 2018; Nuranifah & Fuadah, 2022).

The findings obtained from the rubric scales aligned with the results of the pre- and post-tests. There were big differences between the pre-test and post-test scores, with the latter showing higher scores. These quantitative findings, consistent with other qualitative results, demonstrate that the JAMED method enhances students' academic success in multiplication. Similarly, Sidekli et al. (2013) found that a simplified multiplication method, partially resembling JAMED, improved students' multiplication success scores. The fundamental reasons for the success of methods like JAMED are believed to be their facilitation of understanding mathematical concepts and their positive impact on computational skills. Indeed, studies by Fuadah et al. (2019) and Hidayah (2016) have shown that the JAMED method positively affects the understanding of mathematical concepts, while Mustafa et al. (2021) found that it positively impacts computational skills.

This study found that, similar to Altıntaş and Sidekli’s (2017) findings on Napier's bones, JAMED enhances academic success in multiplication. Both JAMED and Napier's bones are used to visualize multiplication, highlighting the importance of visualization methods and materials in teaching multiplication. Therefore, when considered together, these studies underscore the value of visual methods and materials, like JAMED, in teaching multiplication.

However, the results of this study also reveal one of JAMED's primary disadvantages: overshadowing other subjects. The students involved in the study showed a strong preference for JAMED, which led them to focus all their attention on learning multiplication with this method, thereby reducing their performance and interest in other subjects. Another disadvantage is the possibility that students may feel lost at the end of the process due to the absence of the JAMED method in the curriculum applied in Turkey. This issue was addressed by blending JAMED with traditional methods in the sixth-week action plan. Nevertheless, Rianti (2017) highlighted that JAMED may not be suitable for every topic and that children who do not have adequate counting skills might struggle with this method, pointing out other disadvantages of JAMED.

Time constraints are another limitation of JAMED. Findings from interviews and observations indicate that JAMED is time-consuming and can lead to inefficiencies. Supporting these findings, Grain and Kumar (2018) and Rianti (2017) have also noted that the JAMED method takes considerable time. Thus, the feasibility of using JAMED may be reduced in situations where teachers and students have limited time.

Throughout the research process, students experienced various difficulties with both traditional and JAMED methods. The difficulties identified included marking intersection points, counting dots, grouping, carrying over, drawing diagonal lines, shifting digits, and transferring the results obtained with JAMED to the traditional method. The reasons for these difficulties were examined and addressed. Issues with marking intersection points, counting dots, and grouping were attributed to crooked or overly close diagonal lines and students' haste. Difficulties with carrying over were found to stem from a lack of knowledge of addition. Problems with diagonal lines arose from aesthetic concerns. The difficulties with place value shifting and communicating the results of JAMED in the sixth-week action plan were due to confusion caused by blending traditional and JAMED methods.

During this research, various strategies were attempted to address the challenges students faced. For difficulties with marking intersections, counting dots, and grouping, students were initially given grid paper to help them practice, eventually transitioning to unlined paper as they became more comfortable. Additionally, students were encouraged not to rush, which gradually resolved this issue. To tackle the problem of students' lack of understanding of addition, which led to errors in carrying over, a week of remedial lessons on addition was provided to the affected student. However, this was insufficient, so it was suggested that students draw a number of dots on the next higher place value corresponding to the carry-over. This approach successfully resolved the issue and also helped the student improve their addition skills over time. Colored pencils were used to address the grouping issues, and this approach proved to be successful. The difficulty stemming from students' aesthetic concerns when drawing diagonal lines was addressed through practice, and over time, this issue was also resolved. During the implementation of the sixth action plan, the difficulties related to shifting digits and transferring the results obtained with JAMED to the traditional method were overcome through extensive practice. By the end of the process, students were able to correctly solve multiplication problems using the JAMED method along with traditional methods.

In conclusion, the JAMED method has been shown to have a positive impact on developing multiplication skills. This research demonstrates that even when the JAMED method cannot be fully utilized or is not desired, multiplication can still be taught to students by partially incorporating this method. Additionally, the successful implementation of this research process with students who have reading and writing difficulties highlights another aspect of the JAMED method's effectiveness.

Based on the results of this study, the following recommendations are made:

- The JAMED method could be included in the Mathematics Curriculum.
- When teaching multiplication with the JAMED method, it is advisable to start with grid paper in the first week.
- Colored pencils should be used for place value grouping during the JAMED multiplication process.
- Prior to teaching multiplication with the JAMED method, students should be equipped with prerequisite skills, such as addition, that are necessary for multiplication.
- It should be emphasized to students that they should not rush when solving multiplication problems using the JAMED method.
- To reduce students' aesthetic concerns, more practice with drawing diagonal lines should be encouraged.
- The combination of traditional methods and the JAMED method can be used to teach multiplication skills.

- Students should be given adequate time when solving multiplication problems using a combination of traditional and JAMED methods.
- Continuous practice should be provided to students to speed up their problem-solving skills when using both traditional and JAMED methods.

Compliance with Ethical Standards

Disclosure of potential conflicts of interest

Authors declare no conflict of interest.

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CRediT author statement

The thesis from which this study was derived was written by the second author under the supervision of the first author. The process of preparing the manuscript from the thesis was carried out under the responsibility of the second author (corresponding author).

Research involving Human Participants and/or Animals

The study involves human participants. Ethics committee permission (Date: 14.11.2022, Number: 392051) was obtained from Dicle University Social and Human Sciences Research Ethics Committee. The study has been performed in accordance with the ethical standards.

Japon Çarpma Yöntemi ile Çarpma İşlemi Öğretimi: Bir Eylem Araştırması

Özet:

Japon çarpma (JAMED) yöntemi, soldan çapraz çizgilerin üzerine sağdan çapraz çizgiler çizildikten sonra bu çizgilerin kesiştiği yerlere konulan noktaların sayılıp çarpım sonucuna yazılması olarak tanımlamaktadır. Bu araştırmada, ilkokul 3. sınıfta çarpma işlemini klasik yöntemle öğrenememiş çocuklara Japon çarpma yöntemi ile çarpma işleminin öğretilmesi ve bu sürecin değerlendirilmesi amaçlanmıştır. Bu araştırmada eylem araştırması türlerinden teknik/bilimsel/işbirlikçi model kullanılmıştır. Araştırma Diyarbakır ili Hani ilçesinde bulunan bir ilkokulda 3. sınıf düzeyinde öğrenim gören ve geleneksel yöntem ile çarpma işlemini öğrenememiş dört öğrenci ile yürütülmüştür. Bu araştırmanın verileri, araştırmacı tarafından geliştirilen 3. sınıf Çarpma İşlemi Başarı Testi, Uygulama Öncesi ve Sonrası Öğretmen Görüşme Formu, Uygulama Sonrası Öğrenci Görüşme Formu, Araştırmacı Günlüğü, Öğretim Sürecinde Alınan Ses Kayıtları, Ders Sonu Değerlendirme Etkinlik Kâğıdı ve bu etkinlik kâğıtlarına ilişkin Dereceli Puanlama Anahtarları aracılığıyla toplanmıştır. Araştırmadan elde edilen nitel verilerin analizinde içerik analizi ve betimsel analiz kullanılmıştır. Sonuç olarak JAMED yönteminin çarpma işlemi becerisini geliştirme ve çarpma işlemine yönelik negatif duyuşsal özelliklerin olumlu duyuşsal özelliklere dönüşmesi konusunda olumlu bir etkisinin olduğu görülmüştür. Buna rağmen öğrencilerin JAMED ile çarpma işlemi yaparken kesişim noktalarını işaretleme, nokta sayımı, gruplandırma, elde ekleme, çapraz çizgi, basamak kaydırma ve JAMED'le elde ettiği sonucu geleneksel yönteme aktarma gibi konularda zorluk yaşadığı görülmüştür. JAMED'in bir yöntem olarak diğer dersleri gölgeleme gibi bir dezavantajı ile birlikte zaman açısından da bir sınırlılığı olabileceği anlaşılmıştır.

Anahtar kelimeler: Çarpma işlemi, JAMED, Japon çarpma yöntemi, dört işlem, çapraz çizgi yöntemi.

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Research Article

Investigation of Positive Error Climate in Mathematics Teaching with Mixed Method*

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Abstract – The purpose of the study is to investigate the effects of the classroom climate created according to the 'positive error climate framework programme' on the error orientations of teachers and students in mathematics lessons. Intervention design based on mixed methods was used. The data were collected from four classes (two study and comparison classes) selected by purposive sampling, involving 145 students and 4 mathematics teachers. 'Classroom Error Climate Scale' (CECS), lesson observation form and notebook, semi-structured teacher and student interview form were used. At the end of the fifteen-week study, interviews were conducted with the teachers and students in the study groups. T-test results showed positive and significant change in the perceived classroom error climate in the study groups. Qualitative data analyses showed that the error orientations of the study group teachers and students were more positive than the comparison group. Teachers and students stated that positive error climate helps them to comprehend the correct information better, increases participation and self-confidence in the lesson and helps permanent learning.

Keywords: Error Orientation, mathematics teaching, mixed method, permanent learning, positive error climate.

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Introduction

For a long time in the field of education, errors have been seen as signals of lack of ability or misunderstandings in the learning process (Matteucci et al., 2015). However, studies in the literature show that making mistakes positively affects learning and improves the learning process (Borasi, 1989; Huelser & Metcalfe, 2012; Rach et al., 2013; Soncini et al., 2021). Evidence from studies in the field of educational psychology suggests that making mistakes can promote learning and create opportunities for teaching (Borasi, 1989; Metcalfe, 2017; Tulis, 2013). According to these studies, errors are natural elements of the teaching process and can be utilised as teaching tools (Borasi, 1989; Matteucci et al., 2015).

A positive error climate is observed in classroom environments where errors are used and evaluated as an integral part of the teaching process (Steuer et al., 2013; Tulis, 2013). The error climate of the classroom is determined by the error orientations of teachers and students. Error orientation consists of perception, attitude and subsequent behaviours towards errors (O' Dell, 2015; Özkaya et al., 2022). In a positive error climate, teachers see student errors as learning opportunities, act tolerant towards errors, and make errors a topic of discussion in the classroom. Instead of responding to student errors directly, they guide the student toward the correct answer using appropriate (McMillan & Moore, 2020; O'Dell, 2015; Oser & Spychiger, 2005; Tulis, 2013). In a positive error climate, teachers constantly interact with students who make mistakes. During these interactions, the teacher avoids verbal or non-verbal negative indicators (anger, frustration) (Steuer & Dresel, 2015). In such an environment, the student's attitude towards errors and error orientation is positive (Käfer et al., 2019; Tulis, 2013; Özkaya et al., 2022). In positive error climate students do not hesitate to make mistakes, take the risk of making mistakes and participate actively in the lesson (Özkaya et al., 2022; Soncini et al., 2021).

Tulis (2013) categorised the error climate of the classroom as positive or negative by looking at the adaptive or maladaptive responses of teachers to errors. She showed adaptive responses as including the whole class in the discussion environment, giving the student enough time to respond, preventing negative reactions of classmates, and emphasising that errors are opportunities for learning. Maladaptive reactions are ignoring errors, criticising the student, directing the question to another student, laughing, mocking or showing disappointment. In a negative error climate, maladaptive error correction feedback is used more frequently and as a result, students develop negative feelings towards making errors and avoid the risk of making errors. However, it has been observed that in positive error climates, students can learn more easily from errors and actively participate in the lesson (He, 2020; Soncini et al., 2021).

Steuer et al. (2013), in their study investigating the perceived classroom error climate, stated that the error climate has eight interconnected sub-dimensions. These are; error tolerance by the teacher, independence of errors from evaluation, teacher support following errors, absence of negative reactions of the teacher against errors, absence of negative reactions of classmates against the error maker, taking the risk of making errors, analysis of errors, and functionality of errors for learning. Özkaya et al. (2022) states that the first four of these sub-dimensions are related to the teacher's error orientation. While taking the risk of making mistakes and the absence of negative reactions to mistakes in the classroom are related to the student's error orientation, the last two sub-dimensions are related to the evaluation of errors (Özkaya et al., 2022). Käfer et al. (2019) stated that the error climate is a multidimensional structure that includes not only student-specific but also classroom-wide and teacher's attitude towards errors.

Research in neuroscience has found that the human brain is programmed to learn from errors (Boaler, 2022; Moser et al., 2011). Similarly, evidence from studies in cognitive and educational psychology suggests that making errors can promote learning (Borasi, 1988; He, 2020; Metcalfe, 2017; Tulis, 2013). These studies indicate that making mistakes can create valuable opportunities for learning when corrective feedback is given after an error occurs (He, 2020; Metcalfe, 2017). In a positive error climate, positive motivational responses such as positive learning orientation, joy, and decreased fear of making mistakes have been found to occur in students (Käfer et al., 2018; Rach et al., 2013). In such an environment, students feel safe about making mistakes and take the risk of making mistakes (He, 2020; Steuer et al., 2013).

When error-based teaching studies are examined, it is seen that video recording studies are predominant (Didiş et al., 2016; Ingram, 2013; Matteucci et al., 2015; Santagata, 2005; Son, 2013; Tulis, 2013; Türkdoğan & Baki, 2012). These studies describe the current situation and offer solutions to the problems identified. When the studies on error climate are examined, there are very few qualitative-quantitative supported or mixed design studies (Alvidrez, 2019; O'Dell, 2015; Soncini et al., 2021; Tulis, 2013; Wasilewski, 2023). It is seen that these studies generally investigate the affective effects of positive error climate on teachers and students.

When the teacher dimension of error-based learning studies was examined, it was observed that although teachers generally accepted the instructional potential of errors, they had concerns about their use in the classroom environment. Teachers stated that the use of errors in the classroom is not appropriate and may create some affective (embarrassment, loss of self-confidence, etc.) and cognitive barriers (learning the wrong, learning incorrectly, etc.) in students (Palkki & Hastö, 2018; Wasilewski, 2023).

When the feedback given by teachers to errors are analysed, it is seen that feedback such as ignoring, telling the right directly, and redirecting the question to another student are used more frequently. These feedback are ineffective error correction feedback (Didiş et al., 2016; Oser & Spychiger, 2005; Santagata, 2005; Son, 2013; Tulis, 2013; Tükdoğan & Baki, 2012). These findings suggest that teachers are not sufficiently aware of the instructional potential of student errors.

In the studies, it is seen that teachers who create a positive error climate in classrooms sometimes do this consciously and sometimes unconsciously (Abay & Clores, 2022; Alvidrez, 2019; Matteucci et al., 2015). In these studies, it is seen that a framework plan that will help to create a positive error climate in the classrooms has not been put forward. For this reason, Özkaya et al. (2022) proposed the "positive error climate framework programme" to create a positive error climate in the classroom (Appendix 1). The programme includes the steps to be followed to create a positive error climate in the classroom. In the "positive error climate framework programme", what needs to be done for teachers to create a positive error climate in the classroom with adaptive error correction behaviours and attitudes and to reinforce this with assessment exams are explained item by item. "Positive error climate framework programme" is given in the appendix.

In scientific studies, it can be said that a framework plan that helps to create a fully positive error climate in classrooms has not been put forward. For this, there is a need for planned intervention research to reveal the effects of classroom error climate. Looking at the studies claiming to conduct such research (Soncini et al., 2021), it was observed that they proceeded through a lesson scenario and limited observations were made. However, positive error climate is a multidimensional field that needs to be observed in long-term and real teaching environments (Käfer et al., 2019; O'Dell, 2015; Spychiger et al., 1998; Steuer et al., 2013; Soncini, 2021; Özkaya et al., 2022; Tulis, 2013; Wasilewski, 2023).This is also the reason for the current study. The aim of the study is to examine in detail the effects of the classroom climate created according to the "positive error climate framework programme" on teachers' and students' error orientations in mathematics lessons. The sub-problems sought to be answered in this context are given below;

1. Is there a significant difference between the classroom error climates perceived by the study and comparison groups before the implementation?

2. Is there a significant difference between the classroom error climates perceived by the study and comparison groups after the implementation?

3. What are the similarities and differences between the error orientations of the teachers in the study and comparison groups?

4. What are the error orientations of the students in the study and comparison groups?

5. What are the opinions of the study group teachers and students about the positive error climate process?

Method

The intervention design, which is one of the mixed method designs, was selected in order to investigate in detail the effect of the positive error climate created in the classrooms on students and teachers. The purpose of this design is to study the research problem in detail by adding qualitative data to an intervention programme process (Creswell, 2021). In the current study, the intervention programme was examined with a quasi-experimental design and the process was observed with qualitative data. In this method, when presenting findings, qualitative and quantitative findings are given separately and their interpretation is usually made in the discussion section. (Creswell, 2013).

In the quantitative dimension of the study, a quasi-experimental design with pretest-posttest comparison groups was used. In this model, which is the most frequently used type of quasi-experimental design, study and comparison groups are selected. Pre-test and post-test are applied to both groups, but the intervention process is applied only to the study group (Creswell, 2013; McMillan & Schumacher, 2010). In the qualitative dimension of the study, the positive error climate intervention programme was observed through the lesson observation forms. At the end of the implementation, interviews were conducted with the teachers and students in the study groups. At the end of the intervention, a focus group interview was conducted with 16 students from the study group. These students were selected according to the opinions of the teachers and the purpose of the research according to the purposeful sampling maximum diversity method. In maximum diversity, the experiences of different participants are obtained (Yağar & Dökme, 2018).

Sample

The research data were collected in a secondary school in a province in eastern Turkey during the 2022-2023 academic year. The research sample consisted of four classes (two study and two comparison classes), 145 students studying in these classes, and four mathematics teachers teaching in these classes, selected by purposive sampling. Purposive sampling occurs when the researcher makes a judgement about which participants should be selected to provide the best information to address the purpose of the research based on the population information about the subject of the study (McMillan & Schumacher, 2010).

While determining the school to be researched, one of the schools with strong representativeness was selected. Although this school is one of the central schools in the province, its achievement level is at the provincial average according to the LGS (a High school entrance exam) exam. It was understood from the opinions of the school administrators and teachers that the socio-economic level of the students was moderate. Class size varies between 25-35. The school has eight mathematics teachers and five different classes at each grade level. This school was selected as the research school by purposive sampling with the belief that it would serve the purpose, external validity and generalisability of the research.

It was confirmed by the school administrators that the selected classes were equivalent to each other in terms of academic success compared to the previous semester and that their socio-economic levels were close. These classes were randomly assigned as study and comparison groups. The classes in the study groups were coded as 6D and 7D, while the classes in the comparison groups were coded as 6K and 7K. The numbers of students in these classes are given in Table 1.

Table 1 Number of Students in the Study and Comparison Groups

Group	Class	Female	Male	Total
Study	6D	17	19	36
	7D	18	20	38
Comparison	6K	15	21	36
	7K	16	19	35

In order to reveal the effects of the error climate implementation at different grade levels, two different grade levels were selected. The mathematics teachers of these four grades are different persons and the implementation was carried out with these teachers on a voluntary basis. Teachers in both groups stated that they had not heard of error climate before. In addition, all of the teachers stated that although they believed that errors were inevitable in the classroom and that errors played an important role in teaching, they rarely made use of errors in their lessons. This situation suggested that teachers' error orientations were similar.

Data Collection Tools

Classroom Error Climate Scale (CECS). The scale was developed by Steuer et al. (2013) to measure the perceived error climate in the classroom. The adaptation, validity and reliability studies of the scale for use in the Turkish sample were conducted by Kalaç et al. (2022). As a result of the adaptation studies, it was determined that the scale consists of seven factors and 27 items. The internal consistency Cronbach Alpha coefficient of the scale was .86, and the internal consistency coefficients of the factors were determined between .73 and .89. When calculating students' perceived error climate scores, negative items were first reverse coded. Afterwards, the subscale averages were summed and the total scores were obtained. CECS was chosen because it measures the perceived error climate of the classroom in a multidimensional way and serves the purpose of the research. The scale was used to measure the perceived error climate of the classroom. Craonbach's alpha coefficient for this study was found to be .85.A summary of the scale is given in Appendix 2.

Lesson Observation Forms. Lesson observation forms, which include the teacher's attitudes, behaviors and feedback regarding errors in the classroom, are semi-structured forms designed according to the "positive error climate framework program". Two field experts were consulted for the form. This form was used to analyse the teacher's error orientation. It was completed for both study and comparison groups at the end of each lesson. During the lesson, observers noted the dialogues and observations about the lesson. At the end of the lesson, the observers compared their notes and corrected the missing and incorrect parts. Thus, a single lesson observation note was created for that lesson. The observation notes were checked and the teacher's attitude and behaviour in the face of errors in that lesson and the feedback given were written on semi-structured forms. Then qualitative analysis was applied to the data. The lesson observation form is given in detail in Appendix 3.

Lesson Observation Notebooks. The observation notebooks in which the in-lesson activities and dialogues were written were filled in separately by the two observers who attended the lesson by giving the date and time information. At the end of the lesson, both observation notebooks were combined by the observers to form a single lesson observation.

These notes were used to investigate the error orientations of the students and the teacher. Then qualitative analysis was applied to the data.

Focus Group Interview Form. Focus group interviews were conducted with eight 6th grade and eight 7th grade students in the study classes at the end of the experimental research. The students were selected by purposive sampling and maximum diversity method. Observer and teacher opinions were taken into consideration while selecting the students. Focus group interviews were conducted through a semi-structured interview form prepared with expert opinions. The interviews of both groups were conducted separately and lasted 35 minutes each. Questions that were not understood or thought to be misunderstood by the students were immediately corrected and asked again. The groups were interviewed separately. During the interviews, students were asked about the positive error climate process and what kind of changes occurred in their mathematics lessons and what effects these changes had on them. This form was used to analyse students' error orientations. Then qualitative analysis was applied to the data.

Teacher Interview Form. Semi-structured interviews were conducted with two teachers in the study groups after the implementation. The teachers were asked about their error climate experiences, their thoughts, whether they found this method effective or not, their strengths and weaknesses, and whether they would like to use it again or not. Expert opinion was used while preparing the form. The interviews with the teachers were conducted separately and lasted 25 minutes each. This form was used to analyse teachers' error orientations. Then qualitative analysis was applied to the data.

Procedures

Necessary ethical permissions were obtained from relevant institutions before starting the research. There are three teacher candidates who served as observers in the research. Observers, like teachers, stated that they had never heard of the concept of error climate before. Twelve hours of scientific research techniques training and eight hours of positive error climate training were provided to prospective teachers. Teachers in the study groups were given eight-hour positive error climate training simultaneously with the observers. The implementation phase of the research lasted 15 weeks. The groups were observed for two hours a week.

A study group and a comparison group were selected at the sixth and seventh grade level. Classroom observations were made in all four groups and observation forms were kept.

Likewise, CECS was administered to all groups as pre-test and post-test. At the end of the research, interviews were conducted with the teachers and students in the study groups. An intervention programme with the "Positive Error Climate Framework Programme" was applied to the study groups. No intervention was applied to the comparison groups.

"Positive Error Climate Framework Program" was taken into consideration when planning lessons in the study groups. Errors were included in the teaching process in a planned manner, and the causes of errors and correct answers were discussed in the classroom so that students could learn from these errors. Students were asked to express the correct answers in their own words. Erroneous questions were added to the course, not at the first stage, but after sufficient question solving was completed at the end of the subject. Otherwise, since the student's readiness is lacking at the first stage, she/he may perceive the incorrect information as correct and develop misconceptions (Konyalıoğlu, 2021). To prevent this, the use of incorrect questions or statements in the process must be planned. Lesson plans were prepared with the teachers in the study groups the week before the topic would be taught, and any mistakes students might make were added to the plan. Lesson plans were made separately for both grade levels. The plans were prepared in accordance with national education outcomes by taking the opinions of two field experts and teachers. An example of a lesson plan applied in the study groups is given in Appendix 4.

Data analysis

When analysing the data, quantitative and qualitative data were analysed separately and the two grade levels were evaluated within themselves. CECS pre-test post-test scores were used to determine the perception of classroom error climate. Before analysing the quantitative data, the conformity of the scores obtained from the CECS to the normal distribution was examined. To decide normality, Shapiro-Wilk normality test, skewness (SC), and kurtosis (KC) coefficients were examined. The CECS pre-test and post-test data of all classes were found to fit the normal distribution according to Shapiro Wilk normality coefficient ($p>.05$) and skewness kurtosis values (-1.5, +1.5) (Büyüköztürk, 2020; Tabachnick&Fidell, 2013). While the differences between groups were analysed by independent samples t-test, the differences within groups were analysed by paired-samples t-test (Büyüköztürk, 2020). Cohen's effect size formula was used to find the effect size value of the significant values (Cohen, 1988). The d (effect size) value found is interpreted as follows; if $0.5>d>0.2$, it is considered as small effect, if $0.8>d>0.5$, it is considered as medium effect, if $d>0.8$, it is considered as large effect (Büyüköztürk, 2020).

In the research, descriptive analysis and content analysis were applied to the qualitative data obtained through observations and interviews. In accordance with research ethics, the names of participating teachers and students were coded and stated in the forms. Firstly, the obtained data was converted into written form and made suitable for the analysis process. The data was coded by the researcher and the MAXQDA analysis program was used to analyze it. Relevant codes were brought together, placed under appropriate themes after the appropriate category, and the findings were interpreted. Presentation and visualization of the findings were also provided with the same program.

As a result of content analysis and descriptive analysis in the research, the themes of the teacher's error orientation, the student's error orientation and the positive error climate process were created in accordance with the literature. Under these themes, the data are presented by associating them with appropriate codes and categories. While coding, another researcher other than the author, who is an expert in the field, was asked to code the data. The consensus between coders was found to be 90%, which is within acceptable limits according to Miles and Huberman (1984).

Validity and Reliability of the Research

To ensure the validity and reliability of the research, Büyüköztürk et al. (2020) and Creswell (2013) suggestions were taken into consideration. Accordingly, the precautions taken for the validity and reliability of the research are as follows; the groups to be investigated were randomly assigned as study and comparison groups. The research was conducted at the same grade levels in the same school. According to the opinions of the school administration and teachers, classes with similar socio-economic levels were selected. The selected school is one of the central and most representative schools in the province where the research was conducted. In addition, four classes were selected in terms of representation adequacy. A wide range of data collection tools were used in the research process. Long-term observations were made. Participant confirmation was frequently used in the interviews. The research findings were examined by different researchers.

The study was limited to four class sections of secondary school mathematics courses in a school located in a province in eastern Turkey during the second semester of the 2022–2023 academic year.

Results

In order to examine the changes in the error climates perceived by the groups before and after the implementation, which are the first and second sub-problems of the study, the CECS data were analysed. In order to measure the perception of classroom error climate, CECS was applied to all groups at the beginning and end of the study. Independent sample t test was applied to determine whether there was a difference between the groups' perceptions of classroom error climate. Significant differences within groups were analysed with paired-samples t-test. Independent samples t test analysis and effect values between groups are given in Table 2 below.

Table 2 CECS Independent-Samples T-test Analyzes

Test	Class	n	M	t	p	d
CECS pre-test	6D	28	28.520	1.489	.14	-
	6K	30	27.306			
	7D	30	27.238	.471	.61	-
	7K	26	26.730			
CECS post-test	6D	24	31.138	4.918	.001	1.42
	6K	24	28.138			
	7D	29	29.669	2.098	.041	.61
	7K	19	27.802			

When Table 2 is examined, it can be seen that there was an increase mean scores in the post-test in all classes. When the pre-test was examined, no significant difference was found between the study and comparison groups at both grade levels ($p>.05$). In this context, it can be said that the error climate perceptions of the study and comparison groups were the same before the application.

When looking at the CECS post-test, significant differences were found in favor of the study groups at both grade levels. ($p<.05$). While the Cohen effect size value of the significant difference in the sixth grades shows a high effect ($d>.80$), the Cohen effect size value of the difference in the seventh grades shows a medium effect ($.5<d<.80$). In this case, there was a positive increase in the perceptions of classroom error climate in the study groups compared to the comparison groups at the end of the intervention programme. This increase was found to be significant and effective.

It was decided to conduct a paired t-test to determine whether the increase in the CECS scores of the groups in the post-test created a significant difference within the group. Paired-samples t-test analyses are given in Table 3 below.

Table 3 CECS Paired-samples T-test Analyzes

Class	n	t	p	d
6D	19	3.456	**.003**	**.80**
6K	21	1.564	.133	-
7D	24	3.819	**.001**	**.77**
7K	16	.464	.649	-

When Table 3 is examined, it is seen that there is a significant difference in favor of the post-test in both study groups ($p <.05$). While the effect size value of the significant difference occurring in the 6D class indicates a large effect ($d>.80$), the significant difference occurring in the 7D class has a medium-sized effect ($.50<d<.80$). When looking at the comparison groups, no significant difference was found in terms of CECS pre-test and post-test. As a result of the pre-test and post-test findings of CECS, it can be said that the intervention program made a significant and effective change in the study groups' perceptions of classroom error climate.

Content analysis was applied to the observation form data in order to analyse the similarities and differences between the error orientations of the teachers in the study and comparison groups, which is the third sub-problem of the research. The analyses obtained from both grade levels are given separately below. As a result of the analysis, the categories of attitude towards errors, feedback on errors and handling of errors were formed under the theme of teacher's error orientation. Different codes emerged under these categories. The frequency of the resulting codes according to the code matrix browser of the classes is given in Figure 1 below.

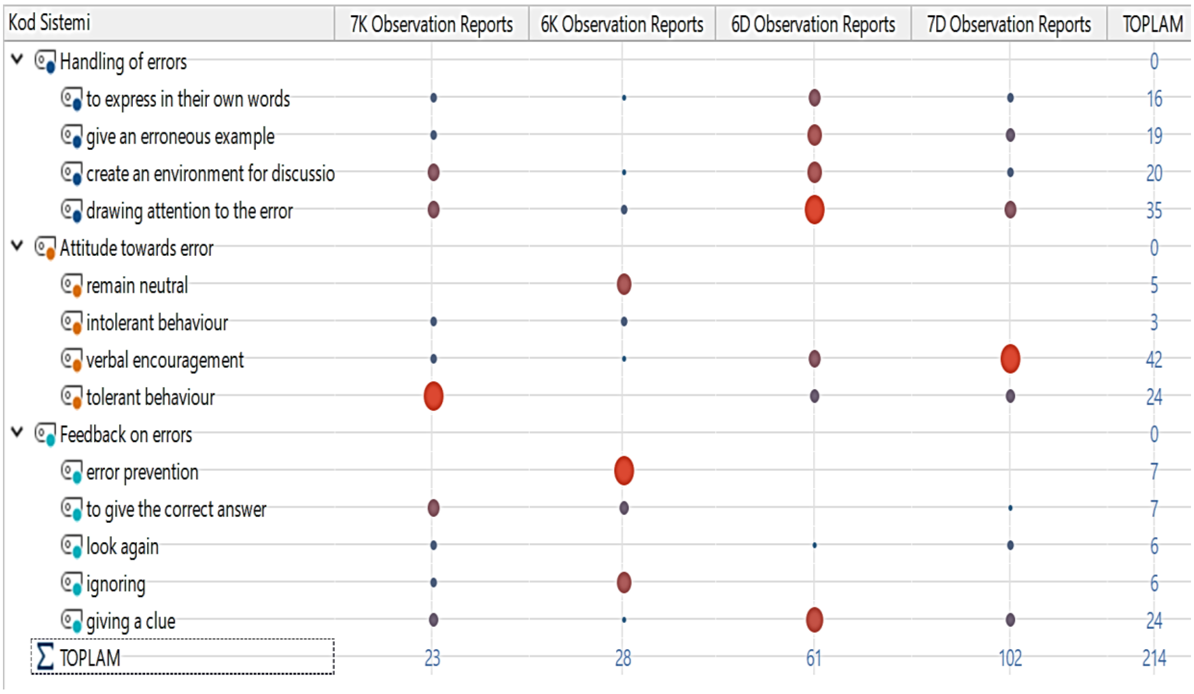


Figure 1 Frequency of Codes by Code Matrix Browser

When Figure 1 is examined the size of the dots in the figure shows the frequency of the code in the observed class. The total row and column show how many times the code is repeated in total. According to the observation reports, the most recurring code in class 7K was tolerant behavior, the most recurring code in class 6K was error prevention. In class 7D, the most recurrent code was verbal encouragement, and in class 6D, the most recurrent code was drawing attention to the error. In the study groups, the codes of remain neutral, intolerant behaviour, error prevention and ignoring, which are among the negative teacher feedbacks, were not encountered during the 15-week observation.

The comparison of the 6D study group and the 6K comparison group at this grade level under the theme of *teacher's error orientation*, and the codes resulting from this comparison and their frequency are given in Figure 2 below.

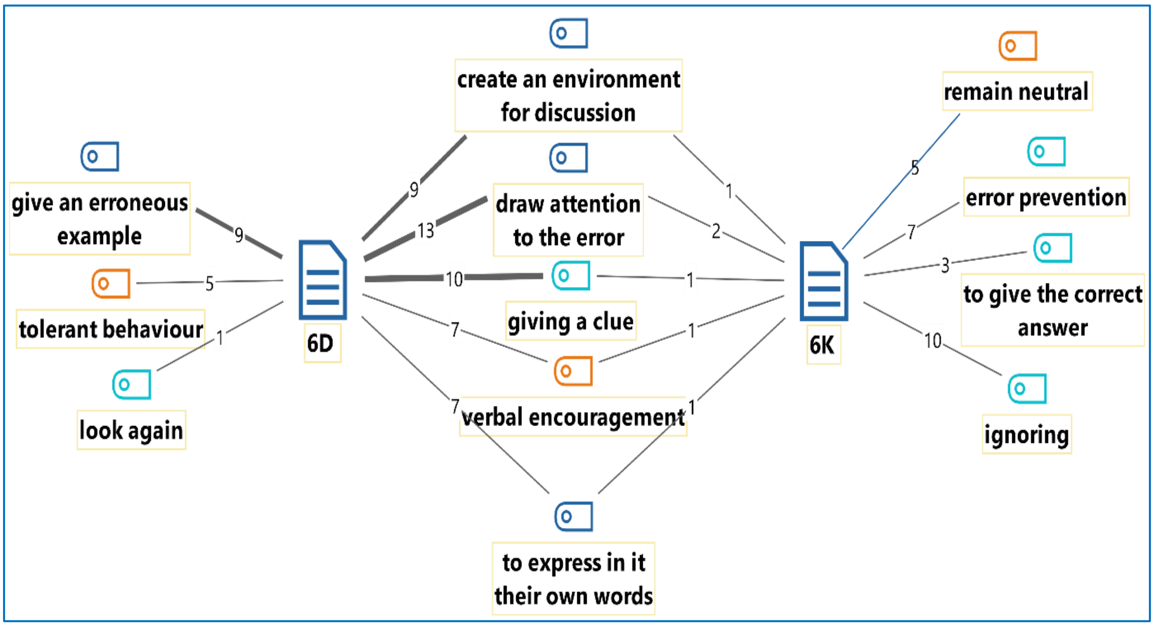


Figure 2 Comparison of 6th Graders under the Theme of Teacher's Error Orientation

When Figure 2 is examined, although there are common codes observed in both classes, the classes also have their own codes. Accordingly, while the codes of create an environment for discussion, draw attention to the error and to express in it their own words under the category of handling of errors were observed in both classes, the code of give an erroneous example belonging to this category was observed only in the study group. Likewise, while the giving a clue code, belonging to the category of feedback on errors, was observed to be common in both classes, the code look again, belonging to this category, was observed only in the study group. Again, the codes of error prevention, ignoring and to give the correct answer belonging to this category were observed only in the comparison group. According to Figure 2, it can be said that a positive error climate was observed in the 6D class and a relatively negative error climate was observed in the 6K class throughout the process. At the same time, when the error orientations of the teachers are examined, it can be concluded that the error orientation of the study group teacher is more positive than the error orientation of the comparison group teacher.

Comparison of the 7D study group and the 7K comparison group at this grade level under the theme of *the teacher's error orientation*, the resulting code map and the frequency of the codes are given in Figure 3 below.

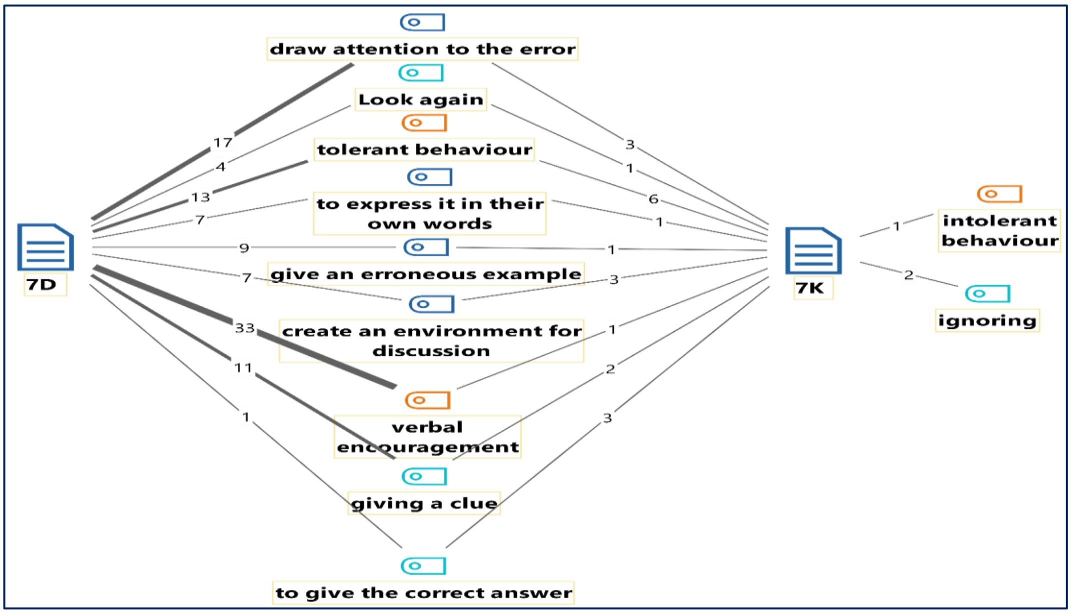


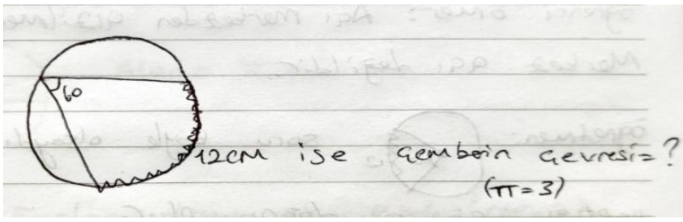
Figure 3 Comparison of 7th Graders under the Theme of Teacher's Error Orientation

When Figure 3 is examined, although there are common codes observed in both classes, the classes also have their own codes. Accordingly, under the category of handling of errors, the codes of create an environment for discussion, draw attention to the error, give an erroneous example and to express it in their own words were observed in both classes. While the intolerant behaviour code belonging to the attitude towards errors category was observed only once in the comparison group, the ignoring code belonging to the feedback on errors category was observed twice during the in-class observations in the comparison group.

In order to examine the error orientations of the students in the study and comparison groups, which is the fourth sub-problem of the research, content and descriptive analyses were applied on the lesson observation books. The themes of teacher's error orientation, student's error orientation and positive error climate process for the study groups were analysed. As an example, one lesson observation of the study and comparison classes is shared below, and the 15-week observation process was evaluated at the end according to the lesson observation notebooks of the classes. In the Table 4 below, a lesson observation of class 7D in the study group is presented.

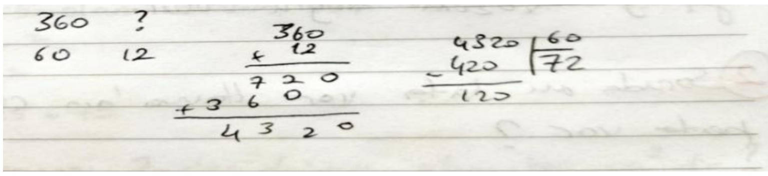
Table 4 Class 7D Lesson Observation

7D 12.05.2023



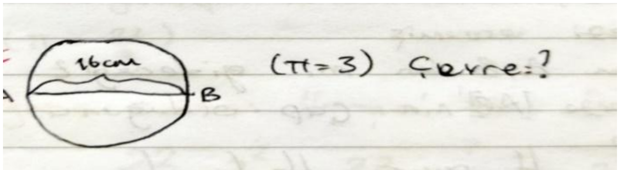
The teacher wrote a question on the board and asked the students to solve it. (The question asks for the perimeter of the circle).

Teacher said "Don't be afraid to get on the board, don't be afraid of making mistakes. I want someone who has never came up before." Student N stood up and did the solution as follows.



When the teacher did not get any reaction from the class, he asked "What is the problem in this question?".
Student O: "Since the angle is not drawn from the centre, angle isn't a Central angle"

Teacher said "Well done" and drew the correct form of the question and said "Very good, if the question was like this, Student N's solution would be correct. Thank you Student N you have made us see a very good point."



The following example was written. The teacher waited for a while for the students to read and understand the question. (The question asks for the perimeter of the circle)

Student H: "we are given the diameter 16. To find the radius, we divide it by two. R=16, r=8, 2.πr=2.3.8=48"

After the solution, the teacher asked the class "Is there a mistake in the question or in the solution?".

Student N said, "We were not given a centre."

Student O said, "Teacher, do we go from A, B?"

Teacher: "Yes, well done. Did he say that [AB] is the diameter? The mistake is here. If we write [AB]diameter, the question would be corrected."

In class 7D, the teacher frequently encouraged students to participate in the lesson. Over time, the number of students who hesitated to participate in the lesson decreased. The teacher frequently used the feedback of drawing attention to the error and giving hints. It can be said that the error orientations of teachers and students in this class are positive and errors are actively used in the classroom. Similar situations were also observed in class 6D. In the study group classes, it was observed that participation in the lesson was very diverse throughout the semester and almost all students came up to the board for questions. It was observed that while the students were timid at the beginning of the implementation, they participated more at the end of the term. In this case, it can be said that the error climate process in the study groups progressed as planned. Lesson observations of the comparison groups are given in the Table 5.

Table 5 Class 6K Lesson Observation

6K	27.03.2023

Teacher: Children, we continue where we left off. Let's solve some questions.

Question: If the arithmetic mean of the data group 5,8,12,20,a is 16, what is a?

Student K: Teacher 35

Student M said, "Teacher, it was 35".

Teacher: Student B, how did you do it?

Student B said "Because it is the arithmetic mean..." (the teacher intervened before the student finished his sentence).

Teacher: "What do we do first? We write the arithmetic mean formula." and did the solution himself/herself. “Mean=Sum of data/ Number of data, 16=SD/5=>80, 5+8+12+20+a=80=>. 80-45=35=a” (S/He waited 1-2 minutes to write the solution)

Question: Esra got 60-70-80 in maths. How many marks should she get in the 4th exam for her average grade to be 75?

Teacher: We can do it by using a formula, but we can also do it by balancing. The grades are balanced at what point. Several students answered at the same time and said 70.

Teacher: No, they said 75.

Student K said, "But my teacher's average is 70."

Teacher: Yes, but it becomes 75 with the 4th exam. Let's do it with the formula first to balance 75. He said and did the solution himself. M=SD./ND. => 75=SD/4 => SD.=300, 60+70+80=210, 300-210=90.

In class 6K, the teacher preferred to solve the questions himself/herself throughout the term. This attitude also prevented the emergence of an erroneous situation in the classroom. This situation, which was done with the possibility of students making mistakes, reduced the participation of the students in the lesson and even the students who wanted to participate in the lesson experienced distraction towards the end of the lesson. In this class, three hardworking students generally participated in the lesson and the others preferred to remain passive in the lesson. With this observation, it can be said that the error orientations of the students are sometimes neutral and sometimes negative.

As a result of the lesson observations, it can be said that the situation was similar in class 7K, another comparison group. In class 7K, although the teacher occasionally used behaviour to encourage the students, the participation in the lesson was limited to a few hardworking students. In this class, the teacher sometimes used intentionally misleading questions to attract students' attention. However, since it was not a planned process, it was insufficient to create the desired effect on the students. The teacher was generally tolerant towards student errors. As a result of the findings, it can be said that the teacher's error orientation in this class was sometimes positive and sometimes neutral. However, it can be said that the error orientation of the students was neutral throughout the class. Although the students were not hesitant to stay for the lesson, indifference and passivity towards the lesson were observed throughout the semester. It can be said that this situation is caused by the teacher's sometimes positive and sometimes neutral attitude towards errors.

The fifth sub-problem of the research, which is to examine the views of the study group teachers and students on the positive error climate process, focus group interviews were conducted with students and semi-structured interviews were conducted with teachers. Content and descriptive analyses were applied to the interview data. Interview analyses were handled separately.

Focus group interviews were held with 16 students in the study groups at the end of the application. Students of the two groups were interviewed separately. The students' answers during the interview were coded with related words and the students' positive error climate process category was created under the theme of positive error climate process. The code created under this theme, frequency and some expressions selected from participant responses are presented in Table 6.

Table 6 Students' Positive Error Climate Process

Code	f	Participant statements
Didn't feel the change	3	I didn't feel any change. My teacher is normally like this (S1, 7D)
Self-confidence increase	4	Even if we make mistakes now, our teacher does not get angry with us. He makes an effort for us to learn. (S6, 6D)
Engagement in the lesson	5	I used to not want to take maths lessons, sometimes I would fake it for that reason. But after the beginning of this semester, I focused more on maths and now most of the questions are easier for me, so my maths is better now than before. (S2, 6D)
Pleasant-fun	4	I think it's more fun if the lesson is like this.(S8, 6D)
Permanent learning	4	This teaching method did not cause wrong learning. I think it was the opposite, the mistake remained in our minds and we made the right one. (S10, 7D)
A useful process	8	In this way, teaching is more useful (S2, 6D)
Learning from mistakes	8	The teacher used to see the mistake at first but left it and picked up another one. Now he says his mistake and expects us to correct him. (S8, 6D). Now we learn right from wrong. (S1,7D)

When Table 6 is analysed, it can be said that the positive error climate process changed students' error orientation positively. The students who stated that they experienced an increase in self-confidence during the process stated that they were more connected to the lesson and did not hesitate to make mistakes. Similarly, students stated that they experienced permanent learning and learnt from mistakes. Students defined the process as a pleasant, fun and useful process.

Teachers' error climate experiences and thoughts, whether they found this method effective or not, its strengths and weaknesses, and whether they wanted to use it again were asked using a semi-structured interview form. Teacher interviews were evaluated under the theme of positive error climate process. Below is the positive error climate process category of teachers created from the common and separate opinions of both classroom teachers.

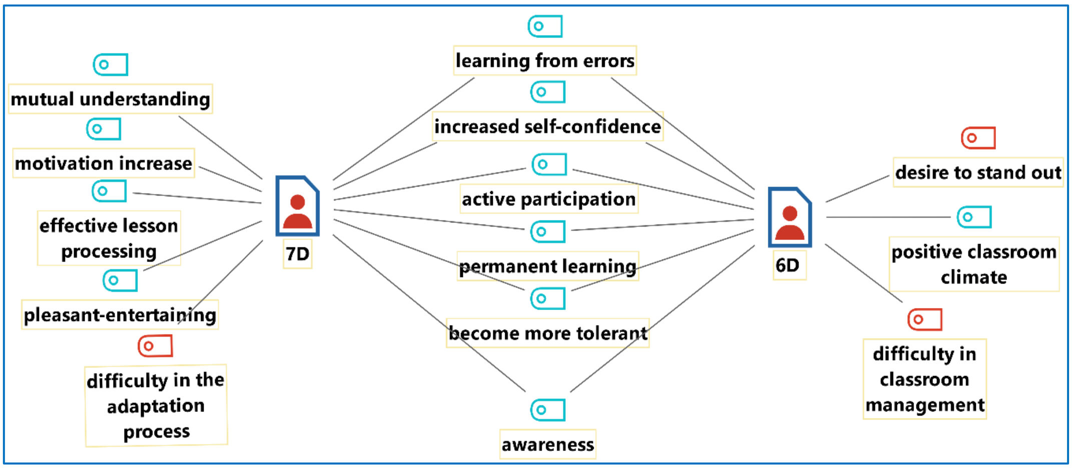


Figure 4 Teachers' Positive Error Climate Process

When Figure 4 is examined, the positive aspects of the process that teachers see in common are; increased self-confidence, learning from errors, active participation, awareness, become more tolerant, and permanent learning. While the 7D class teacher added the words "mutual understanding, motivation increase, effective lesson processing and pleasant” to these positive aspects, the 6D teacher added the expression "positive classroom climate" to these positive aspects. There was no common negative expression used by both teachers for the negative aspects of the process. While the 7D classroom teacher stated that he had difficulties in the implementation at the beginning, the 6D classroom teacher stated that the students' desire to stand out sometimes caused difficulties in classroom management. Both teachers stated that they would use the positive error climate in their classes in the future. From the data obtained as a result of the interviews with the teachers and the statements of the teachers, it can be said that the error orientations of the teachers have changed positively and that they have seen this change in the students as well.

Discussion and Conclusion

It was observed that there was a positive and significant increase in the classroom error climate perceptions of the study groups due to the positive error climate, and that teachers and students emphasised the positive aspects of the process. At the same time, it was observed that the error orientations of the students in the study groups turned positive over time. Students stated that they participated more in mathematics lessons compared to the previous semesters and this was also determined through lesson observations. Students described the positive error climate process as useful, teaching from mistakes, helping permanent learning and developing self-confidence. Teachers stated that the process was beneficial for active participation, helped permanent learning and created awareness. It can be said that in classrooms where positive error climate is established, positive development and change are experienced in terms of both affective and cognitive aspects (Özkaya, 2015; Steuer et al., 2013; Soncini et al., 2021). The results in the study are similar to the literature at this point. In the studies, most of the teachers and students stated that they believe that making mistakes is an important part of the learning process (Özkaya, 2015; Palkki & Hastö, 2018). As a matter of fact, in Wasilewski's (2023) study, the belief in the instructiveness of errors was found to be 100% in teachers and 79% in students. However, teachers and students stated that errors may create affective barriers in the use of errors in the lesson. These barriers were also mentioned by the teachers before the current study and it was determined that they were concerned about the use of errors in the lesson. As a result of the findings, it can be said that prejudices and concerns are ungrounded.

When the qualitative and quantitative findings were evaluated together, the positive error orientations of the study group teachers changed their students' error orientations into positive ones. When the literature is examined, it is seen that the students of teachers with positive error orientation are more tolerant towards errors and do not hesitate to make mistakes (Heinze & Reiss, 2007; Tulis, 2013). This situation was also observed in the current study. While class participation was low in the study groups at the beginning, it was observed that there was more participation in the lesson at the end of the process and students gained self-confidence. One of the reasons for this situation can be said to be the corrective feedback given by the teachers. When the feedback types of the teachers in the study group are examined, it can be said that mostly adaptive feedback are used (Soncini et al., 2021; Tulis et al., 2018). Huelser and Metcalfe (2012) emphasised the importance of corrective feedback and stated that it serves to remember more than giving ready answers at the point of reaching the correct answers. The emergence of permanent learning code in the interviews with teachers and students also supports this situation. Qualitative findings revealed that teachers in the study groups used corrective feedback more than teachers in the comparison groups. With feedback and correct guidance, individuals not only reach the correct answer, but also their ability to analyse and explain increases. In this way, they start to question and the amount of learning from errors increases (Metcalfe, 2017). Corrective feedback, which is one of the sub-items of the "positive error climate framework programme", was frequently used by the study group teachers and was found to have positive effects on students.

During the process, it was observed that the teachers in the comparison groups prevented the emergence of errors. Teachers showed direct intervention behaviour to prevent erroneous learning and to ensure the continuation of the lesson. This finding coincides with the finding in the literature that direct intervention is one of the ways to prevent errors from occurring (Özkaya, 2015; Santagata, 2005). Although the comparison group teachers stated that they gained awareness and experience by accepting the role of errors in teaching, it can be said that the feedback they used was aimed at preventing errors rather than using errors. According to Tulis (2013), the feedback used by teachers are maladaptive error correction feedbacks. Although teachers exhibit positive error correction behaviours from time to time in the process, it is seen from the findings that this is not sufficient to create a positive error climate. At the same time, the fact that there is no significant change in CECS pre-test and post-test findings of the comparison groups supports this conclusion.

Research shows that some teachers believe that if more attention is paid to students' mistakes, students will be embarrassed and confused by the spread of their mistakes in the classroom (Bray, 2011; Wasilewski; 2023). However, research has also shown that students in more reliable and supportive error environments can learn from mistakes more easily (Soncini et al., 2021). At the same time, it has been observed that learning from errors increases students' success (Heinze & Reiss, 2007; Steuer et al., 2015) and their interest in the course by providing motivation to students (Borasi, 1988; Özkaya et al., 2022). As a result, it can be said that the positive error climate does not interrupt the lecture and waste time, on the contrary, it provides permanent learning.

In this study, it is seen in the qualitative findings that the comparison group teachers sometimes wanted to use errors as a teaching tool in the lesson. Teachers sometimes supported this situation with their tolerant attitudes. However, as a result of both qualitative and quantitative findings, it can be said that this situation did not have the desired and expected effect on students. Likewise, when the study group teachers first started the intervention programme, it was observed that the students did not have the expected change in error orientation and that their error orientations turned positive over time. In this case, it can be said that the error climate should be implemented in a planned manner. As a result of qualitative and quantitative data, it can be said that the positive error climate led to a positive change in the error orientations of the study group students. However, it can be seen from the observation findings that the emergence of this situation is a matter of process. The change in the teacher's error orientation caused the student's error orientation to change. However, it is important that the process is implemented effectively.

Suggestions

In the study, it was seen that the use of the "Positive Error Climate Framework Program" in mathematics lessons at two different grade levels yielded positive results. Accordingly, the use of "Positive Error Climate Framework Programme" in other grade levels and courses can be the subject of future research.

Thanks

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Compliance with Ethical Standards

Disclosure of potential conflicts of interest

Authors declare that they have no competing interest.

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CRediT author statement

The researchers took full responsibility for the research.

Research involving Human Participants and/or Animals

The research was approved by Atatürk University Social and Human Sciences Ethics Committee dated 10.12.2021, meeting number 13, decision number 12.

Matematik Öğretiminde Olumlu Hata İkliminin Karma Yöntem ile Araştırılması

Özet:

Çalışmanın amacı, matematik derslerinde "olumlu hata iklimi çerçeve programına" göre oluşturulan sınıf ikliminin öğretmen ve öğrencilerin hata yönelimlerine etkilerini incelemektir. Karma yöntem desenlerinden müdahale deseni kullanılan araştırmanın verileri, amaçlı örneklem ile seçilmiş dört sınıf (iki çalışma ve iki karşılaştırma sınıfı), bu sınıflarda öğrenim gören 145 öğrenci ve dört matematik öğretmeninden toplanmıştır. Araştırmada "Sınıf Hata İklimi Ölçeği" (SHİÖ), ders gözlem formu ve defteri, yarı yapılandırılmış öğretmen ve öğrenci görüşme formu kullanılmıştır. On beş hafta süren araştırma sonunda çalışma gruplarında yer alan öğretmen ve öğrenciler ile görüşmeler yapılmıştır. T-testi sonucuna göre çalışma gruplarında karşılaştırma gruplarına göre algılanan sınıf hata ikliminde olumlu ve anlamlı bir değişim gözlemlenmiştir. Nitel veri analizlerinde çalışma grubu öğretmenlerinin ve öğrencilerinin hata yönelimlerinin karşılaştırma grubuna göre daha olumlu olduğu görülmüştür. Öğretmen ve öğrenciler, olumlu hata ikliminin doğru bilgiyi daha iyi kavrattığını, derse katılım ve özgüveni artırdığını ve kalıcı öğrenmeye yardımcı olduğunu belirtmiştir.

Anahtar kelimeler: Hata yönelimi, kalıcı öğrenme, karma yöntem, matematik öğretimi, olumlu hata iklimi.

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Appendix 1

Positive Error Climate Framework Program

1. The teacher expresses her/his tolerance towards mistakes verbally and in behavior. ***The feedback that can be given as follows:*** ***Verbal feedback*** • Answer even if you think you are wrong. • Errors are ways that are not right, the m ore wrong ways we eliminate, the better. • All mistakes are ways that will bring us closer to the truth. • You are a student, of course you will make mistakes to find the truth, do not hesitate. • Do not think that I will be angry with you if you make a mistake. • You are all classmates, let's try to learn a lesson instead of laughing or getting angry at wrong answers. ***Behavioral feedback*** • S/he encourages students with low attendance and who are behind the class academically to get up and respond to the lesson. • S/he encourages the student, who is hesitant and does not want to get up, to participate in the lesson and encourages them to respond. • S/he asks students to answer even if they are wrong. • S/he asks the students who make mistakes why they think that way without getting angry. • Be tolerant towards student mistakes.
2. The teacher is tolerant of the student who makes an error or gives an incorrect answer, thanks him/her for the error s/he finds and turns students' attention to that error. ***The feedback that can be given as follows*:** • Why did you think like that? • Shall we think together? • Your friend has mentioned a very good mistake, let's be careful about it. • Thanks for your friend's reply. • Well done, you have caught a very important point -to class- do you think your friend's answer is correct? • If it's wrong, let's think about why it's wrong. • You gave a very good answer. Thank you.
3. Instead of giving the answer directly, the teacher gives clues to the students. Discusses the given answers in class. Draws students' attention to the given answer. ***The feedback on this issue is as follows.*** • S/he does not directly say that the mistake made is wrong. Or s/he does not give the correct answer directly to the student. • S/he asks questions that will help the student find the right answer. • S/he draws the attention of the students in the class to the mistake made. • S/he involves the whole class in the process. • S/he explains the importance of the mistake made by the student. • S/he gives corrective feedback to the student. • S/he discusses the student's mistake in class. • S/he allows students who gave wrong answers to express the correct answer in their own words.
4. The teacher encourages the student, who is shy and does not want to attend to lesson. S/he enables them to participate in the lesson and promotes them to respond. ***The feedback that can be given as follows:*** • It does not directly say that the answer given is wrong. • Asks the students why they gave such an answer.

• Asks the class for the student's answer. • Makes the students think about their errors. • S/he thanks the student for the point s/he caught.
5. After the teacher decides that s/he has solved enough examples at the end of the subject, he gives an incorrect statement about the subject or makes an incorrect solution and waits for the students to catch the mistake. Ask students to express both the incorrect statement/solution and the correct statement/solution in their own sentences. ***The feedback that can be given as follows:*** • Let's examine the given statement/solution/question. • Do you think it is true? • If it's wrong, why is it wrong. • If true, why is it true?
6. At the end of the subject, the teacher exams the students, the exam is not for scoring. Puts an erroneous example in the exam. At the end of the exam, he/she solves the questions in detail in the class.

Appendix 2

CECS Sub-Dimensions and Representative Items

Sub-Dimensions	Representative Items
1. Irrelevance of errors for assessment	If someone in our Math class makes a mistake, he will get a bad grade.
2. Teacher support following errors	If someone in our Math class can't solve an exercise correctly,the teacher will help him.
3. Absence of negative teacher reactions to errors	If someone in our Math class says something wrong, sometimes the teacher will embarrass him in front of the entire class. If someone in our Math class solves an assignment incorrectly, once in a while the teacher will become angry.
4. Absence of negative classmate reactions to errors	If someone in our Math class makes mistakes, his classmates will sometimes make fun of him.
5. Taking the error risk	In our Math class a lot of students would rather say nothing at all than something that is wrong
6. Analysis of errors	In our Math class we discuss it in detail when something is done incorrectly.
7.Functionality of errors for learning	In our Math class we learn a lot from assignments that were not done correctly.

Appendix 3

Observation Form

(Write if the situation is observed, write if the opposite situation is observed)

Date: **Teacher:** **Lesson time:**

- The teacher verbally expresses tolerance towards mistakes.
- The teacher expresses his/her tolerance towards mistakes in behaviour.
- The teacher is tolerant to the students who make mistakes or give wrong answers.
- The teacher thanks the student for making a mistake or giving the wrong answer.
- The teacher draws the attention of the class to the error. The teacher discusses the answers given in the class.
- The teacher gives hints to the students instead of giving the answer directly.
- The teacher draws the attention of the students to the given answer.
- The teacher encourages the students who do not want to participate in the lesson.
- After the teacher decides that he/she has solved enough examples at the end of the subject, he/she gives an incorrect statement or makes an incorrect solution related to the subject and waits for the students to catch the error.
- The teacher asks the students to express both the incorrect statement/solution and the correct statement/solution in their own words.
- At the end of the subject, the teacher gives an evaluation exam to the students and puts an incorrect example in the exam.
- At the end of the exam, the questions are solved in detail in the classroom

Appendix 4

Example of a lesson plan

Course	Mathematics
Learning area	Ratio-proportion
Acquisitions	Solves problems related to direct and reciprocal proportion.
Academic and Social Skills	Reasoning, association, communication, Developing a positive attitude towards mathematics, creating a sense of curiosity, critical thinking,
Teaching Methods and Techniques	Investigation, active learning, question and answer, problem solving and discussion
Teaching practices	Positive Error Climate Framework Programme
Material	7th grade textbook, Smart board

Teaching and Learning Process

<u>The teacher explains the relevant topic.</u>

- ✓ The questions in the course materials are solved and the points that are not understood are explained again through the questions.

<u>The teacher creates a positive error climate in the classroom.</u>

- ✓ Encourages students with low attendance to attend the lesson.
- ✓ Gives clues to student errors s and makes them realise the errors.
- ✓ Discusses student errors in the classroom.
- ✓ Does not say any mistake is directly wrong.
- ✓ Gives appropriate time for the student to answer. It allows them to remember with clues.
- ✓ It makes the students rephrase the correct answer with their own sentences.
- ✓ Thank the student for his/her answer (it does not matter right or wrong).

<u>Erroneous question use</u>

The teacher utilises the teaching potential of errors. For this purpose, at the end of the subject, after solving enough examples, he/she uses questions containing erroneous expressions. The teacher asks the students to read the problem and think about the solution. He/she waits for the students to notice the incorrect expression. If the error is not noticed in the class, he/she ensures that the students notice it by using clues. The teacher evaluates these questions again in the class.

<u>Examples of erroneous questions that can be used for the related subject</u>

Question: The older of the two brothers who receive allowance in proportion to their ages is 15 years old and receives 100 TL. Since the younger brother receives 150 tl, what is his age?

Evaluation: The question is a direct proportion question and the first expectation here is that as the age increases, the allowance they will receive should increase. The student is expected to analyse the question through a logic filter before proceeding to the solution. Here, the teacher is expected to be patient and direct the students to the correct answer by giving hints instead of giving the answer directly.

Question: In a garden with 8 apricot trees and 17 apple trees, the ratio of the number of all fruit trees to the number of apple trees is 17/25.

Evaluation: Although the question seems correct as a solution, it is incorrect because we do not know the number of all trees in the garden. The number of all trees should be given in the question.

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Research Article

The Effect of Argumentation-Based Teaching on Conceptual Understanding in Transformation Geometry*

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Abstract – This study examines the effect of argumentation-based teaching on pre-service teachers' conceptual understanding of transformation geometry. The mixed research design was used in this study. In the quantitative dimension of the study, a quasi-experimental design with pretest and post-test control groups was used, in which the existing classes were randomly assigned as experimental and control groups. The qualitative dimension of the research is a case study. The study participants consisted of 43 secondary school pre-service math teachers who studied in the third grade at the education faculty of a state university in Turkey and took the Analytical Geometry course in the fall semester of the 2019-2020 academic year. In line with the purpose of the study, the Transformation Geometry Achievement Test (TGAT) was used as a data collection tool, and interviews were conducted with pre-service teachers. As a result, it has been concluded that argumentation-based teaching positively affects pre-service teachers' academic achievements and conceptual understanding of transformation geometry. In line with this result, it can be said that examining the effects of this teaching practice on academic success and conceptual understanding in other areas of mathematics will contribute to the field.

Keywords: Argumentation, transformation geometry, pre-service teachers, conceptual understanding.

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Introduction

Transformation geometry is an area where learners have learning difficulties (Clements & Burns, 2000; Kandaga et al., 2022; Leikin et al., 2000; Sevgi & Erduran, 2020). It is known that not only students but also teachers struggle with interpreting and applying geometric transformations such as reflections, rotations, and translations (Bansilal & Naidoo, 2012; Lee & Boyadzhiev, 2020; Luneta, 2015). For example, studies show that pre-service elementary mathematics teachers make errors in understanding the algebraic meaning of rotation and translation transformations (Ada & Kurtuluş, 2010; Portnoy et al., 2006; Thaqi et al., 2011; Yanık & Flores, 2009; Yanık, 2011).

Transformation geometry helps students learn about different concepts, such as function, congruence, and similarity, and discover the relationships between these concepts (Hollebrands, 2003; Portnoy et al., 2006). Numerous patterns and structures in daily life have been formed as a result of reflection, translation, and rotational transformations. Examples of geometric transformations can be seen in the shapes of wallpapers, historical places, and works of art. Representing geometric transformations through matrices is essential today in robot technology and motion theory (Selig, 2013; Zembat, 2013). In view of the above, it is extremely important to teach transformation geometry effectively for students to realize the vital link between daily life and mathematics (Çetin et al., 2015).

Due to the importance of transformation geometry, adequate measures should be taken to teach the subject effectively and prevent misconceptions (Kandaga et al., 2022; Leikin et al., 2000; Luneta, 2015). One of the practical teaching approaches to develop students' critical and analytical thinking skills is argumentation (Inglis et al., 2007). Argumentation can be defined as a discussion that includes the processes of putting forward and sharing thoughts on any subject, clarifying these thoughts, and explaining the basic reasons underlying the thought (stating the reasons) (Cross, 2009). Argumentation includes using different forms of representation to express assumptions, hypotheses, mathematical ideas, understanding the perspective of others, and analyzing mathematical expressions. Not all mathematical activities in the classroom are formal activities, and many of these activities include argumentation (Reid & Knipping, 2010). Information on the argumentation approach in mathematics education is included under the title of theoretical background.

Theoretical Background

Transformation Geometry

Transformation geometry studies how each point of a geometric shape corresponds to a point in a new shape formed by transformations such as translation, reflection, and rotation (Argün et al., 2014; Martin, 2012; Solomon, 2014). Translation is a transformation that moves all the points that make up the geometric shape in a specific direction and direction (Sevgi & Erduran, 2020). Reflection transformation takes place with the help of a reflection axis so that the perpendicular distance of the new shape obtained as a result of the transformation to the axis is the same as the perpendicular distance of the reflected shape to the axis (Argün et al., 2014; Martin, 2012). Rotational transformation moves the geometric shape around a certain point (rotation center) by a certain angle in the desired direction (Argün et al., 2014; Martin, 2012; Solomon, 2014).

In transformation geometry, which has an essential place in secondary and high school mathematics curricula, the geometry standards determined by NCTM (2000) also emphasize that students should be made to think about reflection, translation, and rotation transformations. Transformation geometry emphasizes the importance of understanding and teaching geometric transformations (Kandaga et al., 2022; Leikin et al., 2000). Transformation geometry enriches students' geometric experiences, imagination, and thinking abilities and develops three-dimensional thinking skills (Hollebrands, 2003; Lee & Boyadzhiev, 2020). For students to be successful in advanced mathematics, they must have sufficient knowledge of geometric transformations (Carraher & Schlieman, 2007; NCTM, 2000). However, research has shown that students need help understanding transformations (Clements & Burns, 2000; Olson et al., 2008; Rollick, 2009).

Argumentation Approach and Mathematics Education. Argumentation discusses discourses regarding a concept or situation (Fiallo & Gutierrez, 2017). In other words, argumentation is a process that requires individuals to base their thoughts on a cognitive filter and defend them with appropriate data (Naylor et al., 2007). Toulmin (2003), who conducted the first studies on the argumentation approach, revealed an argumentation model widely used in education (Rumsey & Langrall, 2016). This argumentation model, created by Toulmin (2003), is not unique to a particular field. This model is used for the analysis of arguments for various purposes in research on different fields (Erduran et al., 2004; Knipping & Reid, 2015). The basic argumentation model created by Toulmin (2003) includes three components:

data, warrant, and claim, each of which has a separate function in the argument generation process (Metaxas et al., 2016).

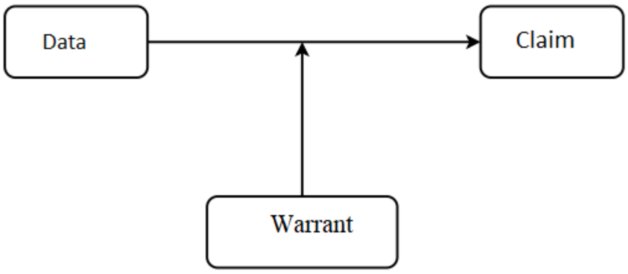


Figure 1 Toulmin Basic Argumentation Model (Toulmin, 2003)

This three-component argumentation structure constitutes the basic structure of argumentation (Pesen, 2018). Data refers to the reason for the claim and the information supporting it. Claims are thoughts based on data, the results that the individual wants to achieve based on the data. Warrants explain how the claim is reached and the relationship between data and the claim (Conner et al., 2014; Driver et al., 2000; Toulmin, 2003).

Many researchers consider argumentation necessary for mathematics learning (Reid & Knipping, 2010). The argumentation approach is one of the learning approaches that positively affects students' scientific thinking and logical reasoning skills (Kosko et al., 2014; Yackel & Cobb, 1996). With the realization of the importance of communication and social processes in mathematics education, interest in the argumentation approach is increasing daily (Erduran et al., 2004; Reid & Knipping, 2010). According to Eemeren and Grootendorst (2010), during the argumentation process, students are encouraged to make new claims and to support these claims by providing evidence while appropriately evaluating the claims made by their friends.

In the mathematical argumentation process, teachers undertake the task of helping students actively participate in the learning process (Ayalon & Hershkowitz, 2018). There should be a suitable learning environment for an effective argumentation process in which students can collaborate (Douek, 1999; Şengül & Tavşan, 2019). In this study, transformation geometry teaching was carried out with an argumentation-based teaching approach. GeoGebra dynamic geometry software was used in the activities during the teaching process. During the course process, technology is only a supporting component of the teaching process with the argumentation approach. Drawing is essential in teaching transformation geometry. Therefore, GeoGebra program was used to use time efficiently in teaching transformation geometry and to provide a learning environment suitable for the argumentation approach. By using GeoGebra program, it was aimed for students to be able to obtain data in the argumentation process, to present a claim based on this data, and to perform justification and generalization steps quickly and effectively.

Boero (1999) evaluates the argumentation process that occurs in mathematical activities in six stages: Hypothetical production, formulation of an expression, investigation of the content of the assumption, creation of a deduction chain with the help of arguments, turning the relevant arguments into a proof and approaching a formal proof. The main goal in learning environments where the argumentation approach is adopted in mathematics education is for students to make claims based on data, to strengthen these claims by basing them on justifications, to evaluate their ideas by comparing them with the ideas put forward by others, and to obtain mathematical knowledge at the end of this process (Brown & Redmond, 2007; Yackel & Cobb, 1996).

Studies revealed that the argumentation approach positively affected students' mathematics achievement (Cross, 2009; Semana & Santos, 2010) and desire to learn (Brown & Redmond, 2007; Civil & Hunter, 2015; Mueller & Yankelewitz, 2014); on the contrary, Hollebrands et al. (2010) stated in their research on geometry that argumentation skill was not related to academic achievement. Sanchez and Uriza (2008) determined that students created arguments directly without any influence from teachers. Brown and Reeves (2009) stated that the argumentation approach positively affects active participation in the learning process in mathematics lessons. In their study, Mueller and Yankelewitz (2014) stated that the argumentation approach improves mathematical discourse and contributes to a practical argumentation skill. Pesen (2018) concluded in his study that misconceptions are one of the factors affecting the quality of the argument.

Purpose of the Study

One of the main components of a teaching process is the teacher. Students' learning is directly related to teachers' teaching styles. Teachers will use the argumentation approach effective (Hollebrands, 2003; Leikin et al.,2000; Metaxas et al., 2016). Considering this situation, pre-service teachers, who are the future teachers, need to be well-trained in what they will teach and how they will teach (Ball et al., 2008). Transformation geometry is a subject included in curricula and is closely related to other key concepts in mathematics. Therefore, teaching transformation geometry effectively becomes more meaningful. Based on this idea, it is thought that this study, which is about teaching transformation geometry with an argumentation-based learning approach, is necessary. Therefore, this study examines the effect of argumentation-based teaching on pre-service teachers' conceptual understanding of transformation geometry. The main research question is, "How does argumentation-based teaching affect pre-service mathematics teachers' conceptual understanding of transformation geometry?". The sub-problems of the study are as follows;

1. What is pre-service teachers' knowledge in the experimental and control groups about the transformation geometry before argumentation-based teaching?

2. Is there a statistically significant difference between the academic achievements of pre-service teachers in the experimental and control groups on transformation geometry after argumentation-based teaching?

3. How does argumentation-based teaching affect pre-service teachers' conceptual understanding of transformation geometry in control and experimental groups?

Method

Research Design

The mixed research design was used in this study. Events in life are not unidimensional. They are more complex and related. Mixed studies are deeper and more comprehensive than studies in which qualitative and quantitative research approaches are preferred (Johnson & Christensen, 2004; Creswell, 2012). This is the main reason for using mixed methods. In order to sufficiently explain the situations to be investigated in the field of social sciences, it is recommended to use more than one research method. The mixed research approach is based on the idea that a situation has both qualitative and quantitative dimensions. Therefore, in order to discuss our research problem with a more in-depth and holistic view, a mixed research approach was used.

In the mixed research process, the data obtained with different approaches and techniques used in data collection are verified. The results obtained from the research become more acceptable. This is another important reason for using mixed methods in this study. In addition, some results obtained with a single data collection technique may need to be explained by results obtained with another data collection technique. In this context, it was thought that the triangulation and complementary functions of the mixed method would make a significant contribution to the research (Johnson and Onwuegbuzie, 2004; Yıldırım and Şimşek, 2016).

The mixed research design used in this study is the explanatory embedded design. The aim of this design is to explain, support or generalize the results obtained from one method with the results obtained from the other method (Creswell & Plano Clark, 2007). In this study, qualitative data were collected after the experimental implementation process and it was aimed to better explain the quantitative data.

In the quantitative dimension of the study, a quasi-experimental design with a pre-test and post-test control group was used. The research was conducted at a state university. The faculty administration created two different classes in which the participants would study when they enrolled at the university. At the beginning of the research, it was randomly determined which of these classes would be the experimental group and which would be the control group. The qualitative dimension of the research is a case study. Case studies require a comprehensive review to understand complex facts or events (Johnson & Christensen, 2004; Timans et al., 2019).

Participants

The study participants consist of 43 pre-service secondary school mathematics teachers who studied in the third grade at the education faculty of a state university in Turkey and took the Analytical Geometry-I course in the fall semester of the 2019-2020 academic year. Accordingly, 21 pre-service teachers in the experimental group and 22 in the control group participated in this study.

Table 1 Distribution of Teacher Candidates Participating in the Research

Groups	Gender		
	Female	Male	Total
Experiment	15	6	21
Control	19	3	22
Total	34	9	43

For the interviews in the qualitative dimension of the research, four pre-service teachers were selected, two pre-service teachers from each group. These pre-service teachers were determined according to their pre-test and post-test scores. From each group, one pre-service teacher whose pre-test and post-test scores differed and one pre-service teacher whose pre-test and post-test scores did not differ were selected.

Data Collection Tools

Transformation Geometry Achievement Test (TGAT)

In the study, we prepared a Transformation Geometry Achievement Test (TGAT) that consisted of 20 open-ended questions. Mathematics books used at high school and higher education levels were used to select questions (Altun, 2018; Balcı, 2007; Emin et al., 2018; Kemancı et al., 2018; MoNE, 2017; Ünlü and Er, 2015). The questions in these books were either adapted for the study or used directly. Care was taken to ensure that the questions were clearly articulated and could be understood equally by everyone. Regarding the questions, the opinions of three academicians who are experts in mathematics education were also consulted. Consensus has been reached by experts on the point that TGAT consists of questions suitable for the research. The content validity of TGAT was ensured with some partial corrections and changes made in line with expert evaluations. Accordingly, out of the twenty questions in the test, six are about translation, six are about reflection, and eight are about rotation transformation. TGAT was finalized after expert evaluations and opinions received from pre-service teachers within the scope of the pilot study. TGAT was applied to 47 pre-service teachers before starting the main study to test the achievement test's reliability. This way, the reliability coefficient (Cronbach α) of 0.74 was calculated. According to this value, it can be said that TGAT is reliable (Streiner, 2003; Büyüköztürk, 2014).

Interviews

The study conducted semi-structured interviews with the pre-service teachers from both the experimental and control groups to understand pre-service teachers' written solutions. The aim here is to better understand their written explanations and provide data combinations. Interviews were conducted with two participants from each group. They were determined according to their pretest and post-test scores. Interviews were conducted with one pre-service teacher whose pre-test and post-test scores showed a difference and one pre-service teacher whose pre-test and post-test scores showed no difference from each group. The first author conducted all interviews with these four volunteer pre-service teachers. The interviews were recorded with a tape recorder. Then, the recorded speeches were listened to, and transcripts were prepared. Transcripts prepared for each interview were shown again to the interviewed pre-service teacher, and their approval was obtained.

Pilot Study, Experimental Implementation Process, and Data Collection

A pilot study was carried out in the spring semester of the 2018-2019 academic year with a single group consisting of 17 pre-service teachers at the same university in the upper class of the main study participants. Since the study requires active use of the GeoGebra program, the lessons were conducted in the computer lab. All pre-service teachers in the pilot study use the Geogebra program proficiently. In the current study, Geogebra was preferred because it is easy to use with its simple interface, and it is free.

In the experimental study, the lessons were taught by the study's first author in the experimental group and by the responsible lecturer in the control group. The lessons are planned to last four weeks, 3 hours per week. Translational transformation was discussed in the first week; reflection transformation in the second and third weeks; and rotational transformation in the fourth week. The TGAT, which is a data collection tool applied as a pre-test and post-test in the study, was applied piecemeal in line with the results obtained from the pilot application. The questions about translation in TGAT were applied as a pre-test and post-test before and after the first week's lesson, in which the translation transformation was explained. The questions about reflection were administered before the second week's lesson, where the reflection transformation was introduced, and after the third week's lesson, in which the topic was completed. Lastly, the questions about rotation in TGAT were applied before and after the fourth week's lesson, in which the rotation transformation was explained.

In the experimental group, the lessons were taught with argumentation-based teaching. A total of 16 activities were used in the study. To prepare appropriate activities, textbooks used in mathematics classes in high schools and education faculties and related literature were examined. Regarding the activities prepared, the opinions of three field experts were consulted. The evaluation determined that the activities were suitable for transformational geometry learning and argumentation-based teaching.

The activities were projected onto a screen that all pre-service teachers could see clearly. Thus, all participants could follow the instructions the researcher gave. The researcher voiced the instructions for the activities. In addition, the researcher applied the process steps of the activity on his computer. After the GeoGebra applications, an argumentation process was created within the framework of the questions in the activity. The information, relations, and generalizations that the pre-service teachers reached as a result of the argumentation were noted on the board on the other side of the laboratory. An example of the argumentation process in the study is given below with "the translation of a point along the vector."

First of all, the transformation process is shown in GeoGebra. Then, the participants were asked to transform the arbitrary two points along the two vectors they determined. The participants noted the coordinates of the new points obtained as a result of the transformations. Then, they were asked to compare the coordinates of the new points and the shifted points. Thus, they created the data they can use in the argumentation process. With questions such as "What kind of change in the coordinates of the shifted points draws your attention?" and "How can you mathematically generalize the coordinates of the new points obtained by the translation of a point along the vector in the analytic plane?", the participants were enabled to put forward their claims on the subject. Thus, as Toulmin (2003) stated in the argumentation model, the participants realized the process of creating claims based on the data. After evaluating the answers, they were asked to give a few examples showing the correctness of the generalizations and justify their claims. In addition, considering the results obtained from other activities, they were asked to put forward new claims regarding the issue. Then, the participants were asked to give their reasons for their claims. During the activity, the researcher took the role of guiding the participants and giving them instructions. Other activities were carried out, like the exemplary activity process.

In the control group, teaching was mainly carried out by presentation. The same questions were solved in the control and experimental groups. No digital technology was used in the control group, and the drawings made on the classroom board were used to present the information directly.

After the lessons in the experimental and control groups were completed, TGAT (as explained above) was applied as a post-test. After the solutions of the pre-service teachers for the questions in TGAT in the pre-test and post-test were evaluated qualitatively, interviews were conducted with two pre-service teachers from each group in order to examine the effect of the teaching practices on their conceptual understanding of transformation geometry. Interviews were conducted with one pre-service teacher whose pre-test and post-test scores showed a difference and one pre-service teacher whose pre-test and post-test scores showed no difference from each group.

Data Analysis

The answers given by the participants to the questions in the TGAT were evaluated separately by the researcher and a field expert. If a student gave a mathematically correct and complete answer to a question on the TGAT, this answer was considered a correct answer. It was scored with 2 points. If the answer had missing aspects, it was considered partially correct and was scored with 1 point. If the answer was irrelevant or completely wrong, it was coded as incorrect, and if no answer was given to the question, it was coded as blank. Both cases were scored with 0 points.

The percentage of agreement between the evaluations was calculated with the formula expressed by Miles and Huberman (1994) as the agreement percentage = [(Agreement / (Agreement + Disagreement)] x100 and was found to be 94%. According to Miles and Huberman (1994), if the percentage of agreement is more significant than 70%, the analysis is reliable. The evaluations made in this direction are reliable. The evaluations made in this direction are reliable. 812 of the 860 cases that were independently examined were evaluated in the same way. Researchers and field experts came together for 48 cases where different evaluations were made, exchanged views on the reasons for these evaluations, and reached a consensus.

The study's quantitative data were analyzed using the licensed SPSS 22 package program at a 95% confidence level (p = 0.05). In the study, it was first examined whether the data followed a normal distribution. Skewness and kurtosis coefficients were examined to determine whether the data followed normal distribution.

Table 2 TGAT Skewness and Kurtosis Coefficients

	Groups		Mean	SD	Skewness	Kurtosis
TGAT	Control	Pre-test	12.18	4.95	-0.257	-1.316
		Post-test	13.32	6.27	0.004	-0.915
	Experiment	Pre-test	11.95	4.14	0.467	-0.373
		Post-test	22.62	8.01	-0.770	0.319

It is seen that the skewness and kurtosis coefficients presented in Table 2 are between -2 and +2 values. It can be said that the data are distributed normally if the skewness and kurtosis coefficients are between -2 and +2 (George & Mallery, 2020). Accordingly, it was decided to use parametric analysis techniques for data analysis. Independent groups t-test was used to compare pre-service teachers' academic achievements in the experimental and control groups. In addition, in cases where a statistically significant difference was detected due to the t-tests, the effect size (Cohen d) was calculated to interpret this significance (Leech et al., 2008; Myors et al., 2010). Effect size is interpreted regardless of sign (Timans et al., 2019). According to Cohen (1988), an effect size smaller than 0.2 is considered a “weak effect” and an effect larger than 0.8 is considered a “strong effect” (Myors et al., 2010). Leech et al. (2008) stated that an effect size of 1 and above could be interpreted as a “very strong effect”.

In the study, those in the experimental group were coded from E1 to E21, and those in the control group from C1 to C22, and these codes were used instead of real names. For the sub-problem related to conceptual understanding, the solutions made in the pretest and post-test were evaluated qualitatively, and semi-structured interviews were conducted with two pre-service teachers from each group. As a result of the evaluations made with the field experts, it was decided to conduct the interviews with the solutions of the fourth and twentieth questions in TGAT. Interviews were conducted with pre-service teachers coded as E1, E2, C1 and C2. Pre-service teachers coded as E1 and C1 represent participants whose TGAT pre-test and post-test scores differ, while pre-service teachers coded as E2 and C2 represent participants whose TGAT pre-test and post-test scores do not differ.

With the permission of the pre-service teachers, the speeches were recorded with a tape recorder. The data obtained here were transcribed and analyzed. The descriptive analysis technique was used to analyze qualitative data from solutions and interviews. Findings have been described with direct quotations. Since the interviews with four pre-service teachers would be pretty long to be reported in this article, only one interview with one pre-service teacher (E1) was included in the findings section.

Validity and Reliability

In experimental studies, various factors threaten validity, such as the selection of the participants, the background of the participants, the data collection tool, and the loss of participants (Büyüköztürk et al., 2016). During the research process, it was assumed that events other than experimental conditions had a similar effect on the participants. The data were collected from the experimental and the control groups with the same data collection tools, and the same people made the evaluations. Since no pre-service teachers left the study group, there was no effect on the difference between the two groups due to the loss of participants.

In the study, the role of the researcher in the research process was clearly explained, the study group, the research process, and the social environment where the data were collected were clearly defined, and the data collection and analysis methods were explained in detail (Timans et al., 2019). In addition, the triangulation strategy was used in data collection and analysis using different methods (Merriam, 2009). At each stage of the research, such as the preparation of data collection tools, data analysis, and the writing of the research report, the confirmation analysis strategy was used, and expert evaluation was applied.

To ensure the internal reliability of the study, as LeCompte and Goetz (1982) suggested, descriptions were enriched with direct quotations, and the findings obtained from written data collection tools were tried to be confirmed with the data obtained from the interviews. However, the data was also analyzed by another evaluator, and in this way, it was aimed to confirm the results. Participant confirmation strategy was used for internal validity. The data collected from the interviews were summarized and shared with the interviewed pre-service teachers. Thus, it was confirmed whether their explanations were understood correctly or not. To ensure the external validity of the study, as suggested by Miles and Huberman (1994), the analysis of the data and the findings and results obtained from these analyses are presented in detail. In addition, the purposeful sampling method, another way to increase external validity, was used in qualitative research. Interviews were conducted with pre-service teachers whose pretest and post-test scores differed from both groups.

Findings

Findings Related to First Sub-Problem

In this section, the findings regarding the first sub-problem of the study are presented. The analysis results of the data collected to answer the question "What is the knowledge of the pre-service teachers in the experimental and control groups about transformation geometry before the teaching process?" are given. The averages of the TGAT pretest scores of the pre-service teachers in the experimental and control groups are presented in Table 3.

Table 3 T-test Results Regarding the TGAT Pre-test Scores

	Groups	N	Mean	SD	df	t	p
TGAT pre-test	Control group	22	12.18	4.95	41	0.164	0.870
	Experimental group	21	11.95	4.14			

When Table 3 is examined, it is seen that there is no statistically significant difference between the pretest scores of the experimental and control groups ($t = 0.164$; $p > 0.05$). According to the t-test results, the experimental and control groups are equal regarding academic achievement in transformation geometry before the teaching process. Considering the maximum score that can be obtained from the TGAT (a maximum of 40 points can be obtained) and considering that pre-service teachers have encountered this issue in middle school and high school before, it can be said that the candidates' knowledge about transformation geometry is at a low level.

Findings Related to Second Sub-Problem

In order to examine whether argumentation-based transformation geometry teaching affected academic achievement, the post-test scores of the experimental and control groups were compared. The results of the independent groups t-test conducted for this purpose are presented in Table 4.

Table 4 T-test Results Regarding the TGAT Post-test Scores

	Groups	N	Mean	SD	df	t	p
TGAT post-test	Control group	22	13.32	6.27	41	-4.250	0.000
	Experimental group	21	22.62	8.01			

Table 4 shows that the statistically significant difference between the post-test averages is in favor of the experimental group ($t = -4.250$; $p < 0.05$). The mean score of the control group is 13.32, whereas the mean score of the experimental group is 22.62. Considering the pretest averages, the increase in the experimental group is much more significant than in the control group.

As a result of the independent groups t-test regarding TGAT post-test scores, it was determined that technology-supported argumentation-based teaching affected academic achievement in transformation geometry. In order to interpret the significance of this finding more effectively and to determine the level of effect of technology-supported argumentation-based teaching on academic achievement, the effect value (Cohen d) was calculated.

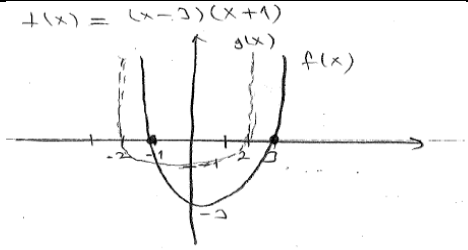
$$d = t.\sqrt{\frac{N_1 + N_2}{N_1 . N_2}} = (-4.250).\sqrt{\frac{22 + 21}{22.21}} = -1.296$$

The value of d=-1.296 calculated in the equation above shows that technology-supported argumentation-based teaching has a very high effect on academic achievement.

Findings Related to Third Sub-Problem

This sub-problem aims to examine how teaching practices affect the conceptual understanding of transformation geometry. For this, the solutions given by a selected pre-service teacher (E1) to the questions in the TGAT were examined qualitatively in depth. Then, interviews were conducted on the pre-service teacher's solutions to the fourth question, which is a translation question, and the twentieth question, which includes rotation and reflection transformation. The solutions of E1 for the fourth question in TGAT are presented in Table 5.

Table 5 E1's Solutions for the Fourth Question

<table>
<tr><th>Pre-test</th><th>Post-test</th></tr>
<tr><td>$f(x) = (x-3)(x+1)$


$g(x) = a(x+2)(x-2)$
$(0,-1)$ denklemi sağlar.
$-1 = a(2)(-2)$
$-1 = a(-4)$
$\frac{1}{4} = a$ $\boxed{g(x) = \frac{1}{4}(x^2-4)}$</td><td>$(x,y) \rightarrow (x+1, y-2)$
$y-2 = (x+1)^2 - 2(x+1) - 3$
$y-2 = x^2+2x+1-2x-2-3$
$y = x^2+\cancel{2x}-\cancel{2x}-4+2$
$y = x^2-2$</td></tr>
</table>

The fourth question in TGAT is "Find the equation of the parabola formed by translating the parabola f(x) = x^2-2x-3 in the negative direction by 1 br along the x-axis and in the positive direction by 2 br along the y-axis." When the solutions were examined, it was seen that E1 could not reach the correct answer in the pretest, but the solution was correct in the post-test. This question involves the problem of translating the parabola along the axes. In the solution in the pretest, it is seen that the participant first factors the parabola equation. As understood from his drawing, he determined the points where the parabola intersected the x-axis in this way. Although he did not show it by processing, he also determined where the parabola intersected the y-axis and drew the parabola. It can be seen from the parabola expressed by g(x) that the points where f(x) intersect the x-axis are shifted by 1 unit in the negative direction. However, it can be seen that he translates two units in the positive direction along the y-axis. Using the new points he obtained this way, he found the equation of g (x) by using the points where the axes intersected. It can be seen that E1 did not make any drawings in his solution for the same question in the final test. In this solution, it is seen that E1 has written (x + 1) instead of x and (y-2) instead of y in the parabola equation given in the question. Then, he edited the equation and got the correct answer. In the solution, E1 applied the transformations specified in the question (as points on the x-axis or y-axis) without distinguishing between points on the parabola.

The interview with E1, who offers different solutions in the pretest and post-test for the same question, is given below.

Researcher: “What did you think about this solution in the pretest?”

E1: “First of all, I needed to learn the formula for translation. That is why I drew graphics. I tried to comment on the graph. I proceeded through the points where the function intersects the axes on the graph. After that, because it says in the negative direction along the x-axis, for example, I came from point 3 to 2, the other from -1 to -2. Since it says along the y-axis in the question, I brought the point -3, which intersects the y-axis to -1.”

Researcher: “Then?”

E1: “I used this formula to write the equation for the graphic I just created. This way, I found the equation for the new graph.”

Researcher: “… Now, looking at the last test, your answer is correct. How did you come up with the solution here?”

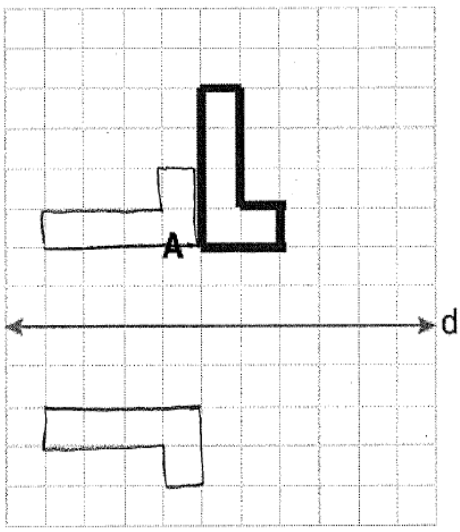
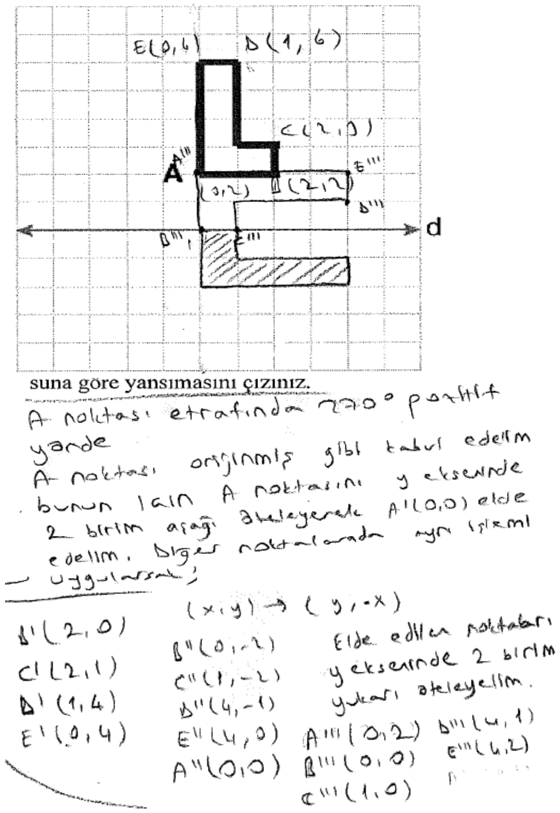
E1: “I learned the formula after the GeoGebra application. So, for example, we need to write (x + 1) for a 1-unit unfavorable translation on the x-axis. When I followed this rule, I could find the new equation immediately.”

Researcher: “Well, the last thing I want to ask about this question is:…. When you compare these two solutions, what could be the problem with the thinking in the pretest? ….”

E1: “I previously thought, for example, that for a unit displacement in the negative direction, the graph would shift one unit to the left on the x-axis. That is why I came to such a wrong conclusion.”

As a result of the interview, it was understood that in the pretest process, E1 tried to create a new function by shifting the points where the function intersected the axes according to the instructions. In the post-test, it is seen that he gave up the idea of considering the points on the axes separately. Here, it is seen that he makes use of the solution approach he named the "translation formula" regarding translation transformations. The statement of E1, "I learned the formula after GeoGebra application," shows that he was affected by the "generalization" process, which is the last step of the activities used in the argumentation-based teaching process. E1's solutions for the twentieth question in the TGAT are presented in Table 6.

Table 6 E1's Solutions for the Twentieth Question

Pre-test	Post-test
	

The twentieth question in DGBT was "Draw the reflection of the given figure on line d after rotating it 90 degrees in the negative direction about point A." The twentieth question involved the resultant of transformations (rotation and reflection transformation). When the solutions of E1 were examined, it was seen that he did not have a problem with reflection transformation in the pretest, but he made a mistake in the rotation process. When looking at the solution in the post-test, it was seen that E1 did not make an error in the rotation process. In addition, it was seen that he made the reflection transformation correctly in the post-test. A part of the interview with E1 regarding this question is given below.

Researcher: “Regarding the twentieth question, your answer in the pretest is wrong, and your answer in the post-test is correct. Where do you think you went wrong in the pretest?”

E1: “In the pretest, I realized I was doing the rotation movement against what was wanted.”

Researcher: “Well, can you explain your answer in the post-test?”

E1: “I took the given d-line as the x-axis. According to this line, I gave positive values for the upper part and negative values for the lower part. First of all, I made the rotation according to point A. This time, I did it by taking 270 degrees in the positive direction instead of 90 degrees in the negative direction. I saw this in your class. I determined the coordinates of the new points on the figure. Then, I reflected on the new shape according to the d-line. I redefined the coordinates of the corners on the newly formed shape according to this reflection transformation. It is easier to make such transformations when the figure is given on a scaled ground."

It is understood from this interview that E1 does not know that the negative rotation movement must be clockwise. Therefore, it is seen that he answered the twentieth question incorrectly in the pretest. However, after the teaching process, he corrected his misinformation and gave a correct answer to the question in the post-test. Especially in the post-test, it was seen that he moved the points to their position after the transformation operations. This situation shows that he acted consciously in the solution steps. In this sense, the argumentation processes carried out in the experimental group contributed to E1's creation of knowledge.

Conclusion, Discussion, and Suggestions

Within the scope of the first sub-problem of the study, the knowledge levels of pre-service teachers in the experimental and control groups about the transformation geometry before the teaching process were examined. As a result of the research, there is no statistical difference between the knowledge levels of the pre-service teachers, and the pretest mean scores of both groups are low. Participants in the study have recently encountered geometry transformation in the 11th grade of high school. It is not surprising that the participants have forgotten the relevant topic in the last 3-4 years and their level of knowledge on this subject is low.

In the analysis for the second subproblem of the study, a statistically significant difference was found between the post-test averages of the participants. This difference was found to be in favor of the experimental group. It has been determined that the effect of argumentation-based teaching on the occurrence of this difference is significant. In addition, this type of teaching affects the increase in the average achievement of the participants in the experimental group because argumentation-based teaching offers pre-service teachers the opportunity to share their mathematical thoughts while creating new mathematical knowledge (Cross, 2009). This situation makes them aware of their misconceptions and contributes to effective learning. In the relevant literature, some studies examine argumentation-based teaching and teaching separately and show that these teaching approaches increase academic achievement (Cross, 2009; Güven & Kaleli Yılmaz, 2012; Marshman & Brown, 2014; Sanchez & Uriza, 2008; Semana & Santos, 2010; Shadaan & Leong, 2013).

Contrary to this study, Can et al. (2017) concluded that the argumentation-based learning approach does not affect academic achievement. Can et al. (2017) listed this situation as the students' unwillingness to participate in the argumentation process, individual characteristics such as being afraid to speak in public, negative attitude, and the classroom environment in which the study is conducted is unsuitable for group work. In this study, the argumentation process was adequate for the participants because the experimental group students were open to exchanging ideas. In addition, the teaching practice of the experimental group was carried out in the computer laboratory. The fact that the laboratory is U-shaped made it easy for the participants to be included in the argumentation process.

Studies on teaching transformation geometry with GeoGebra have reached a similar result as in this study (Campbell & Zelkowski, 2020; Hollebrands et al., 2010; Sinclair et al., 2016). Technology is enjoyable for the participants in this study, and the concretization of abstract situations is among the factors that explain the success. Shadaan and Leong (2013) also stated that in a teaching process using dynamic geometry software, students enjoy learning more and can make influential associations between their learning. In summary, even in studies where the argumentation approach or teaching was used alone, there was an increase in academic achievement. In this study, where both the argumentation approach and technology were used together, the increase in the academic achievement of pre-service teachers regarding transformation geometry is a natural result.

Within the scope of the third sub-problem of the study, the effect of the teaching practices in the experimental group on pre-service teachers' conceptual understanding of transformation geometry was examined. The answers to the fourth question in the TGAT before the teaching practices and the interviews showed that the pre-service teachers had an incomplete or incorrect conceptual understanding that all points on a curve should be shifted holistically. After the teaching process, it was observed that only E1 reached the correct answer to this question, and the other three participants needed a better conceptual understanding. In line with his solution and his explanations in the interview, it was understood that E1 was affected by the "generalization" process, which is the last step of the activities used in argumentation-based teaching practice. Research shows that learners can make mathematical generalizations by using GeoGebra in teaching geometry (Campbell &

Zelkowski, 2020; Hollebrands et al., 2010; Santos-Trigo & Cristóbal-Escalante, 2008; Shadaan & Leong, 2013).

The answers to the twentieth question in TGAT showed that pre-service teachers needed to learn about the direction of rotation before teaching. As a result of the solutions and interviews after the teaching process, it was seen that E1 knew what he did and why and used his geometric thinking skills effectively. Based on the explanations made by E1, argumentation-based teaching affects this change. It is understood that E2 has the correct knowledge about the direction of rotation, but due to carelessness, E2 moves in the wrong direction in the solution. It was determined that C1 and C2 also corrected their knowledge about the direction but needed help to make the correct drawing due to their conceptual problems about the center of rotation.

When the research findings are evaluated in general, it can be said that argumentation-based transformation geometry teaching positively affects E1's geometric thinking skills and conceptual understanding of the subject. Although it is seen that there is no significant change in the conceptual understanding of E2, his thoughts on the solution were slightly affected. On the other hand, teaching transformation geometry with the current teaching method does not significantly affect the conceptual understanding of C1 and C2. Studies revealing the positive effect of teaching with the argumentation approach and dynamic geometry software on conceptual understanding support the results of this research (Gürbüz & Gülburnu, 2013; Hollebrands et al., 2010; Jackiw, 2003; Oldknow & Tetlow, 2008). It has also been stated that argumentation-based teaching encourages students' participation in the lesson and allowing them to discuss positively contributes to their mathematical abilities and argumentation levels (Civil & Hunter, 2015; Mueller & Yankelewitz, 2014; Rumsey & Langrall, 2016).

Compliance with Ethical Standards

Disclosure of potential conflicts of interest

No conflict of interest.

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CRediT author statement

The first and the second author jointly carried out the processes of conceptualization of the theoretical framework, the determination of the research questions and the design of the method. The first author carried out the processes of data collection, data analysis and discussion of the results under the supervision of the second author. The first author wrote a Turkish draft of the manuscript on which both authors worked in cooperation. The second author edited the English version. The first author applied the article template before submission, and submitted the manuscript to the journal.

Research involving Human Participants and/or Animals

We hereby declare that the study has not unethical issues and that research and publication ethics have been observed carefully. The study was produced from the first author's doctoral thesis. The research process started in 2017 and the data were obtained before 2020 (2019-2020 Fall Semester). For this reason, the research is among the studies that do not require ethics committee approval.

Argümantasyon Tabanlı Öğretimin Dönüşüm Geometrisinde Kavramsal Anlayış Üzerine Etkisi

Özet:

Bu çalışmada, argümantasyon tabanlı öğretimin öğretmen adaylarının dönüşüm geometrisi konusundaki kavramsal anlayışlarına etkisi incelenmektedir. Çalışmada karma araştırma deseni kullanılmıştır. Çalışmanın nicel boyutunda, mevcut sınıfların deney ve kontrol grubu olarak rastgele atandığı, ön test ve son test kontrol gruplu yarı deneysel desen kullanılmıştır. Araştırmanın nitel boyutu ise bir durum çalışmasıdır. Çalışmanın katılımcılarını, Türkiye'deki bir devlet üniversitesinin eğitim fakültesinde üçüncü sınıfta öğrenim gören ve 2019-2020 eğitim öğretim yılı güz döneminde Analitik Geometri dersini alan 43 ortaokul öğretmen adayı oluşturmuştur. Çalışmanın amacı doğrultusunda, Dönüşüm Geometrisi Başarı Testi (DGBT) veri toplama aracı olarak kullanılmış ve öğretmen adaylarıyla görüşmeler yapılmıştır. Sonuç olarak, argümantasyon tabanlı öğretimin, öğretmen adaylarının akademik başarılarını ve dönüşüm geometrisi kavramsal anlamalarını olumlu yönde etkilediği sonucuna varılmıştır. Bu sonuç doğrultusunda, bu öğretim uygulamasının matematiğin diğer alanlarındaki akademik başarı ve kavramsal anlama üzerindeki etkilerinin incelenmesinin alana katkı sağlayacağı söylenebilir.

Anahtar kelimeler: Argümantasyon, dönüşüm geometrisi, öğretmen adayları, kavramsal anlayış.

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Research Article

Investigating the Change in Mathematical Modeling Competencies of Middle School Students During the Educational Process Designed with Mathematical Modeling Activities*

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Abstract – This study aims to determine how the teaching process designed with mathematical modeling activities affects the mathematical modeling competencies of seventh grade middle school students. The embedded design, one of the mixed methods research designs, was adopted. The embedded design was adopted, one of the mixed methods research designs. The research participants consisted of 27 students studying at the seventh grade level of a middle school. During the 10-week implementation process, an opinion form consisting of open-ended questions and nine mathematical modeling activities developed by the researcher were used as data collection tools. Three of these activities were used for the pretest and posttest, and the remaining six were used in the implementation process. When analyzing quantitative data, the Wilcoxon signed-rank test was used. In the analysis of qualitative data, descriptive analysis was used. According to the results, during the implementation process, students showed the most improvement in understanding the problem and studying mathematically. In contrast, they showed the slightest improvement in the interpretation and verification stages. It is thought that it is essential to constitute environments where students can establish relationships with mathematics and to design mathematical modeling problems in these environments to attract students' attention as much as possible.

Keywords: Modeling competencies, mathematical modeling, middle school students

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Introduction

Mathematical modeling is a dynamic method that makes it easier to see the relationships inherent in problems in all areas of life, discover them and express the relationships between them in mathematical terms, classify, generalize, and draw conclusions (Fox, 2006). Mathematical modeling is the process of expressing a real-life situation mathematically (Kertil, 2008). Borromeo Ferri (2006) defined mathematical modeling as a complex and cyclical process that involves transformations between the mathematical world and real life. According to Kaiser and Maaß (2007), mathematical modeling competence means completing the mathematical modeling process willingly and purposefully. As can be understood from the definitions, the main emphasis in modeling is on the process. Many researchers have studied the cyclicity of the modeling process, including Berry and Davies (1996), Doerr (1997), Mason (1988), Voskoglou (2006), and Borromeo Ferri (2006).

These definitions and studies reveal that mathematical modeling is a structured process that involves multiple stages and competencies. When the stages of the modeling process described in the literature are examined, it is observed that although there are some differences in terms of competencies, most studies commonly emphasize understanding, simplifying, mathematizing, working mathematically, interpreting, and verifying (e.g., Blum & Borromeo Ferri, 2009; Galbraith & Stillman, 2006). Borromeo Ferri (2006) defined mathematical modeling by including this six-stage process. The ability to create a model by performing these six stages correctly and to analyze or compare given models is defined as "Modeling Competency" (Blum & Borromeo Ferri, 2009). Many studies have shown that students are relatively competent in the early stages of the modeling process understanding the problem, simplifying it by identifying relevant variables, expressing the situation symbolically, and performing mathematical operations. However, it has been emphasized that students often have difficulties in stages such as interpreting mathematical results in real-life contexts and verifying solutions (Blum & Borromeo Ferri, 2009; Galbraith & Stillman, 2006; Kaiser, 2020). In the context of this research, it was of particular importance to examine how students performed in these stages and to reveal both their strengths and the challenges they faced.

In parallel with the increasing interest in mathematical modeling worldwide**,** its importance has also grown in the context of education in Türkiye. When the middle school (5th, 6th, 7th, and 8th grade) mathematics curriculum is examined, it seems that it aims to raise individuals who can easily express their thoughts and reasoning in the problem-solving process, understand mathematical concepts, and associate and use these concepts with daily life (Ministry of National Education [MoNE], 2018a). Doruk (2010) stated that teachers must find practical methods to make students feel that mathematics is a part of their lives, enable them to enjoy mathematics and engage them in more meaningful mathematical learning. Çora (2018) states that mathematical modeling problems related to many fields, well-defined, covering rich information and cognitive processes can be included in the classroom environment instead of traditional problem activities for this purpose. Deniz (2014) says modeling is essential in associating mathematical concepts with daily life, considering the difficulties individuals experience in establishing the relationship between the natural and mathematical worlds. If mathematical modeling is used in mathematics education, students will better understand real-world situations and learn the subject in lessons, and various mathematical skills can be developed (Blum, 2002). In this context, the importance of mathematical modeling applications for solving daily life problems emerges.

In this context, an important distinction emerges between traditional problem types and modeling activities. Traditional problems solved in the classroom environment help students improve their computing skills. However, it does not contain a structure that will reveal the mathematical structures in students' minds. Mathematical modeling activities stand out as powerful tools that enable students to create their essential mathematical ideas and processes rather than directly applying the knowledge they have previously learned within the scope of the curriculum (English, 2006). According to Lesh and Doerr (2003), mathematical modeling activities are problems that allow students to work on a problem taken from real life, create their mathematical thoughts, and revise their thoughts. Therefore, confronting students with activities in which they will use their ideas rather than traditional problem-solving activities is a more effective teaching method (Blum, 2002). This study examined how students developed modeling competencies using their ideas and abilities in the teaching process designed with modeling activities.

There are also several studies in the literature that have examined students' competencies in modeling processes through similar learning environments. In their study with 3rd grade primary school students, English and Watters (2004) stated that students' ability to make sense of meaning, problematize, create hypotheses, and mathematize were seen with the help of mathematical modeling activities. Maaß (2006), in his study to determine students' mathematical modeling skills, stated that students showed improvement in mathematical modeling activities and that students with low achievement levels also participated in the process. In their study, Hıdıroğlu et al. (2014) examined students' solution approaches to the comet problem within the framework of the mathematical modeling process. As a result of the study, they stated that their students' performance decreased as the stages of the modeling process progressed. In their study, Tekin Dede and Yılmaz (2015) sought an answer to how the cognitive modeling competencies of 6th grade students could be improved. In the study, where Borromeo Ferri's (2006) cognitive modeling perspective was used as a theoretical framework, the development of students' cognitive modeling competencies was examined. As a result of the study, they stated that the students quickly achieved the desired development in terms of understanding the problem, simplifying, mathematizing, and studying mathematically. On the other hand, they stated that the students did not develop sufficiently in interpretation and verification competence. Özgen and Şeker (2020) examined the modeling competencies of 6th grade students in the context of Borromeo Ferri's (2006) cognitive modeling perspective. As a result of this study, they emphasized that the students showed improvement in the context of all competencies. In their study, where they examined the modeling competencies of 7th grade students in the context of Borromeo Ferri's (2006) cognitive modeling perspective, Alkan and Aydın (2021) stated that the students showed improvement at all stages. Kılıç (2020) used the same cognitive perspective in his study with middle school students. He stated that students improved in all competencies except verification competency in the study. These studies are related to the current study in terms of their focus on mathematical modeling competencies, but they differ in terms of the grade levels studied, the specific modeling tasks used, and the emphasis placed on different stages of the modeling process.

Despite these contributions, mathematical modeling research is still limited in terms of scope and depth. Albayrak and Çiltaş (2017) state that there are few experimental studies on mathematical models and modeling in Türkiye. Most of them were conducted with university students, and how teaching with mathematical modeling is carried out in these studies is not explained in detail. Didiş Kabar and İnan (2018) stated that studies with middle school students studying under different conditions in different socio-economic regions of the country should be increased and that the applicability of mathematical modeling activities in middle school classes studying under different conditions and the possible benefits of these applications for students and teachers should be evaluated. All this shows that mathematical modeling problems are not widely applied in classrooms in our country, and therefore, their use by teachers in the classroom environment should be expanded, and research on mathematical modeling should be diversified. Although there are studies examining mathematical modeling competencies in our country, the number of studies that evaluate the teaching process with more than one activity, as in this study, is low. Considering the methods, samples, and approaches used in previous modeling studies, the number of experimental studies that include qualitative data is also low. This study aims to address this gap by combining multiple modelling activities with a detailed examination of the instructional process through both quantitative and qualitative methods**.** Since this study is an experimental study that includes qualitative data and provides a comprehensive description of the implementation, it is thought that it can guide teachers who want to implement modeling activities in their classrooms on how the process will work. In this respect, it differs from previous studies that often focus on single activities or lack in-depth pedagogical analysis.

Purpose of the Research

The research aims to examine the development of the modeling competencies of seventh grade students in the teaching process designed with mathematical modeling activities. Specifically, answers were sought to the following problems:

1. How are the mathematical modeling competencies of 7th grade middle school students before and after the implementation?

2. How is the change in the mathematical modeling competencies of 7th grade middle school students during the implementation process?

Method

Research Design

In this research, nested design was used, one of the mixed method designs. In the mixed method design organized according to the nested (embedded) design, qualitative and quantitative data can be collected simultaneously, and a data set can support the study's secondary function (Creswell & Plano Clark, 2018).

In the current study, the scores obtained from students' pretest-posttest mathematical modeling activities constitute the quantitative data of the research. The students' solutions to modeling problems (activities) during the implementation and their answers to the opinion form constitute the qualitative data of the research. The research examined student solution sheets of three mathematical modeling problems used for the pretest and posttest to support the quantitative data obtained from the pretest and posttest. At the end of the implementation process, student opinions were also taken through an opinion form to support the quantitative data obtained from the pretest and posttest. Qualitative data obtained by observing the students' situations during the process, examining their activity sheets, and gathering their opinions were used to portray the development of the students' mathematical modeling competencies, especially throughout the teaching process.

Before the implementation, students' solution papers were examined to support the quantitative data obtained from the pretest. Similarly, after the implementation, students' solution sheets and answers to the opinion form were examined to explain the data obtained from the posttest and quantitatively describe the students' situations. In the quantitative dimension of the research, a single-group pretest-posttest design was used.

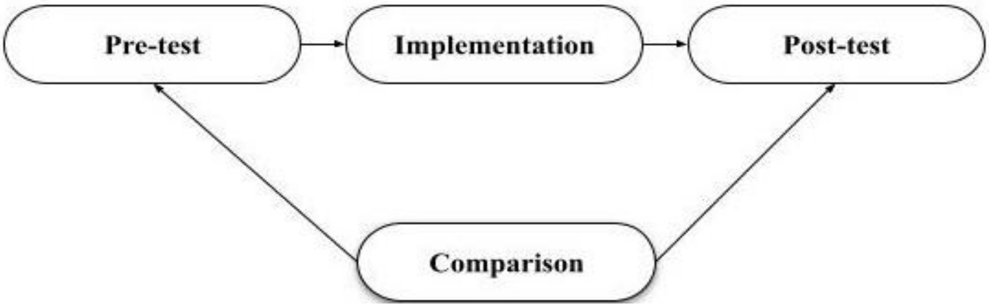


Figure 1 Single Group Pretest-Posttest Design (Johnson & Christensen, 2014)

Study Group

The study group consists of 27 seventh grade students attending a public middle school located in a district where one of the researchers was employed during the 2018–2019 academic year. Among the participants, there are 16 female and 11 male students. The study group was selected using the convenience sampling method, which is one of the purposeful sampling techniques. In this method, the researcher selects participants that are close and easy to reach, which brings speed and practicality to the research process (Yıldırım & Şimşek, 2016). The selected class was one of three sections at the school where the research was conducted. Although the sampling method was based on accessibility, this particular class was preferred because the students generally demonstrated characteristics such as being able to understand what they read, attending school regularly, and showing interest in mathematics. During the implementation process, students were divided into heterogeneous groups of four according to their mathematics course grades. Each designed activity was implemented during two class hours as part of the mathematics applications course.

Data Collection

As a data collection tool in the research,

- Personal information form,
- Three "mathematical modeling activities" to be used in the pretest and posttest,
- Six "mathematical modeling activities" to be used in the implementation process and
- Student opinion form was used.

Personal Information Form

A personal information form was used to obtain personal information about the students. With this form, information about the gender of the students, the general average of the last semester's mathematics course, and the educational status of the parents were obtained.

Mathematical Modeling Activities and Development Process

Nine mathematical modeling activities were used in the study, three of which were used in the pretest and posttest. The researcher developed mathematical modeling activities by scanning the relevant literature, Programme for International Student Assessment (PISA), Trends in International Mathematics and Science Study (TIMSS), seventh grade mathematics textbooks, and seventh grade elective mathematics textbooks published in previous years. Since the developed mathematical modeling activities were implemented for seventh grade students, care was taken to ensure that the activities were appropriate to the real-life context and the 7th grade objectives in the secondary school mathematics curriculum (MoNE, 2018a).

Table 1 Contents of Mathematical Modeling Activities

Weeks	Name of activity	Related objectives	Daily life context
Pretest-Posttest	Perimeter of Lake Hazar	Recognizes rectangle, parallelogram, trapezoid and rhombus.	Field, Hedge
Pretest-Posttest	Population of Küçükkadı	Solves problems that require operations with integers.	Population
Pretest-Posttest	Tomato Garden	Solves problems that require operations with integers.	Daily shopping
1st week	Teacher's time	Solves problems that require operations with integers. Calculates one quantity as a percentage of another quantity.	Time
2nd week	Let's Build Shelters for Sheep	Recognizes rectangle, parallelogram, trapezoid, and rhombus. Solves problems related to the area.	Shelter, warehouse
3rd week	Which Seed Should We Plant?	Finds and interprets a data group's mean, median, and mode values.	Field, average expense
4th week	Let's Repair the Ten-Eyed Bridge	Recognizes rectangle, parallelogram, trapezoid, and rhombus. Solves problems related to space.	Historical place
5th week	Footprint	Given one of two quantities whose ratio is known, finds the other.	Weight, depth
6th week	Let's Find the Suitable Fuel	Solves problems that require operations with integers. Solves problems that require operations with rational numbers.	Vehicle fuel

Modeling activities were created to include an introductory essay, preparation questions, problem situations, and presentation of solutions, which are the principles of modeling activities specified by Tekin Dede and Bukova Güzel (2014). Tekin Dede and Bukova Güzel (2014) described the purpose of the introductory essay and preparation questions as warming up and preparing students for the problem situation. They stated the problem situation as the primary component of modeling activities. They stated that the presentation of solutions involves students presenting their presentations to their friends and reviewing their solutions when necessary. Borromeo Ferri's (2006) modeling cycle under the cognitive perspective was chosen as the theoretical framework. Under this cognitive perspective, cognitive modeling competencies are understanding the problem, simplifying, mathematizing, studying mathematically, interpreting, and verifying. In this modeling process, at the stage of understanding the problem, the student makes sense of it and re-represents it. In the simplification stage, the student extracts the information necessary to solve the problem and makes assumptions. In the mathematization stage, the student creates the mathematical model necessary to solve the problem with the help of existing mathematical knowledge. In the mathematical studying stage, the students make mathematical solutions in the context of their obtained model. The mathematical solution formed in the interpretation stage is interpreted in the context of real life. In the verification stage, the entire process is checked, corrections are made at the necessary stages, and the process is terminated. To determine these mathematical modeling competency levels, students were required to follow the following instructions along with the given activity:

1. Express the problem in your own words.
2. Explain what information you need to solve the problem.
3. Explain mathematically what method you would follow to solve the problem.
4. Complete the necessary operations to solve the problem.
5. Do you think the solution you found is suitable? Write your comments about the result of your solution.
6. How can you be sure that your result is correct? Explain.

Each of these guiding questions corresponds to the mathematical modeling competencies put forward by Borromeo Feri (2006). The “Perimeter of the Lake Hazar Lake” modeling activity used in the pretest and posttest is given in Figure 2 below.

Lake Hazar is a tectonic lake located in the southeast of Elazığ province. Lake Hazar has an essential position in terms of the climate and geographical features of the region. Lake Hazar hides significant riches under its blue cover. Recent studies have led to the discovery of traces of the settlement, which was submerged due to an earthquake in the 13th century and dates back to the 11th century. Since Lake Hazar is located close to Diyarbakır, it is a place where people frequently go daily to cool off during the summer months.

Above is a satellite image of Lake Hazar. Accordingly, estimate the perimeter of Lake Hazar.

1. Express the problem in your own words.
2. Explain what information you need to solve the problem.
3. Explain mathematically what method you would follow to solve the problem.
4. Write and solve the appropriate stage to solve the problem.
5. Do you think the solution you found is suitable? Write your comments about the result of your solution.
6. How can you be sure that your result is correct? Explain.

Figure 2 How Many Kilometers is the Perimeter of the Lake Hazar? (Modeling Activities)

While developing the activities, ten mathematical modeling activities were designed considering mathematical situations that students may encounter in daily life. In addition, the cultural and socioeconomic levels of the students were taken into account in the activities, and care was taken to ensure that the activities were related to the student's immediate environment. The developed activities were examined by two faculty members who are experts in mathematics education and three mathematics teachers with master's degrees in this field. While examining the activities, experts expressed their opinions by considering the introductory essay, preparation questions, problem situation, and presentation of solutions, which are the principles of model-building activities stated by Tekin Dede and Bukova Güzel (2014). As a result of the expert reviews, it was stated that one of the developed activities did not comply with the principles of model-building activities, because the problem situation was too routine and did not provide sufficient opportunity for model development. Therefore, this activity was not evaluated. Experts stated that there were semantic deficiencies in some activities, especially in the preparation questions and the wording of the problem situations. Based on the expert feedback, the semantic deficiencies were revised by clarifying the preparation questions and rewording the problem situations to better guide the modeling process. Thereupon, all activities were examined by a Turkish language teacher. The Turkish language teacher examined the activities regarding meaning, spelling, and spelling-punctuation marks. Within the framework of the suggestions, semantic errors in the questions were eliminated, spelling and punctuation errors in the activities were corrected, and after all revisions were completed, a pilot implementation was conducted with 25 seventh grade students.

Opinion Form

The opinion form, which was developed by the researcher and consisted of open-ended questions, was developed after the posttest to obtain the opinions of the study group about the process carried out with mathematical modeling activities (the difficulties they encountered while solving the activities and their reasons, their differences from routine problems, etc.). The questions in the opinion form were prepared by examining the relevant literature and in line with the sub-problems of the research. The questions were presented to the opinion of two experts in the field, and the experts suggested clarifying the wording of certain questions, especially regarding the distinction between modeling problems and routine problems and recommended making the language more accessible for students. In line with these suggestions, the expressions were revised for clarity, ambiguous terms were replaced with simpler alternatives and the questions were given their final form.

Implementation Process of the Research

Pilot Implementation Process

A pilot study was conducted in the second semester of the 2017-2018 academic year with 25 seventh grade students at the school where the researcher works. The study carried out each activity in the mathematics applications course and two weekly lesson hours for ten weeks. The personal information form was administered in the first lesson hour of the first week of implementation. In the 2nd lesson hour, the first activity of the pretest was administered to the students individually. The second pretest activity was administered to the students in the 1st lesson hour of the second week. The third pretest activity was applied to the students in the second lesson of the second week and the pre-implementation procedures were completed. Then, a 6-week implementation period was started, and six mathematical modeling activities were administered. In the first week after the end of the implementation process, the first activity of the posttest was administered to the students in the first lesson of the mathematics applications course, and the second activity of the posttest was administered to the students in the second lesson. The following week, the third activity of the posttest was administered in the first lesson hour, and the opinion form was administered in the second. With the pilot implementation, necessary corrections were made in the parts that were not understood, such as the implementation time of the activities, the suitability and adequacy of the materials used, the difficulties experienced in the implementation, and the language and expression of the problems. Student feedback was collected orally at the end of the pilot implementation, and based on this feedback, the questions' ambiguities were eliminated, and the activities were finalized. Students were asked which parts they found unclear, difficult to understand, or hard to implement, and their suggestions were taken into account during the revision process. In addition, the pilot implementation process gave the researcher experience for the main implementation.

Actual Implementation Process

The study was conducted with seventh grade students who chose the mathematics applications course, which is two hours a week. When the explanations regarding the implementation of the 2018 mathematics applications course curriculum are examined, it is stated that the modeling method is taken as the basis in the mathematics applications course. It was emphasized that activities to solve and establish problems should be included in developing mathematical models. When developing mathematical models, it is recommended to encourage student discussions within and between groups based on realistic and daily life situations and to allow students to develop their models (MoNE, 2018b). For these reasons, the implementation process with mathematical modeling activities in the mathematics applications course was deemed more appropriate.

The primary implementation process was carried out in the first semester of the 2018-2019 academic year. No information was given about modeling before the implementation, but necessary information was given about how the process would work. The personal information form was administered in the first lesson hour of the first week of the implementation. In the 2nd lesson hour, the first activity of the pretest was implemented to the students individually. The second pretest activity was implemented for the students individually in the 1st lesson hour of the second week. The third pretest activity was implemented to the students individually in the 2nd lesson hour, and the pre-implementation procedures were completed.

Before starting the 6-week implementation process, the students were divided into seven heterogeneous groups of four according to their mathematics course grades. It was stated that the implementation process with mathematical modeling activities would be held in the block course for 80 minutes every week, that the groups would be given 40 minutes for the modeling activities, that the groups would present their solutions after the solutions were completed, and that the students will be given detailed information about the process, such as what is expected from the students after the process is completed.

In the mathematics applications course, an 80-minute block every week, students tried to be motivated by asking interesting questions about the activity to be distributed before the activity sheet. For example, before distributing the "teacher's time" activity, students were asked interesting questions such as: "Have you ever thought about how you spent your time in a day?" or "As you enter a new year, have you ever thought about where and how you spent most of your time in the previous year?". Then, an activity sheet was distributed to each group, and an attempt was made to understand what all groups understood in the question by reading the activity through in-class discussions. After understanding the problem, solutions to other sub-questions were started respectively. It was impossible to move on to the next sub-problem until the solution of each sub-problem was completed. All sub-problems were tried to be solved by discussing them within the groups. The ideas and problems that emerged were guided by the researcher in a way that did not directly provide the answer. After completing the solutions to all questions, two groups presented their solutions on the board each week. The process was completed with six different modeling activities over six weeks.

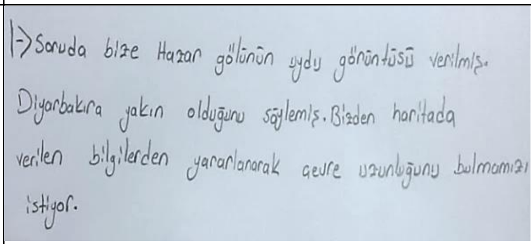
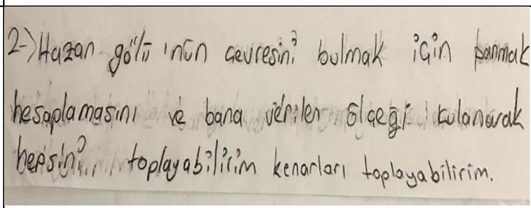
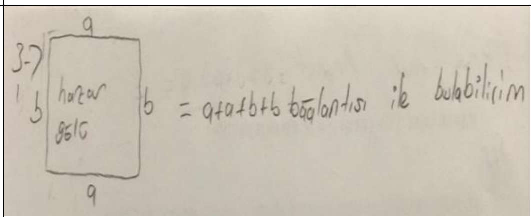
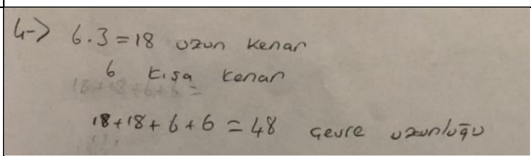
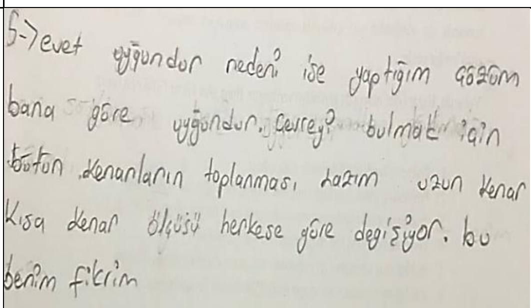
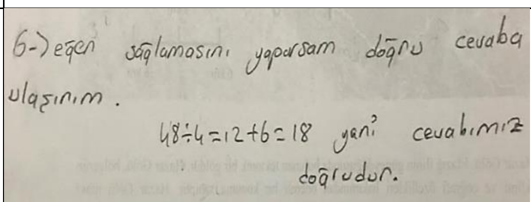
In the first week after the end of the implementation process, the first activity of the posttest was implemented to the students in the first lesson of the mathematics applications course, and the second activity of the posttest was implemented to the students in the second lesson. The following week, the third activity of the posttest was implemented in the first lesson hour, and the opinion form was administered in the second. Thus, the data collection process of the research was completed.

Data Analysis

Quantitative and qualitative analysis methods were used when analyzing the research data.

In the first sub-problem of the research, the Modeling Competencies Evaluation Rubric (Tekin Dede & Bukova Güzel, 2014) was used to determine the scores students received from the pretest and posttest mathematical modeling activities. It is possible to evaluate cognitive modeling competencies quantitatively with an analytical scoring key by examining students' solution papers with the modeling competencies evaluation rubric (Tekin Dede & Bukova Güzel, 2014). The mathematical modeling competencies evaluation rubric consists of 6 dimensions: understanding the problem, simplifying, mathematizing, studying mathematically, interpreting, and verifying. The highest score that can be obtained from the competence of understanding the problem, mathematizing, studying mathematically, and interpreting is four, the highest score that can be obtained from the competence of simplification is three, and the highest score that can be obtained from the competence of verification is six. In this study, the modeling competencies evaluation rubric was rearranged to compare competencies and determine the competencies in which students are successful so that the highest score obtained in all dimensions is 12, and the lowest score is 0. For example, in the simplification stage evaluated at four levels in which Level 1 corresponds to "0 points"; Level 2 corresponds to "4 points"; Level 3 corresponds to "8 points"; Level 4 corresponds to "12 points". Below is the posttest "Lake Hazar" activity sheet of student S24 and the relevant scoring.

Table 2 Quotations and Modeling Competency Levels of S24's Posttest Lake Hazar Activity

Modeling competence	Quotation	Reason	Score/ Competency level
Understanding the problem	 1-> Soruda bize Hazar gölünün uydu görüntüsü verilmiş. Diyarbakıra yakın olduğunu söylemiş. Bizden haritada verilen bilgilerden yararlanarak çevre uzunluğunu bulmamızı istiyor.	It can be said that while scoring the ability to understand the problem, the student used the expression "we will find it by using the information given on the map" and included expressions indicating that the problem was understood and determined what was desired with the given information.	12 points/ Level 5
Simplification	 2-> Hazar gölü'nün çevresini bulmak için parmak hesaplamasını ve bana verilen ölçeği kulanarak hepsini toplayabilirim kenarları toplayabilirim.	The student stated that he benefited from the scale but did not explain how to use the rule of thumb. Therefore, it can be said that he determined the necessary variables and made an acceptable assumption to some extent.	8 points/ Level 3
Mathematizing	 3-> a, b, hazar gölü, a, b = a+a+b+b bağlantısı ile bulabilirim	It can be said that the student compared the shape given in the problem to a rectangle, presented an accurate model suitable for the solution, and explained the model correctly.	12 points/ Level 5
Studying mathematically	 4-> 6.3=18 uzun kenar 6 kısa kenar 18+18+6+6=48 çevre uzunluğu	The student did not specify precisely how he solved the answer he found while solving the model and did not find the answer exactly. It was observed that the mathematical model he created accurately contained deficiencies in its solution.	9 points/ Level 3
Interpretation	 5-> evet uygundur nedeni ise yaptığım çözüm bana göre uygundur. çevreyi bulmak için bütün kenarların toplanması lazım uzun kenar kısa kenar ölçüsü herkese göre değişiyor. bu benim fikrim	The student tried to emphasize mathematically by saying that the edges should be added together and that the length of the short and long sides will vary from person to person. Therefore, it can be said that he interpreted the mathematical solution incompletely in the context of real life.	9 points/ Level 4
Verification	 6-> eğer sağlamasını yaparsam doğru cevaba ulaşırım. 48÷4=12+6=18 yeni cevabımız doğrudur.	He tried to perform mathematical calculations and verify them. While taking the verification approach, he tried to verify only the long side but made mistakes. It has been observed that he does not correct errors in the verification approach	8 points/ Level 5

Before analyzing the quantitative data for the first sub-problem of the research, the Shapiro-Wilks normality test was performed to understand whether the scores were normally distributed. The Shapiro-Wilks test is a test used to find out whether the scores are normally distributed if the group size is less than 50 (Büyüköztürk, 2016). Mathematical modeling pretest-posttest total scores and scores of each sub-stage of mathematical modeling did not show a normal distribution. Therefore, the “Wilcoxon Signed Rank Test” was used in this sub-problem to analyze the relationship between pretest and posttest scores.

In the second sub-problem of the research, students’ activity sheets were analyzed with a qualitative approach (descriptive analysis) to describe the students’ situations during the implementation process with modeling activities. In descriptive analysis, data are described clearly and systematically and presented in an interpreted manner with cause-effect relationships (Çepni, 2010). In this study, students’ written responses were reviewed in relation to each modeling activity and interpreted descriptively without detailed coding or categorization. The aim was to present a holistic picture of students’ approaches, difficulties, and strategies during the modeling process. In descriptive analysis, direct quotations are frequently used in order to strikingly reflect the views of the individuals interviewed or observed (Yıldırım & Şimşek, 2016). This type of analysis aims to convey the findings to the reader in an organized and interpreted way (Yıldırım & Şimşek, 2016).

In addition, the “Modeling Competencies Evaluation Rubric” was used, as in the pretest and posttest, to describe quantitatively the possible development or change in students’ mathematical modeling competencies throughout the implementation process. The quantitative data obtained through the evaluation rubric were interpreted in connection with the students’ written solution papers for the modeling tasks. These qualitative and quantitative data sets were integrated to provide a more comprehensive understanding of students’ performances, and the results were presented descriptively throughout the implementation process.

To ensure the reliability of the scoring process, each activity was evaluated twice by the first author at different times, both before and after the implementation. The comparison of the two scoring rounds revealed an 85% consistency rate. This level of agreement exceeds the 70% threshold recommended by Miles and Huberman (1994) for acceptable reliability. In cases where discrepancies arose, the first and second authors reviewed the scores together and reached a consensus.

Findings

In this section, the findings obtained throughout the implementation process and comments on these findings are given.

Findings Regarding the First Sub-Problem

This section includes findings regarding the first sub-problem of the research, “How are the mathematical modeling competencies of 7th grade middle school students before and after the implementation?”. The students’ pretest and posttest Wilcoxon signed-rank test analysis results are given in Table 3.

Table 3 Wilcoxon Signed Rank Test Results of Pretest and Posttest Mathematical Modeling Scores of the Implementation Process with Mathematical Modeling Activities

Posttest-pretest	n	Mean rank	Sum of ranks	z	p
Negative rank	0	.00	.00	-4.541^{a}	.000
Positive rank	27	28.00	378.00		
Equal	0				

The analysis results show that there is a statistically significant difference between the pretest and posttest scores of the students participating in the research from modeling competencies, $z=-4.541$, $p<.05$. Considering the rank average and total of the difference scores, it is seen that this observed difference is in favor of positive ranks, in other words, the posttest score. This finding shows that the implementation process with mathematical modeling activities significantly affects the development of students’ mathematical modeling competencies.

Pretest and posttest analysis results regarding students’ mathematical modeling sub-competencies are given in Table 4.

Table 4 Wilcoxon Signed-Rank Test Results of Pretest and Posttest Scores Regarding Modeling Competencies

Modelling competencies	Posttest-pretest	n	Mean rank	Sum of ranks	z	p
Understanding the problem	Negative Rank	1	1.50	1.50	-4.430[a]	.000
	Positive Rank	25	13.98	349.50		
	Equal	1				
Simplification	Negative Rank	0	.00	.00	-4.388[a]	.000
	Positive Rank	25	13.00	325.00		
	Equal	2				
Mathematizing	Negative Rank	0	.00	.00	-4.471[a]	.000
	Positive Rank	26	13.50	351.00		
	Equal	1				
Studying mathematically	Negative Rank	0	.00	.00	-4.564[a]	.000
	Positive Rank	26	14.00	378.00		
	Equal	1				
Interpretation	Negative Rank	0	.00	.00	-3.537[a]	.000
	Positive Rank	16	8.50	136.00		
	Equal	11				
Verification	Negative Rank	1	2.50	2.50	-4.314[a]	.000
	Positive Rank	24	13.44	322.50		
	Equal	2				

It is seen that there is a statistically significant difference between the pretest and posttest scores of the students' modeling competencies: Understanding the problem ($z=-4.430$, $p<.05$), simplifying ($z=-4.338$, $p<.05$), Mathematizing ($z=-4.471$, $p<.05$), Studying Mathematically ($z=-4.564$, $p<.05$), Interpretation ($z=-3.537$, $p<.05$), Verification ($z=-4.314$, $p<.05$). Considering the rank average and total of the difference scores, it is seen that this observed difference is in favor of positive ranks, in other words, posttest scores. This finding shows that the implementation process significantly affects the development of all sub-competencies of mathematical modeling in students. The average scores students received from each competency of mathematical modeling are given in the chart below

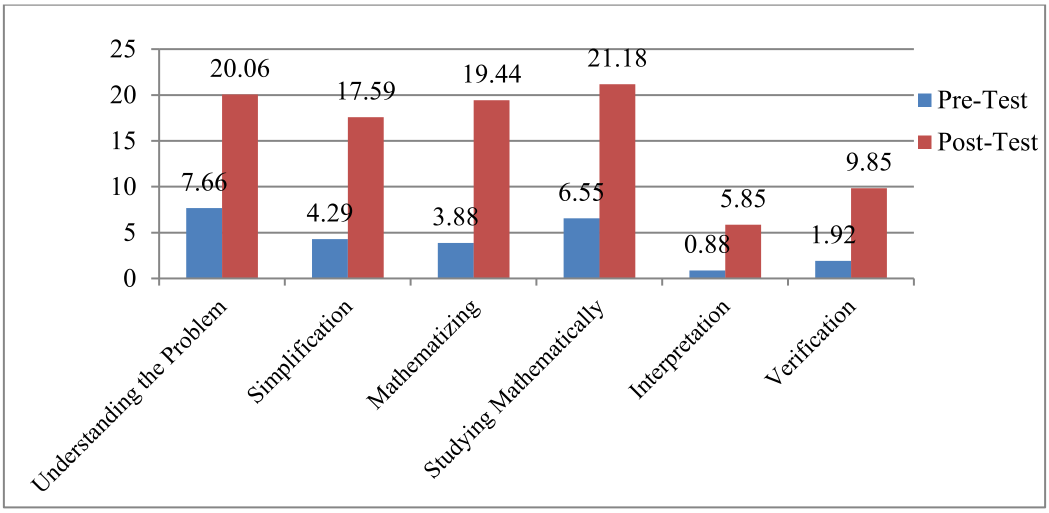
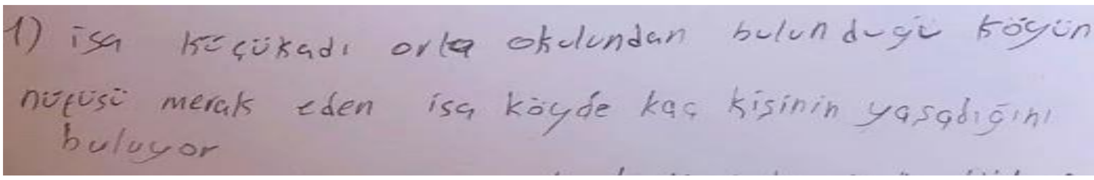


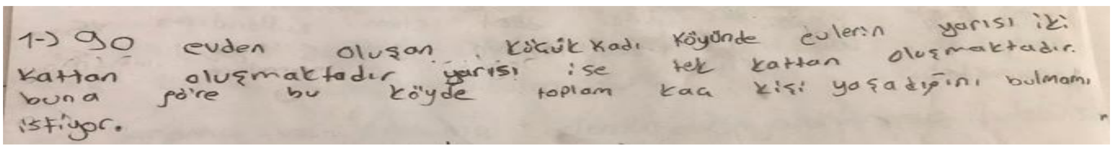
Figure 3 Students' Mathematical Modeling Competencies Pretest and Posttest Average Scores

According to the figure, there was an increase in students' posttest scores in all modeling competencies. In the posttest, the competency in which the students had the highest mean score was "Understanding the Problem", while the competency in which they had the lowest mean score was "Interpretation". The increase in students' scores in all modeling competencies can be interpreted as the implementation process with mathematical modeling activities positively affecting their mathematical modeling competencies.

The students' expressions and related solutions in the activity sheets supported the above quantitative data. Some of the expressions and solutions of the students in the activity sheets are exemplified below in the context of modeling competencies and the relevant order. A section from student S24's solution sheet for the "Population of the Village" activity used in the pretest and posttest regarding competency in understanding the problem is given in Figure 4 as an example.



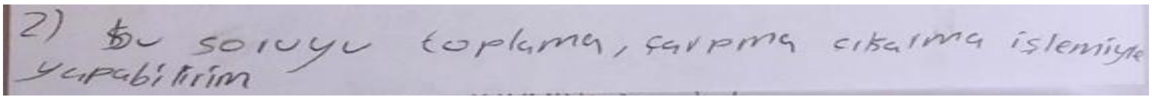
Pretest



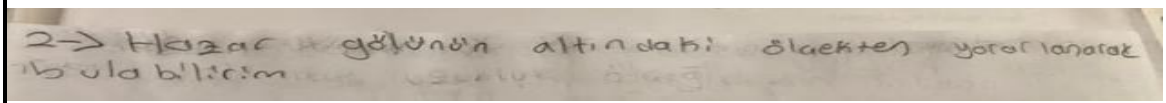
Posttest

Figure 4 A Section from the Pretest-Posttest Village Population Activity on S24's Proficiency in Understanding the Problem

While scoring for the ability to understand the problem, it was determined that S24 was at level 2 in the pretest and was given 6 points. In the posttest, since the expression "half of the houses are two-floor and half are single-floor" was used in the student's answer, it was determined that he was at level 5, and 12 points were given because he understood the problem and determined what was wanted with the given information. Below is a section from the pretest and posttest solution paper of the S19 student in the Surrounding of the Lake Hazar activity regarding simplification proficiency.



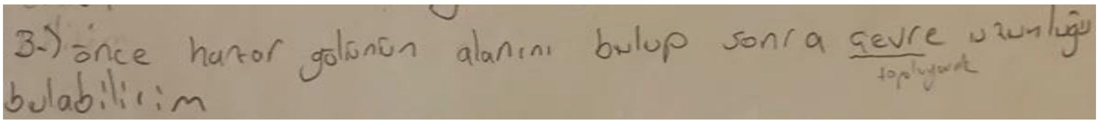
Pretest



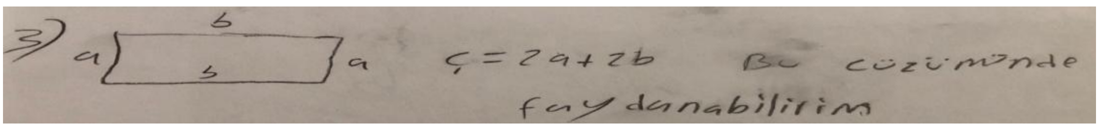
Posttest

Figure 5 A Section from the Lake Hazar Activity Pretest-Posttest Regarding S19 Student's Simplification Proficiency

While scoring for simplification skills, student S19 was seen to be at level 2 because she simplified the problem to some extent with the statement "I will use four operations" in the pretest and was given a score of 4. In the posttest, S19 stated that she would use the scale with the statement "I can use the scale below", but did not fully explain how she would do this. For this reason, since it determined the necessary variables and made acceptable assumptions to some extent, it was determined to be at level 3 in the evaluation rubric and was given 8 points. Below is a section from the pretest and posttest solution paper of S2 in the Surrounding of the Lake Hazar activity regarding mathematization proficiency.



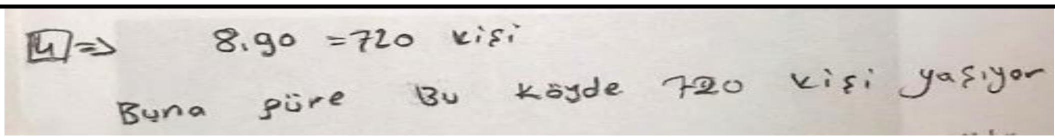
Pretest



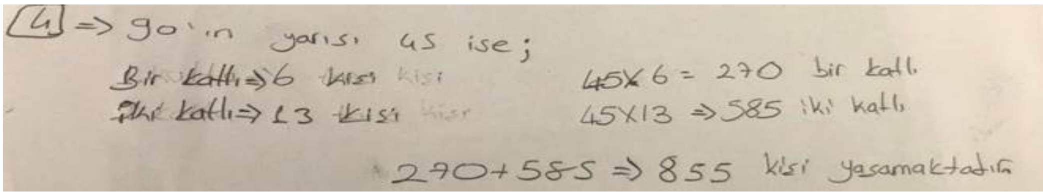
Posttest

Figure 6 A Section from the Pretest-Posttest Hazar Lake Activity on S2 Student's Mathematization Proficiency

Student S2 was determined to be at level 1 because she did not create a mathematical model in the pretest with the statement "I will find the area of the Hazar Lake and add the perimeter" and was given 0 points. The posttest determined that he was at level 5 in the evaluation rubric and was given 12 total points because he compared the shape given in the problem to a rectangle, presented an accurate model suitable for the solution, and explained the model correctly. A section from the solution sheet of the S6 student in the "Population of the Village" activity regarding Competency in Studying Mathematics and the solution scoring are given below.



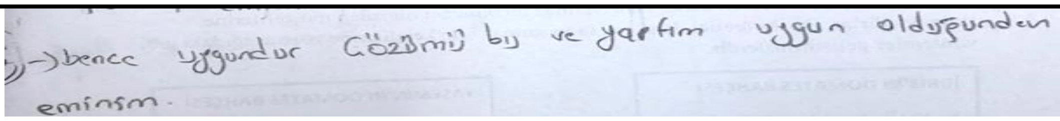
Pretest



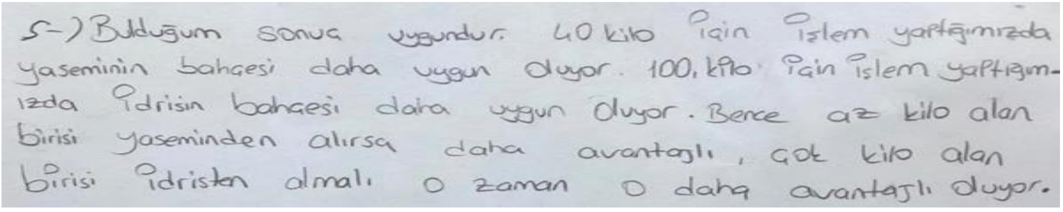
Posttest

Figure 7 A Section from the Pretest-Posttest Village Population Activity on S6 Student's Proficiency in Studying Mathematically

In the pretest, the student S6, while solving the mathematical model, did a multiplication operation and stated that there were 720 people. Since he solved it incorrectly and incompletely, he was determined to be at level 2 and was given 3 points. In the posttest, he did a mathematical operation while solving the model and found the answer as 855, but he did not state exactly how he solved the answer he found and did not find the answer exactly. It was observed that the mathematical model he created accurately contained deficiencies in its solution. For this reason, the evaluation rubric was determined to be at level 4, and 9 points were given. A section from student S1's solution paper in the Tomato Garden activity regarding interpretation proficiency is below.



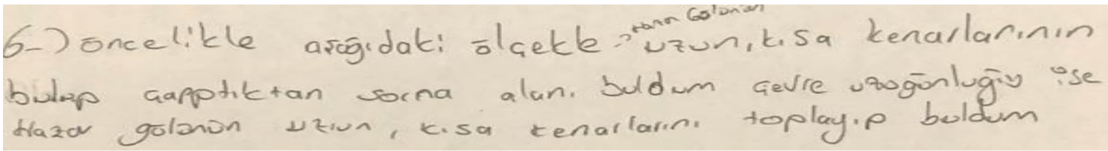
Pretest



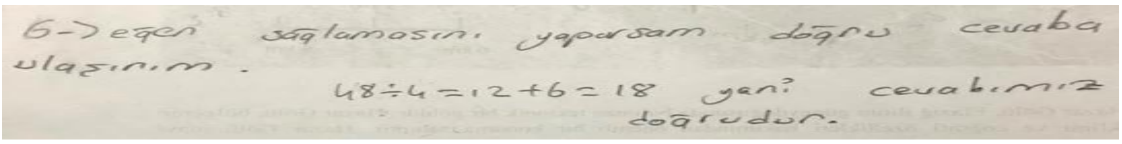
Posttest

Figure 8 A Section from the Tomato Garden Activity Pretest-Posttest Regarding S1's Interpretation Competence

For the interpretation stage, it was determined that student S1 was at level 2 because he partially made the mathematical interpretation in the pretest. In the posttest, she tried to emphasize mathematics by saying that "the sides should be added together, the length of the short and long sides will vary from person to person". Therefore, it was accepted that it was at level 4 because he interpreted the mathematical solution incompletely in the context of real life. A section from student S25's solution paper regarding verification proficiency in the Surrounding of the Lake Hazar activity is given.



Pretest



Posttest

Figure 9 Pretest-Posttest Regarding S25's Verification Competency A Section from the Hazar Lake Activity

In the verification step, it was determined that student S25 tried to make a verbal verification with the statement "I found the long and short sides of the lake by adding them together" in the pretest, but it was at Level 2 because it contained errors. In the posttest, he said that he would verify it and tried to make a mathematical calculation and to do so. While taking the verification approach, he tried to verify only the long edge. He was determined at level 5 because he did not correct errors in the verification approach.

Findings Regarding the Second Sub-Problem

In this sub-problem, it was tried to reveal how the groups developed during the process. Figure 10 shows the groups' average scores regarding their ability to understand the problem.

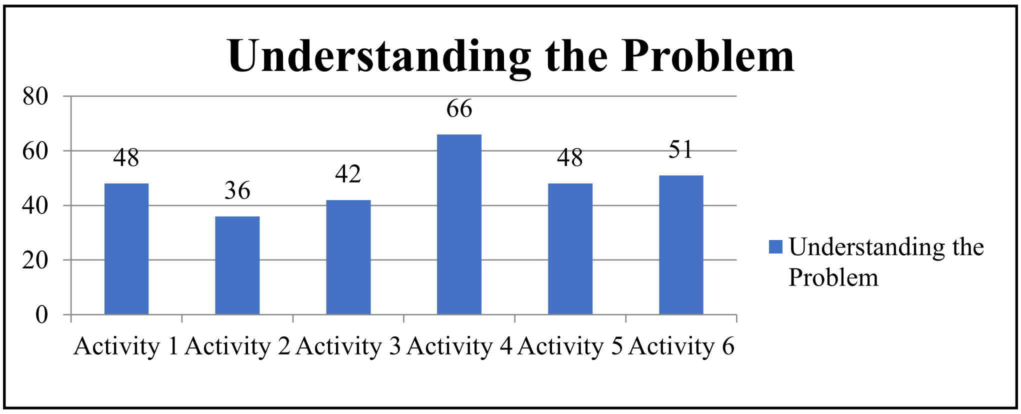


Figure 10 Average Scores of the Groups Regarding the Adequacy of Understanding the Problem

The figure shows that the average problem-understanding scores of the activities are high. It can be said that the average scores in this competency are close to each other, except for the fourth activity. This situation can be interpreted as students not having difficulty in understanding the problem. Below is the solution sheet for the 7th group's ability to understand the problem in the Which Seed Should We Plant activity.

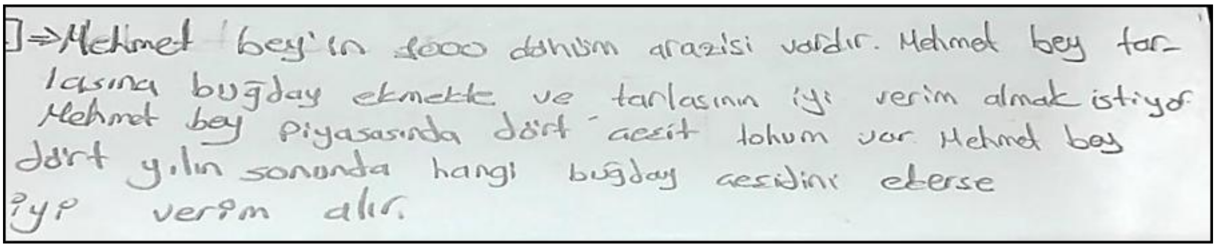


Figure 11 An Excerpt from the Seventh Group's Opinions on the Adequacy of Which Seed Should We Plant Activity in Understanding the Problem

The students in this group expressed the problem in their own words by saying, "There are four types of seeds and whichever seed is planted will yield the best yield at the end of four years". It was determined that they were at level 4 in their ability to understand the problem because they determined what was given and wanted in the problem. This finding is essential for developing students' ability to understand the problem. Figure 12 shows the average scores of the groups regarding simplification competence.

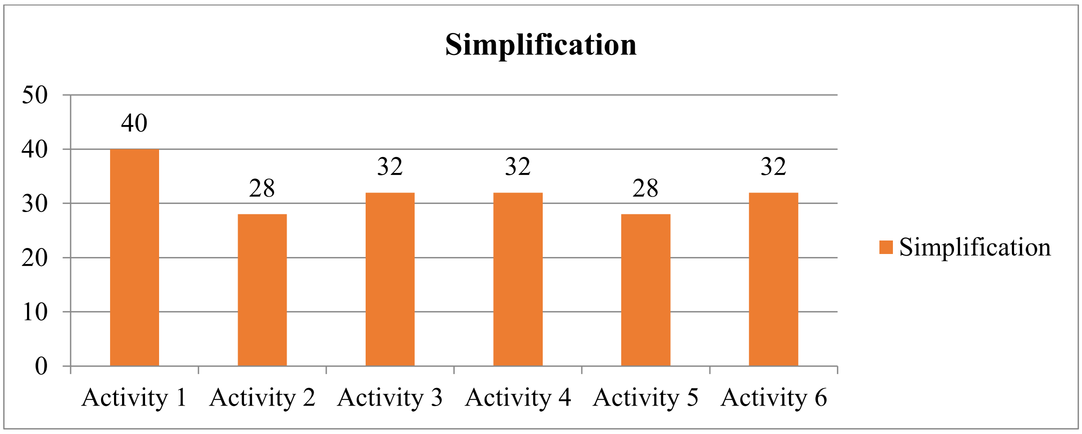


Figure 12 Average Scores of the Groups Regarding Simplification Competency

The students' average scores regarding simplification competence are given in the figure above. It is seen that students' scores in this competency are lower than the problem understanding competency. It can be seen that the highest score in this competency belongs to activity 1. The difference in the scores in the activities can be explained by the difficulty levels of the activities and the student's psychological state while performing the activity. Below is the solution sheet for the simplification competence of group 7.

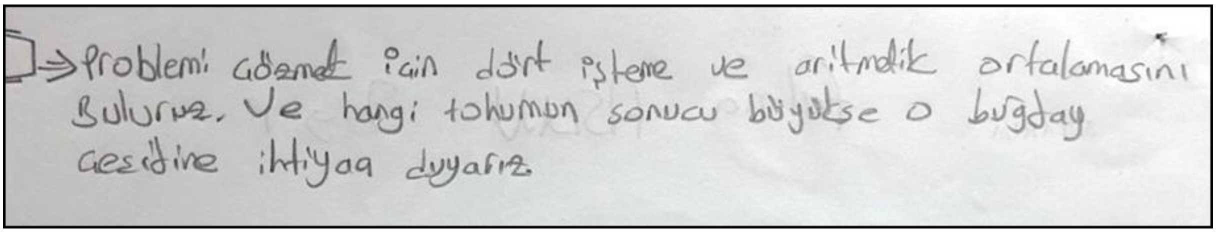


Figure 13 An Excerpt from the opinions of the Seventh Group on the Adequacy of Simplification of Which Seed Should We Plant Activity

It is seen that the students in this group are at level 4 because they determined the necessary and unnecessary variables and made realistic assumptions with the statement "we need four operations and the arithmetic mean" in the Simplification step. In this competence, students must emphasize the arithmetic mean and the four operations. This shows that the students have a high level of simplification competence. Figure 14 shows the average scores of the groups regarding Mathematization competence.

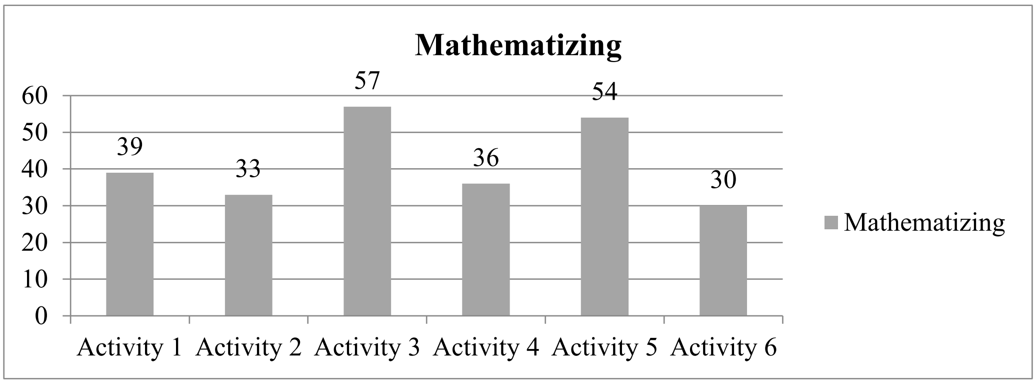


Figure 14 Mean Scores of the Groups on Mathematization Competence

As seen in the figure, it can be seen that the average scores of the activities are generally high. It is seen that the third and fifth activity scores are high in this competence. The reason why other activities are low can be explained by the fact that students have difficulty in these activities. Below is the solution sheet for the Mathematization competency in the Which Seed Should We Plant activity of the seventh group.

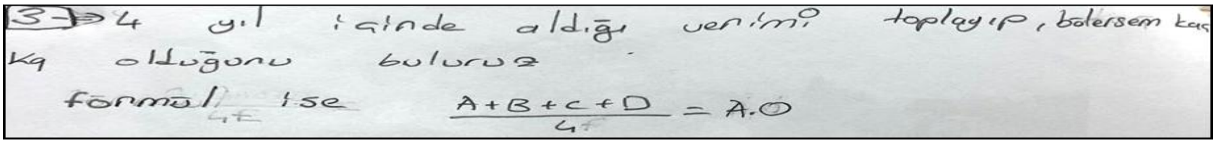


Figure 15 An Excerpt from the views of the Seventh Group on the Mathematization Competence of the Which Seed Should We Plant Activity

The students in this group correctly created and explained the average formula, which is the necessary mathematical model, in the mathematization step with the statement "If we add the yield in 4 years and divide by 4". It was determined that they were at level 5 in the evaluation rubric because they correctly constituted the necessary mathematical model. This situation reveals that the students' Mathematization competencies are high. Figure 16 shows the groups' average scores regarding competency in Studying Mathematically.

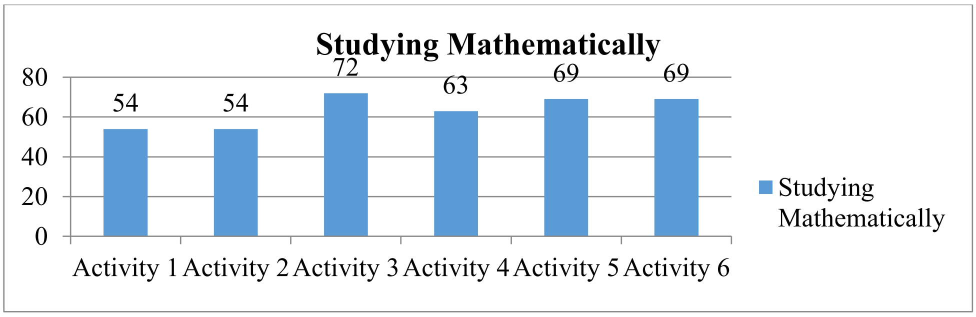


Figure 16 Average Scores of the Groups Regarding Mathematical Studying Proficiency

Considering Figure 15, it can be seen that the average scores in the activities are high. It can be said that the average scores in the activities are close to each other. Students focus on solutions to routine problems. The groups' high scores in this competence can be interpreted as their familiarity with this situation.

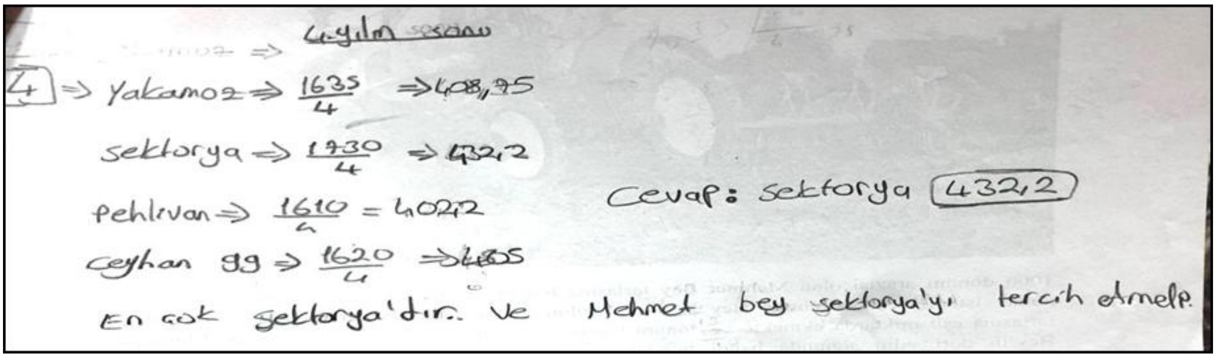


Figure 17 An Excerpt from the views of the Seventh Group on the Competence of Studying Mathematically in the Which Seed Should We Plant Activity

It is seen that the students in the group made solutions using the average relation according to the mathematical model they constituted correctly. According to the evaluation rubric, the students in this group are at level 5. This situation is essential regarding the students' status in this proficiency. Figure 18 shows the average scores of the groups regarding Interpretation competence.

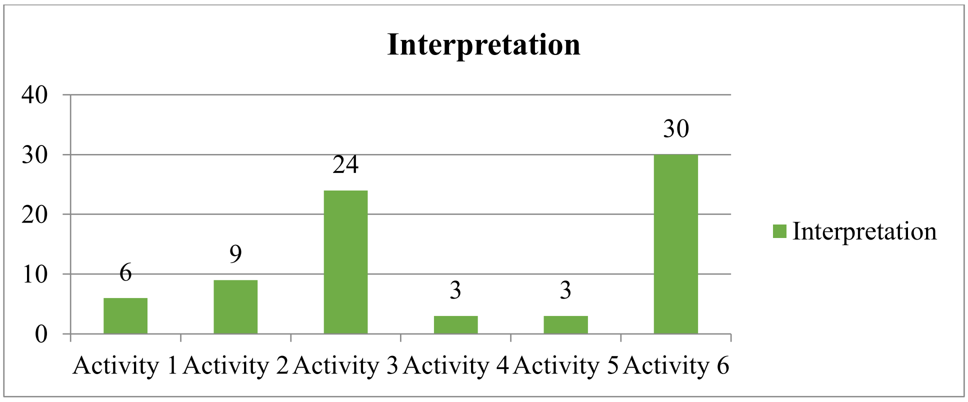


Figure 18 Average Scores of the Groups Regarding Interpretation Competence

Considering the activity scores in Figure 18, it can be seen that the scores are low. It can be seen that the activities with the highest scores in this competence are the third and sixth activities. This situation shows that students have difficulty in this competence. Students' difficulty in this competence can be interpreted as not being used to this situation. In addition, the scores in the two activities are higher than the other activities, which can be explained by the fact that the other two activities are related to their close environment.

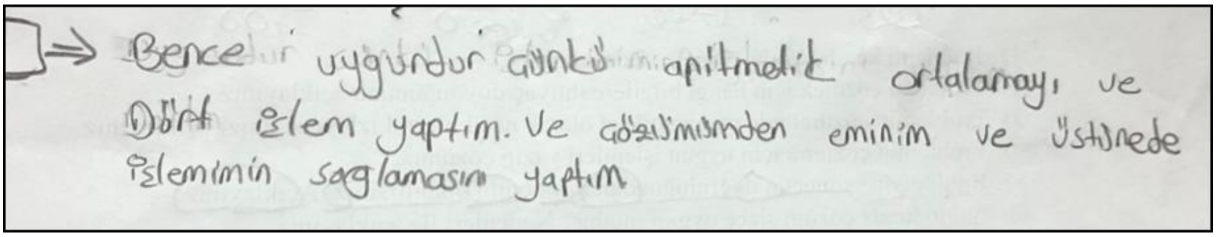


Figure 19 An Excerpt from the Joint Views of the Seventh Group on the Adequacy of Interpretation of Which Seed Should We Plant Activity

When the solution paper of the seventh group regarding interpretation competence was examined, it was seen that the students could not interpret in the context of daily life with the statement "We are sure that we did the average and the four operations". In this case, it was determined that the students were at level 1 in interpretation competence. This situation shows that students have difficulty in this competence. Figure 20 shows the average scores of the groups regarding Verification competence.

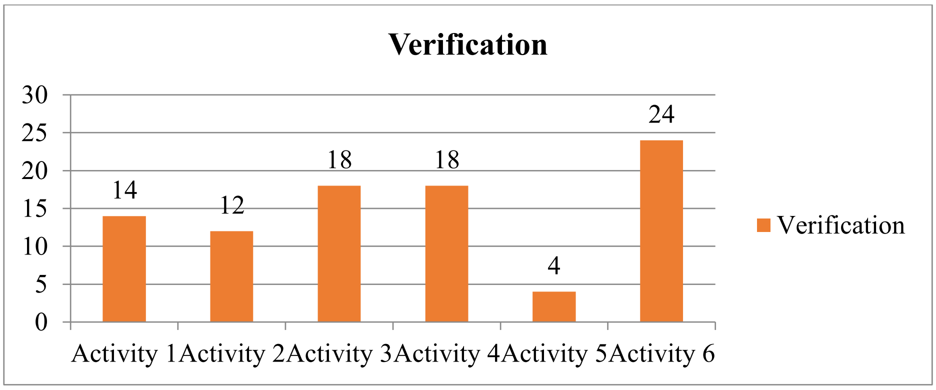


Figure 20 Average Scores of the Groups Regarding Verification Adequacy

Considering the verification competence scores, it was seen that the activity scores are at a low level. The score in the fifth activity was determined to be lower than the other activities. This situation can be explained by students having difficulty in this activity. Students' low scores can also be interpreted as unfamiliarity with this competency.

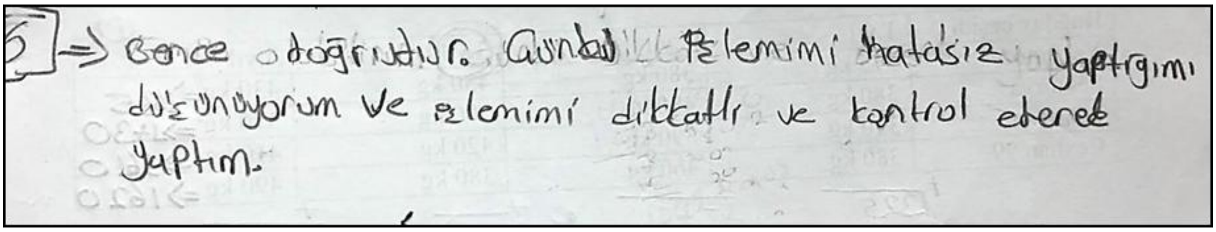


Figure 21 An Excerpt from the joint views of the Seventh Group on Which Seed Should We Plant Activity Verification Adequacy

When we look at the solution paper for the verification step of the seventh group, we see that they did not take a verification approach with the return of "We did the operation without any errors". This shows that they are at level 1 in the evaluation rubric. The data of this group in the solution sheet and the data in the graph are parallel.

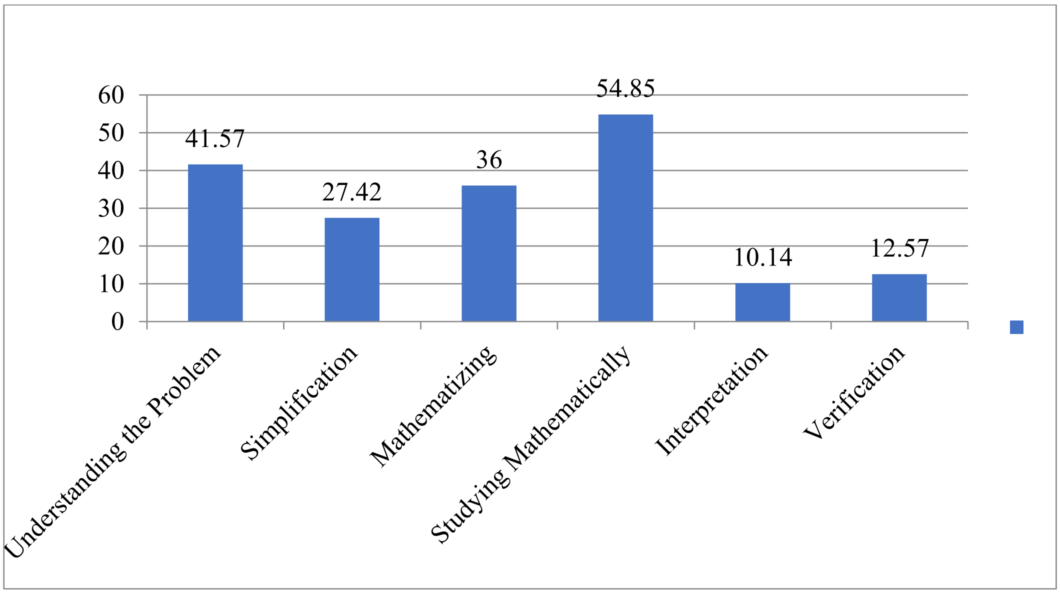


Figure 22 Average scores of the groups for all competencies

While the stage in which the students had the highest mean score was "Studying Mathematically", the stage in which they had the lowest mean score was "Interpretation". The average scores obtained by the students during the process and those received by the students in the posttest are similar. Students' opinions about their difficulties while solving the activities are summarized in Table 5 below.

Table 5 Student Opinions on the Difficulties Encountered While Solving the Activities

Category	Opinions	Students	f
Difficulty situations	I had a hard time in general	S2, S3, S5, S9, S11, S13, S19, S21, S23, S26	11
	I had a hard time understanding the problem	S6, S16, S27	3
	I had a hard time finding a solution	S4, S15, S16,	3
	I had difficulty interpreting	S1, S12, S14, S18, S20, S24, S25	6
	I was not forced	S7, S8, S10, S22	4
	Total		27

As seen in Table 5, after the implementation, it was observed that the student's opinions on the question "What difficulties did you encounter while solving the activities" were mostly "I Had Difficulty in General" and secondly "I Had Difficulty in Interpreting". Some student opinions according to the category in the table are given below.

S5: I had a hard time and put in a lot of effort while solving these activities.

S9: I already have difficulty in mathematics and also had difficulty while solving these activities.

S6: The difficulty I encounter while solving these activities is that I do not understand the problem well.

S27: Sometimes, I did not understand the question when I read it.

S4: I had difficulty analyzing these activities.

S15: I had the most difficulty solving these activities' operations.

S12: While solving these activities, I had the most difficulty in the comments section because I could not express my thoughts much.

S14: I had difficulty making interpretations and could not add any comments.

After the implementation, opinions were received from the students about the implementation process. Most students stated that they had difficulty in all steps of the activities, some had difficulty understanding the problems, and some stated that they had difficulty in the interpretation and verification stages. It can be said that the difficulties students face in activities have changed. After the implementation process, the results of the content analysis of the opinion form regarding the difference between mathematical modeling activities and mathematical problems encountered in the lessons are given in Table 6.

Table 6 Student Opinions on the Difference Between Modeling Activities and Traditional Mathematics Problems

Opinions	Students	f
There is a difference in revealing our thoughts	S1, S2, S5, S6, S8, S9, S12, S13, S14, S16, S18, S20, S24, S25, S27	15
No difference	S3, S4, S7, S10, S11, S15, S17, S19, S21, S22, S23, S26	12
Total		27

As seen in Table 6, after the implementation, it was observed that the students' opinions regarding whether there was a difference between these activities and the mathematical problems they encountered in the lessons were mostly "There is a difference". Some student opinions according to the category in the table are given below.

S5: The difference between these activities is that they want to know how much we use our minds and how much we think.

S6: I think everyone's answers differ in the implementations we make differently. Everyone has their thoughts and hypotheses.

S12: I think there is a difference. In these activities, we put our thoughts on paper because they relate to daily life, whereas in regular lessons, we only need information for the questions.

S11: I think there is no difference because we answer mathematics questions and do the same in the activities.

S23: I think there is no difference because whatever we study in mathematics class, we encounter in these activities.

After the implementation, students' opinions were received regarding the difference between the activities and routine mathematics problems. While some students stated that they revealed their thoughts that there was a difference between them, others stated that there was no difference. It can be said that these activities impact revealing some students' thoughts.

Discussion and Conclusion

In this part of the research, the findings were discussed in the light of the relevant literature considering the sub-problems of the research.

According to the findings obtained from the pretest in the research, the students had low levels of all modeling competencies (understanding the problem, simplifying, mathematizing, working mathematically, interpreting, and verifying). In his study conducted with secondary school students, Kılıç (2020) reported that students demonstrated limited competencies in mathematical modeling prior to the implementation. He attributed this to the fact that mathematical modeling is not sufficiently embedded in the structure and practice of the mathematics curriculum. Similarly, Tekin Dede and Yılmaz (2015) examined the cognitive modeling competencies of sixth grade students in the study and concluded that modeling competencies were mainly at a low level. Students' modeling skills were low before the implementation could be interpreted as the students encountering modeling activities for the first time. They were unfamiliar with these activities and did not have sufficient experience with them.

As a result of the analysis, it was concluded that the teaching process with mathematical modeling activities provided a significant increase in students' mathematical modeling competency scores. In a similar study, Tekin Dede and Yılmaz (2015) applied twelve action plans in their study on the development of modeling skills of 6th grade students. As a result of the study, it was stated that the student's cognitive modeling skills showed a statistically significant difference, and the students had the most difficulty in the interpretation stage. Similar to this study, Özgen and Şeker (2020) determined that at the end of the implementation process with modeling activities in the experimental and control group study, they constituted with the participation of 6th grade students, the modeling competencies of the students in the experimental group were better than the modeling competencies of the students in the control group. In his study, Maaß (2006) concluded that students showed positive development in mathematical modeling activities, low-level students also participated in the process, and students could enter the modeling process individually even if they did not demonstrate all of the sub-modeling competencies. As a result of another study conducted by Maaß (2005) stated that 8th grade students could improve their modeling competencies through modeling applications, and modeling could be taught at the middle school level. In their study examining the relationship between 7th grade students' modeling and reading comprehension skills, Alkan and Aydın (2021) stated that their modeling competencies improved after the 8-week implementation period. When the studies are examined, it is seen that teaching processes with mathematical modeling activities improve modeling competencies. This can be interpreted as an appropriate teaching process improving modeling competencies.

Although students showed improvement in all mathematical modeling competencies in this study, when the literature was examined, it was stated that students had difficulty improving particularly in interpreting and verifying competencies in some studies (Didiş Kabar & İnan, 2018; Kılıç, 2020; Şahin & Eraslan, 2016; Tekin Dede & Yılmaz, 2015). In this study, opinions were taken from the students after the implementation. Most students stated that mathematical modeling activities differed from routine problems and that mathematical modeling activities revealed their thoughts differently from routine problems. In addition, most students stated that they had difficulty in all stages, while most stated difficulty interpreting competence. Considering that the most difficult competencies in the modeling process were interpretation and verification competencies (Blum & Borromeo Ferri, 2009; Tekin Dede & Yılmaz, 2013), results consistent with this finding were obtained in the study. Most of the students could not analyze the mathematical results they obtained and interpret them completely in a real-life situation. This result of the study is similar to many studies in the literature that concluded that students had difficulties in interpreting and verifying the mathematical operations and results they performed in the modeling process (Alkan & Aydın, 2021; Blum & Borromeo Ferri, 2009; Kaya & Keşan, 2022; Sarı Uzun et al., 2023; Şahin & Eraslan, 2016). The opinions expressed by the students support the statistical data. Şahin and Eraslan (2016), in their study where they tried to reveal the modeling processes of 4th grade primary school students, stated that the students had difficulty in competencies for understanding and interpreting the problem. He stated that this difficulty stems from students' limited experience in such activities inside and outside the school. Likewise, Hıdıroğlu et al. (2014), in their study examining secondary school students' solution approaches to the comet problem, stated that as the modeling process progressed, the performance of the students decreased and that the students could not find any approach in the verification stage. This situation is attributed to students who focus on the result tend to stop interpreting and verifying the problem and their actions as soon as they find the mathematical result, so they do not show much progress in the last two stages. In their study with middle school students, Şahin and Eraslan (2017) stated that students generally accepted the accuracy of the solutions of modeling activities without commenting or verifying them. Sarı Uzun et al. (2023) stated in their study with 5th grade middle school students that almost all of the students could not approach the verification and interpretation step. They emphasized that this caused the students to have difficulty in verification and interpretation competence by generally sticking to a single result and performing a procedural problem solution. Considering the conducted studies, it is seen that students generally have difficulties in interpretation and verification competencies. It can be said that the students' difficulties in some of the modeling competencies are due to reasons such as not having knowledge about modeling activities before, being accustomed to the multiple-choice exam system, and teachers not attaching importance to the verification and interpretation stages when solving routine problems in the classroom environment.

In the second sub-problem of the research, the students' situations were examined in modeling activities throughout the implementation process. As a result of the analysis, it was seen that the students' modeling competencies were generally in good condition throughout the process. It was observed that the students were better at understanding the problem, simplifying, mathematizing, and studying mathematically than interpreting and verifying competencies. When the literature was examined, Kılıç (2020) found in his study with middle school students that there was a significant difference in favor of the posttest between the pretest and posttest comprehension, simplification, mathematization, mathematical working, and interpretation competencies of the experimental group However, he stated that there was no significant difference between verification competencies. It was emphasized that this may be because students are not asked to interpret the problem solutions in the context of daily life and are not asked to verify as in the verification stage, which is one of the modeling competencies. In their study with middle school students, Alkan and Aydın (2021) stated that the stage where the students' development was the least was the interpretation stage. Tekin Dede (2017), in his study with middle school students at different grade levels, found that all competencies except verification and modeling competencies increased as the grade level increased. In another study, İnan Tutkun and Didiş Kabar (2018) emphasized in their case study with middle school students that after reaching the desired solution during the modeling process, the students did not interpret the mathematical results in the context of real life and did not check the accuracy of the results. They stated that this might be due to their students' habits of result-oriented problem-solving in the solution process of traditional verbal problems in mathematics classes and that the students participating in the study had their first experience with a modeling problem. When the process is examined, in parallel with the studies conducted, it is seen that in this study, students' modeling competencies decreased at the verification and interpretation stage, as in the last test. It was determined that the modeling competencies were not regular from the first activity to the last activity. In addition, it was observed that students' modeling competencies were better in some activities, and in others, their modeling competencies were not as good as in others. It can be said that the reason for this is that the difficulty levels of the activities are different based on the informal observations of the researcher. In addition, based on observations, it can be interpreted that activities related to students' immediate environment attract their attention more. Therefore, they have less difficulty in the activities. In this context, it can be said that it is essential to constitute environments where students can establish relationships with mathematics and daily life and to design mathematical modeling problems to attract students' attention as much as possible.

Suggestions

The following implications were made in the context of the results of the research:

This study showed that teaching with mathematical modeling activities generally improved the mathematical modeling competencies of 7th grade students. Therefore, mathematical modeling activities can be developed. The development of modeling competencies of students at different grade levels can be examined, and a contribution to the literature can be made.

As a result of this study, when examining modeling competencies, it was determined that students showed low levels of development in the "interpretation" and "verification" stages. When the literature is examined, it is possible to encounter similar results. In this context, qualitative studies can be conducted to investigate the reasons for this in depth.

The findings of this study were conducted with students studying in a class at a public middle school in a rural area. Future studies can examine the modeling processes of students studying in various regions of Türkiye with different socio-cultural characteristics.

It is thought that it is essential to create environments where students can establish relationships with mathematics and to design mathematical modeling problems in these environments to attract students' attention as much as possible.

Compliance with Ethical Standards

Disclosure of potential conflicts of interest

The authors declare that they have no competing interests

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CRediT author statement

First author: research design, analysis, methodology, data collection, resources, discussion, conclusion, writing-original draft, writing - review & editing. The second author: methodology, writing -original draft, writing - review & editing, resources, discussion, conclusion, supervision.

Research involving Human Participants and/or Animals

The study involves human participants. Ethics committee permission was obtained from Dicle University, Social and Human Sciences Ethics Committee.

Matematiksel Modelleme Etkinlikleri ile Tasarlanan Öğretim Sürecinde Ortaokul Öğrencilerinin Matematiksel Modelleme Yeterliklerindeki Değişimin İncelenmesi

Özet:

Bu çalışmanın amacı, matematiksel modelleme etkinlikleri ile tasarlanan öğretim sürecinin ortaokul yedinci sınıf öğrencilerinin matematiksel modelleme yeterliklerini nasıl etkilediğini belirlemektir. Araştırmada karma yöntem araştırma desenlerinden iç içe (gömülü) desen benimsenmiştir. Araştırmanın çalışma grubu bir devlet okulunun ortaokul yedinci sınıf düzeyinde öğrenim gören 27 öğrenciden oluşmaktadır. Katılımcılar, amaçlı örnekleme yöntemlerinden kolay ulaşılabilir durum örnekleme yöntemiyle oluşturulmuştur. 10 hafta süren uygulama sürecinde veri toplama aracı olarak araştırmacı tarafından geliştirilen ve açık uçlu sorulardan oluşan görüş formu ile dokuz matematiksel modelleme etkinliği kullanılmıştır. Bu etkinliklerden üçü ön test ve son testte kullanılmış, geri kalan altı etkinlik ise, uygulama sürecinde kullanılmıştır. Nicel veriler analiz edilirken, Wilcoxon işaretli sıralar testi kullanılmıştır. Nitel verilerin analizinde ise betimsel analiz kullanılmıştır. Elde edilen sonuçlara göre, uygulama süreci boyunca öğrenciler en çok problemi anlama ve matematiksel olarak çalışma basamağında gelişim gösterirken, en az gelişimi yorumlama ve doğrulama basamağında göstermişlerdir. Öğrencilerin matematik ile ilişki kurabileceği ortamların yaratılması ve bu ortamlarda matematiksel modelleme problemlerinin mümkün olduğunca öğrencilerin dikkatini çekecek şekilde tasarlanmasının önemli olduğu düşünülmektedir.

Anahtar kelimeler: Modelleme yeterlikleri, matematiksel modelleme, ortaokul öğrencileri.

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Research Article

The Relationship Between High School Students' Perceived Self-Regulation Skills and Mobile Technology Acceptance Levels in Mathematics Learning*

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Abstract – With the widespread use of mobile technology in education, individual learning came to the fore, which required the student to organize his/her work in the best way, that is, to develop self-regulation skills. This study examined the relationship between high school students' perceived self-regulation skills and mobile technology acceptance levels in mathematics learning. In addition, the study also examined students' self-regulation skills and mobile technology acceptance levels in mathematics learning in terms of gender, grade level and academic achievement averages. The research included students studying at a high school determined by the appropriate sampling method and evaluated the data of 752 students. The study used Student Information Form, Perceived Self-Regulation Scale and Mobile Technology Acceptance Scale in Mathematics Learning as data collection tools. The study also employed descriptive and relational screening methods. According to the research, a low positive correlation existed between high school students' perceived self-regulation skills and their mobile technology acceptance levels for learning mathematics. In addition, the perceived self-regulation skills of the students were above the average; and their mobile technology acceptance levels in learning mathematics were close to the average.

Keywords: High school students, mathematics, mobile learning, mobile technology acceptance, self-regulation.

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* This paper is formed in line with the first author's thesis titled " The Relationship Between High School Students' Perceived Self-Regulation Skills and Mobile Technology Acceptance Levels in Mathematics Learning"

Introduction

While some students are more willing to learn and grasp, subjects easily in educational environments, others have difficulty understanding and studying. These students usually have low motivation for the lesson. At the beginning of the twentieth century, individual educational differences began to gain importance, and metacognition and social cognition perspectives emerged (Aydın & Atalay, 2015). While metacognition is the awareness of the individual's thoughts, in social cognition, students focus on social factors that affect their self-regulation (Zimmerman, 2002). Self-regulated learning is the process in which the individual is cognitively motivating and behaviorally effective in line with his/her learning objectives (Zimmerman, 1986). Self-regulated learners are motivated to learn, trust their ability, know their strengths and weaknesses, and can use resources to help their learning process (Smith, 2001).

The literature includes different models of self-regulated learning developed by Boekaerts (1999) and Zimmerman (2000). For example, Boekaerts (1999) treats self-regulation as a process of different layers. Zimmerman (2000), on the other hand, explains the functional aspect and different stages of self-regulation. Self-regulated learning strategies created by Zimmerman and Pintrich are based on Bandura's social cognitive theory (Pustinen & Pulkkinen, 2001). Depending on this theory, personal, environmental, and behavioural factors influence self-regulated learning. The personal regulation model developed by Zimmerman (2000), which indicates the process that allows the regulation of personal feelings and thoughts, is one of the most commonly used models.

Self-regulation can be improved through some educational activities. According to Aydın and Atalay (2015), self-regulation increases with some factors, such as enabling questioning, increasing problem-solving and critical thinking skills, cooperative learning, supporting the use of technology, creating strategies for students to create mental models, and student and teacher beliefs. The use of technology, one of these factors, use of internet-based technology in particular. Thanks to the mobile devices that emerge with the developing technology, information is accessed at the desired place and time. The fact that mobile technologies are smaller, portable, accessible and personal has made such access possible. Mobile technologies' portability and wireless connectivity support students' access to and interaction with information at any time (Demir & Akpınar, 2016).

Mobile devices included mobile phones, smartphones, laptops, tablets, mobile (handheld) computers, personal digital assistants (PDA), portable media players (mp3, mp4, CD, DVD player, audio recorder, camera, etc.), e-book readers, wearable technologies (Su, 2015). The use of mobile devices in all areas of life, such as communication, learning and entertainment, is gradually increasing. However, besides the fact that students find mobile learning interesting, it has many shortcomings, such as small screen size, limited memory capacity and battery life. Also, the weaknesses of mobile learning include high cost, motivation and control difficulties of the student in the learning process, and perhaps most importantly, the acceptance of mobile technology by the student (Diri, 2021; Şener, 2016). Individuals must adopt and accept technology to use it effectively in the learning and teaching process and to develop themselves (Ursavaş et al., 2014). If an individual has a negative attitude toward accepting and using new technological systems, the expected efficiency of that system decreases. In addition, examining personal self-regulated learning skills related to the acceptance of mobile learning technology is very important for preparing educational content suitable for mobile technologies.

While mobile technology in education has become widespread in many disciplines, it also comes to the fore in learning mathematics, which is generally difficult for students to understand. In mathematics learning, the student is expected to understand abstract mathematical concepts and their relationships and use them when solving problems. The use of technology in mathematics education has positive effects on student achievement compared to traditional methods (Cheung & Slavin, 2013). Mobile technologies and applications provide new opportunities to increase students' participation in mathematics and improve their mathematical thinking. Thanks to technology in mathematics education, learning mathematics has exceeded classroom limits with the opportunity to access the internet (Borba et al., 2016). Mobile technologies contribute to students' modelling of concepts and problem-solving processes in mathematics and geometry course achievements. Thanks to the motion sensors that mobile devices have depending on their hardware and software features, users can be drawn into their use, and students can participate effectively in the lesson (Karaarslan et al., 2013). Besides, mobile technology has other benefits such as being easily transferred to different learning conditions and suitable for student cooperation (Larken & Calder, 2016). Although mobile technologies offer the opportunity to learn anytime and anywhere through wireless internet, it is possible to successfully use mobile technology systems in mathematics with students' mobile technology acceptance in mathematics learning. This study examined high school students' mobile technology acceptance level in mathematics education since there are few studies about this issue in the literature.

The study has developed many models to determine the factors affecting the acceptance and use of technology. The Technology Acceptance Model (TAC) developed by Davis (1989) is the most effective and widely used model to explain individuals' acceptance of information technology systems. Nevertheless, explaining the acceptance of information systems is also weak and complex (Šumak & Sorgo, 2016). Venkatesh et al. (2003) developed the Unified Theory of Acceptance and Use of Technology (UTAUT) by considering the conceptual and experimental similarities between eight theories in this field to examine the information technology acceptance behaviours of individuals and to explain technology acceptance completely. Models reviewed by Venkatesh et al. (2003) are as follows: Theory of Reasoned Action, Theory of Planned Behavior, Combined Theory of Planned Behaviours (TPB) and Technology Acceptance Model (TAM), The Model of PC Utilization, The Motivational Model, The Social Cognitive Theory, The Innovation Diffusion Theory, Technology Acceptance Model. Among these models, the principles on which Bandura's social cognitive theory is based include self-regulation capacity (Baysal, 2010). Self-regulation is one of the basic principles in social cognitive theory, one of the theories on which UTAUT is based. Therefore, self-regulation and UTAUT are theoretically related.

In their study, Venkatesh et al. (2003) explained the technology acceptance behaviours of individuals between 17% and 53% in the examination of each model, and UTAUT was solely 70%. In this respect, when investigating the technology acceptance levels of individuals, the use of UTAUT provides an advantage in explaining the behaviours ofindividuals. Behavioural intention determines the technology use behaviours of individuals in UTAUT (Thomas et al., 2013). While four of the eight variables in the UTAUT directly or indirectly affect behavioural intention and behaviour, the other four direct the relationships between the variables. Performance expectation, effort expectation, social impact, and facilitating conditions directly or indirectly affect behavioural intention and behaviour. Additionally, gender, age, experience, and use of voluntariness direct the relationships between variables (Yıldız, 2020).

In UTAUT, the expectation of performance is the degree of the expectation of the increase in the individual's work performance with the use of technology. On the other hand, effort expectation is the degree of convenience perceived by the individual related to the use of technology. Social impact is the perception that important people believe individuals should use this technology. Facilitating conditions are facilitating elements, such as the technical infrastructure the individual requires when using technology (Venkatesh et al., 2003). Figure 1 shows UTAUT.

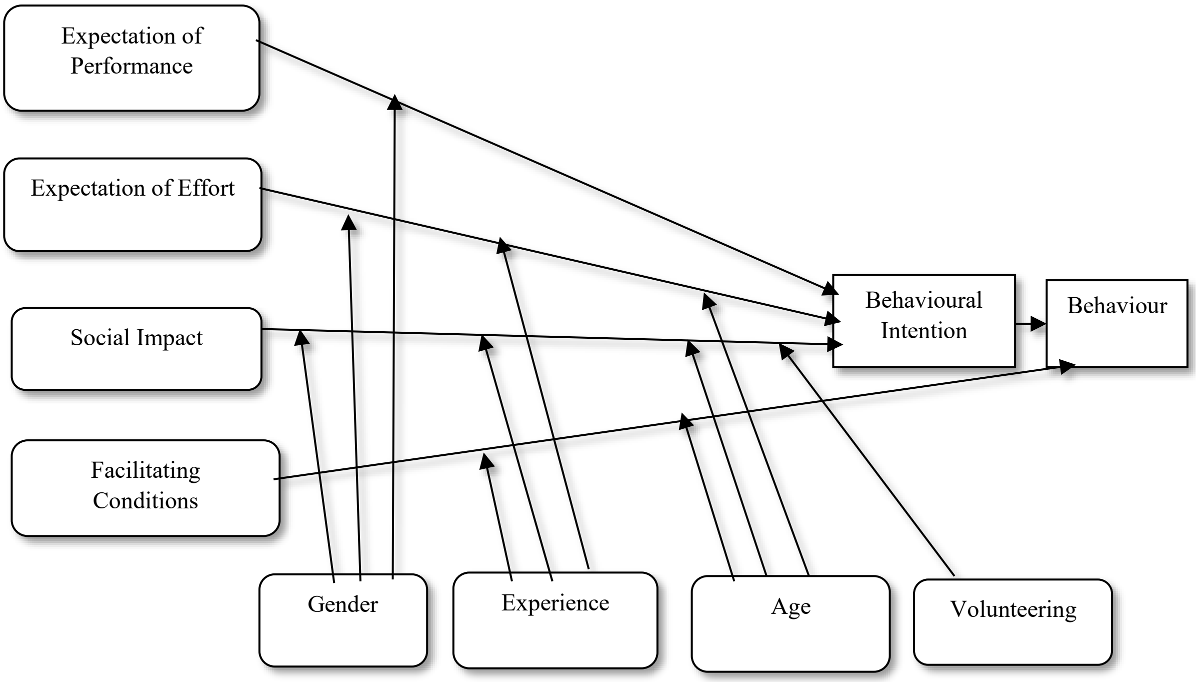

Figure 1 UTAUT (Venkatesh et al., 2003)

Then, Venkatesh et al. (2012) created UTAUT-2 by removing the volunteering variable in the UTAUT and adding hedonic motivation, habit, and price value variables to the model. Hedonic motivation refers to the entertainment and pleasure obtained from using technology. While habit refers to the tendency to change behaviour with the use of technology, and price value is the cognitive exchange between the perceived benefit and the monetary cost of using technology (Açıkgül & Şad, 2021). UTAUT-2, a different synthesis of eight technology acceptance models, is an expanded version of UTAUT for consumers. In addition, the UTAUT-2 model has a better predictive validity than other technology acceptance models with higher percentages of variance by explaining 74% of behavioural intention and 52% of technology use behaviour (Venkatesh et al., 2012). Figure 2 shows UTAUT-2.

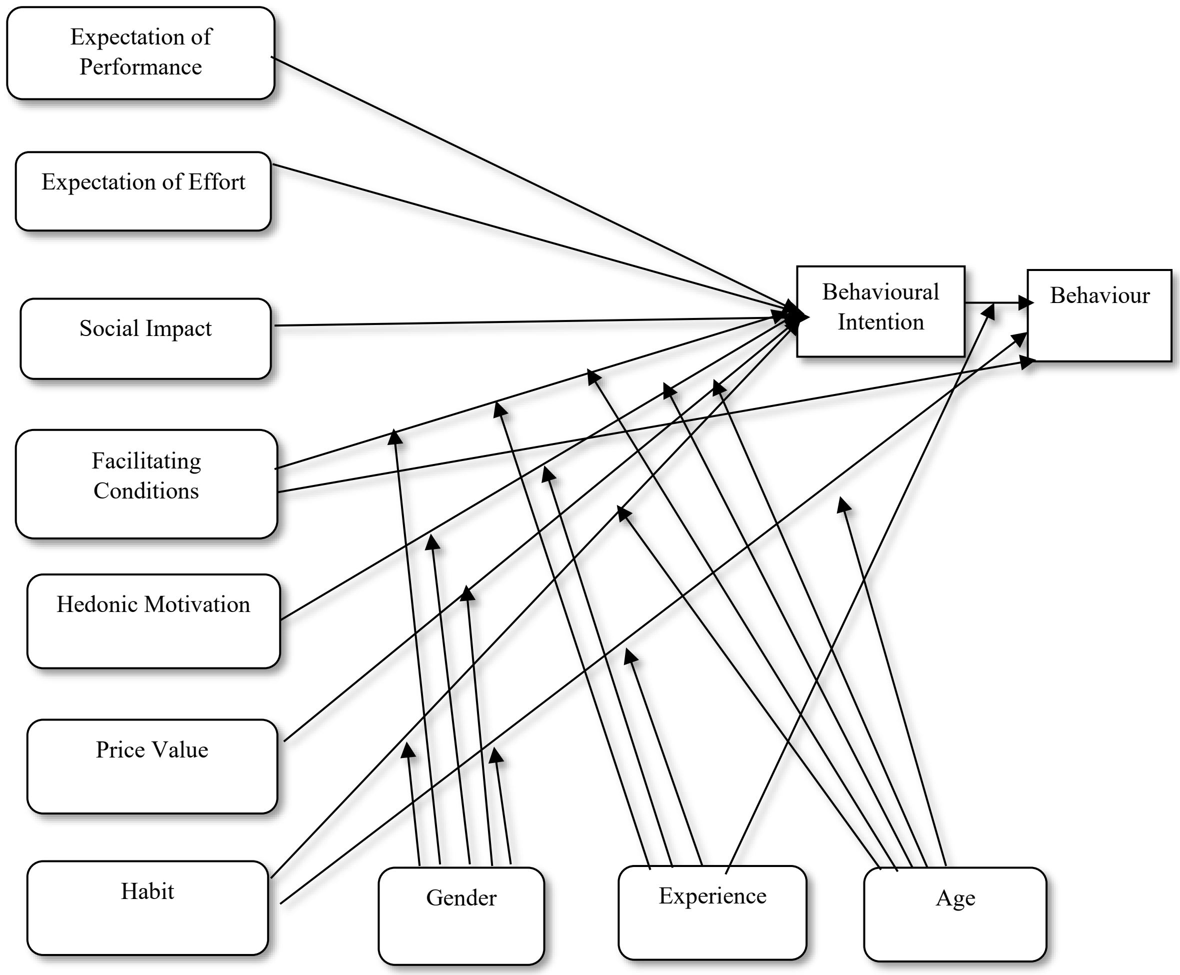

Figure 2 UTAUT-2 (Venkatesh et al., 2012)

In the literature, studies (Bradley et al., 2017; Zare Bidaki et al., 2013) investigate the self-regulation skill levels of preschool and higher education students more. It is inevitable that self-regulation skills, which are important for achievement, will be researched more for students at all educational levels. There are also a small number of studies (Cacciamani et al., 2018; Açıkgül & Şad 2020; Diri, 2021) examining the technology acceptance levels of high school students using UTAUT models. Additionally, a few studies (Chen & Hwang, 2019) examining the relationship between students' self-regulation skills and the UTAUT model in the literature include university students. Considering that the self-regulation skills of the students are very important, especially in the high school period when academic achievement is effective and the foundations are laid for higher education where the student's life will be shaped, such a study with a participant group consisting of high school students will contribute to the literature.

In the literature, there are studies examining the variables of gender (Aksoy & Yaralı, 2017), school type and grade level (Baysal & Özgenel, 2019). Different factors may affect students' behaviours towards accepting and using mobile technology. Nikolopoulou et al. (2020) found that behavioural intention was the most important determinant in the use of mobile phones by university students in mobile learning according to the UTAUT-2 model. Still, gender, age and experience did not have any regulatory effect. In addition, some variables affecting technology acceptance in the literature are gender (Venkatesh et al., 2003), age (Wang et al., 2009), and school type (Demir, 2013). In their research, Rezaei Rad and Naseri (2020) found the positive effect of mobile learning, hence the use of mobile technology, on self-regulation and academic achievement. This study investigated high school students' self-regulated learning skills and mobile technology acceptance level in mathematics learning in terms of gender, grade level (age), and academic achievement score variables. The study also examined the mobile technology acceptance level of high school students in mathematics learning according to the UTAUT-2 model.

The research problem is "What is the relationship between high school students' perceived self-regulation skills and their mobile technology acceptance levels in learning mathematics?".

Sub-problems of the research are;

1. What are high school students' perceived self-regulation skills?

2. Is there a difference in high school students' perceived self-regulation skills according to gender, grade and academic achievement?

3. What are high school students' mobile technology acceptance levels in learning mathematics?

4. Is there a difference in high school students' mobile technology acceptance levels in learning mathematics according to gender, grade and academic achievement?

5. Is there a significant relationship between high school students' perceived self-regulation skills and their mobile technology acceptance levels in learning mathematics?

6. Is there a significant relationship between high school students' perceived self-regulation skills and their mobile technology acceptance levels in learning mathematics learning according to gender, grade and academic achievement?

Hypotheses are;

H1: High school students' perceived self-regulation skills are above average.

H2a: There is a significant difference in students' perceived self-regulation skills according to gender.

H2b: There is a significant difference in students' perceived self-regulation skills according to grade level.

H2c: There is a significant difference in students' perceived self-regulation skills according to academic achievement.

H3: High school students' mobile technology acceptance levels in learning mathematics are above average.

H4a: There is a significant difference in students' mobile technology acceptance levels in learning mathematics according to gender.

H4b: There is a significant difference in students' mobile technology acceptance levels in learning mathematics according to grade level.

H4c: There is a significant difference in students' mobile technology acceptance levels in learning mathematics according to academic achievement.

H5: There is a significant relationship between students' perceived self-regulation skills and their mobile technology acceptance levels in learning mathematics.

H6a: The relationship between self-regulation skills and mobile technology acceptance in learning mathematics significantly differs according to gender.

H6b: The relationship between self-regulation skills and mobile technology acceptance in learning mathematics significantly differs according to grade level.

H6c: The relationship between self-regulation skills and mobile technology acceptance in learning mathematics significantly differs according to academic achievement.

Method

The study used the screening model, one of the quantitative methods. The study determined high school students' self-regulation skills and mobile technology acceptance levels in learning mathematics learning with the descriptive screening model. In addition, the study used correlation analysis and relational screening method to examine the relationship between high school students' perceived self-regulation skills and mobile technology acceptance levels in learning mathematics.

Participants

The study's participant group consisted of 9th, 10th, 11th and 12th-grade students studying at an Anatolian High School in the northern district of Izmir in the 2021-2022 academic year. The study determined the high school by appropriate sampling method. The school within the scope of the study consisted of 846 students. Before collecting student data, the study explained the purpose and stated that participation was voluntary. After eliminating the erroneous data, the study analyzed 752 (486 women, 266 men) data.

Table 1 Findings Regarding the Personal Information of the Research Participants

Variable		f	%
Gender	Female	486	64.6
	Male	266	35.4
	Total	752	100
Grade	9	183	24.3
	10	231	30.7
	11	161	21.4
	12	177	23.5
	Total	752	100
Academic achievement average	50 - 59.9	32	4.3
	60-69.9	354	47.1
	70-84.9	327	43.5
	85-100	39	5.2
	Total	752	100

Data collection

The study used three data collection tools: The student Information Form, the Perceived Self-Regulation Scale and Mobile Technology Acceptance Scale for Learning Mathematics.

Student Information Form

The Student Information Form enabled to collect information about the variables such as the gender of the students (female, male), grades (9, 10, 11, 12th grade), achievement averages (0-100 points), the status of having their rooms for studying, planning and complying with this plan while studying, mobile technologies used, having efficient internet access in the place where they live, the experience of using mobile technologies, frequency of using mobile technologies while studying.

Perceived Self-Regulation Scale

To determine the students' self-regulated learning skills, the study used the "Perceived Self-Regulation Scale" developed by Arslan and Gelişli (2015). KMO (Kaiser-Meyer-Olkin) scale value consisting of 16 items and 2 dimensions explaining 54.3% of the total variance was 95, and Bartlett's test was 2388.664. The first sub-dimension of the scale is "Being Open", consisting of 8 items, and the other sub-dimension is "Search", consisting of 8 items. The scale is of 5-point Likert type and is scored as (5) "always", (4) "frequently", (3) "occasionally", (2) "rarely", and (1) "never". In the scale development studies, the Cronbach Alpha reliability coefficient was 84, 82 for the Search sub-dimension and 90 for the whole scale. In this study, the Cronbach Alpha reliability coefficient for the whole scale was 82. The Perceived Self-Regulation Scale is a valid and reliable data collection tool to measure individuals' "Self-Regulation" skills.

Mobile Technology Acceptance Scale for Learning Mathematics

To determine high school students' mobile technology acceptance levels in learning mathematics, the researchers used the "Mobile Technology Acceptance Scale in Learning Mathematics" developed by Açıkgül and Şad (2020). The scale consisted of 36-item and 8-dimensional structure explaining 66.068% of the total variance. There were 6 items in the Expectation of Performance, 3 in the Expectation of Effort, 4 in the Habit, 3 in the Price Value, and 5 in the Social Impact dimension. Additionally, there were 4 items in the Hedonic Motivation, 5 in the Facilitating Conditions and 6 in the Behavioral Intention dimension. In addition, the scale was in 5-point Likert type as "Strongly Agree (5), Agree (4), Partially Agree (3), Disagree (2) and Strongly Disagree (1)". Within the scope of the reliability analysis of the measurement tool, the Cronbach Alpha internal consistency coefficient was 94 for the Expectation of Performance, 88 for the Expectation of Effort, 91 for the Social Impact, 93 for the Facilitating Conditions, 94 for Hedonic Motivation, 87 for the Price Value, 86 for the Habit, and 92 for the Behavioral Intention dimension. In this study, the Cronbach Alpha reliability coefficient for the whole scale was 89. The analyses showed that the scale was valid and reliable in determining the mobile technology acceptance level in mathematics learning.

Data Analysis

The research utilized frequency and percentage distributions, independent groups T-test, one-way analysis of variance ANOVA, and simple correlation analysis (Pearson Product-Moment Correlation) in the analysis of the data to find answers to the research questions.

Findings and Discussions

1. Findings Regarding High School Students' Perceived Self-Regulation Skills

The study investigated high school students' perceived self-regulation skills for the first sub-problem of the study. Table 2 gives the findings related to the students' perceived self-regulation skills.

Table 2 Descriptive Values Related to Students' Perceived Self-Regulation Skills (SPSS)

Dimension	Mean (*SD*)	SS
Being open	29.54 (3.69)	4.15
Search	26.09 (3.26)	5.81
SPSS	55.64 (3.48)	8.81

According to the results of the descriptive analysis in Table 2, both the mean scores of SPSS and the mean scores in the Being Open and Search sub-dimensions were above average.

2. Findings Regarding the Differentiation of Students' Perceived Self-Regulation Skills According to Gender, Grade and Academic Achievement

This sub-problem of the study investigated whether there was a significant difference in SPSS according to gender. For this purpose independent samples t-tests were conducted on the data. According to the analysis results, the intergroup variances were homogeneous regarding two sub-dimensions and the whole scale ($p>.05$).

According to the examination of the sub-dimensions of the scale, there was a statistically significant difference between the mean score of the Being Open sub-dimension of female students ($M = 29.77$) and that of male students ($M = 29.13$) ($t(750) = 2.01$; $p < .05$). Accordingly, the Being Open sub-dimension scores of female students were higher than that of male students.

The study performed a one-way analysis of variance regarding the significance of the scores of SPSS and sub-dimensions according to the grade variable. There was a significant difference regarding students' scores according to grade in the two sub-dimensions of the scale and the whole scale ($p<.05$). The study also performed a post hoc test to determine the source of this difference. Accordingly, 12th-grade students scored higher in Being Open and Search sub-dimensions and perceived self-regulation skills.

The study performed a one-way analysis of variance regarding the significance of the scores of SPSS and its sub-dimensions according to the academic achievement variable. The study collected the overall achievement means of the students as data. To provide convenience in the analysis, the mean achievement scores of the students were expressed as 1 in the range of 0-49.99, 2 in the range of 50-59.99, 3 in the range of 60-69.99, 4 in the range of 70-84.99, and 5 in the range of 85-100. As a result, the achievement means of the participants were above 50 points. There was a significant difference regarding students' achievement scores in the two sub-dimensions of the scale and the whole scale ($p<.05$). According to the results of the multiple comparison post hoc test, students with achievement scores of 4 and 5 had higher perceived self-regulation skills scores according to the Being Open and Search sub-dimensions and the whole scale.

3. Findings Regarding High School Students' Mobile Technology Acceptance Levels in Mathematics Education

For the second sub-problem of the research, the study investigated mobile technology acceptance levels of high school students in learning mathematics learning. Table 3 gives the findings regarding the students' mobile technology acceptance in learning mathematics (MTALM).

Table 3 Descriptive Values Regarding Students' Mobile Technology Acceptance Levels (n=752)

Dimension	Mean (*SD*)	SS
The Expectation of Performance	21.16 (3.53)	4.57
The Expectation of Effort	11.16 (3.72)	2.68
Social Impact	15.37 (3.07)	4.46
Facilitating Conditions	20.66 (4.13)	3.99
Hedonic Motivation	13.66 (3.42)	4.07
Habit	11.30 (2.83)	3.79
Price Value	7.88 (2.63)	3.45
Behavioral Intention	20.48 (3.41)	5.26
MTALM	121.68 (3.38)	19.18

According to the results of the descriptive analysis in Table 3, both the mean scores of MTALM and the scores in the sub-dimensions of Expectation of Performance, Expectation of Effort, Social Impact, Facilitating Conditions, Hedonic Motivation and Behavioral Intention were above the average. Also, the Habit and Price Value sub-dimensions scores were slightly below average.

4. Findings Regarding the Differentiation of High School Students' Mobile Technology Acceptance Levels in Mathematics Education According to Gender, Grade and Academic Achievement

This sub-problem of the study investigated whether there was a significant difference between the students' mobile technology acceptance levels in learning mathematics according to gender. For this purpose, the study conducted an independent T-test on the data. According to the results of the analysis, the intergroup variances were not homogeneous in terms of Expectation of Performance, Expectation of Effort, Hedonic Motivation and Price Value sub-dimensions ($p<.05$), Social Impact, Facilitating Conditions, Habit, Behavioral Intention, and the intergroup variances were homogeneous in terms of the whole scale ($p>.05$). There was no statistically significant difference between the mean score of female students' mobile technology acceptance levels in mathematics education (M= 122.06) and the mean score of male students' mobile technology acceptance levels in mathematics education (M= 120.98) ($t(750) = 0.74$; $p > .05$).

There was a significant difference in the sub-dimensions of Expectation of Performance, Expectation of Effort, Social Impact and Price Value of the scale in terms of students' scores according to their grades ($p<.05$). Additionally, the expectation of performance of 12th-grade students was higher than that of 9th-grade students in mobile technology acceptance in learning mathematics. In the Expectation of Effort sub-dimension, there was a significant difference in favour of 12th-grade students between the students in the 12th grade and the 10th-grade students in mobile technology acceptance in learning mathematics. In the Social Impact sub-dimension, there was a significant difference in favour of 10th-grade students between 9th-grade students and 10th-grade students in mobile technology acceptance in mathematics learning. In the Price Value sub-dimension, there was a statistically significant difference between 9th-grade students and 10th, 11th and 12th-grade students in mobile technology acceptance in learning mathematics. Also, 9th-grade students had higher scores than other grades. The study performed that students with an achievement score of 4 and 5, that is, students who were considered to be more successful academically, had higher scores in the Hedonic Motivation dimension than students with an achievement score of 2. In other words, more successful students had more fun and enjoyed studying while using mobile technology to learn mathematics.

5. Findings Regarding the Relationship Between High School Students' Perceived Self-Regulation Skills and Mobile Technology Acceptance Levels in Learning Mathematics

Table 4 gives the results of the Pearson correlation analysis conducted to examine the relationship between students' perceived self-regulation skills and mobile technology acceptance levels in learning mathematics learning. According to the table, the correlation value was p<.and significant. There was a low level of positive correlation between SPSS and MTALM.

Table 4 The Relationship between SPSS and MTALM (n=752)

Variables		SPSS	MTALM
SPSS	r	1	.28
	p		.00
MTALM	r	.28	1
	p	.00	

6. Findings Regarding the Relationship Between High School Students' Perceived Self-Regulation Skills and Mobile Technology Acceptance Levels in Learning Mathematics According to Gender, Grade and Academic Achievement

Results of the partial correlation analysis conducted to examine whether there was a significant relationship between SPSS and MTALM according to gender, there was a low level of positive correlation (.10 <r<.29). Which includes the results of the partial correlation analysis conducted to examine whether there was a significant relationship between SPSS and MTALM according to grade, there was a low level of positive correlation (.10 <r<.29). And which includes the results of the partial correlation analysis conducted to examine whether there was a significant relationship between SPSS and MTALM according to grade, there was a lower level of positive correlation compared to gender and grade variables (.10 <r<.29).

The sample of this study consists of 752 students enrolled in an Anadolu High School located in a northern district of İzmir during the 2021-2022 academic year. Since the sample was drawn from a single school and a specific geographic area, the generalizability of the findings to student groups with different socio-economic backgrounds, cultural settings, or school types (e.g., science high schools, vocational high schools, private schools) is limited. This represents a significant constraint on the external validity (generalizability) of the results.

In this study, the relationship between students' self-regulation skills and their mobile technology acceptance levels in mathematics learning was examined based on variables such as gender, grade level, and academic achievement. Other potential variables, such as socio-economic status, digital literacy, teacher attitudes, or the quality of the learning environment, were not included in the scope of the research. This limitation restricts the breadth of the findings and their applicability to a broader context.

Conclusions and Suggestions

According to the findings, high school students' perceived self-regulation skills were above average, consistent with prior research indicating that students tend to acquire effective study habits and learning regulation abilities by this educational stage (Ekşi et al., 2018). No significant gender differences were found in self-regulation skills, although some studies have reported females to possess higher skills due to cognitive and behavioral differences (Fawaıt et al., 2020; Özen & Gencel, 2016). A significant difference was found by grade level, with 12th-grade students demonstrating higher self-regulation skills than 9th graders, supporting the notion that self-regulation improves with age and maturity (Fawaıt et al., 2020). Furthermore, students with higher academic achievement showed significantly better self-regulation abilities, aligning with prior studies that established a positive relationship between academic success and self-regulated learning (Aktan, 2012; Duru et al., 2004; Üredi & Üredi, 2005). In terms of mobile technology acceptance in mathematics learning, students scored above average in "Performance Expectancy," "Effort Expectancy," "Social Influence," "Facilitating Conditions," "Hedonic Motivation," and "Behavioral Intention," but slightly below average in "Habit" and "Price Value." These results may be attributed to students' negative attitudes towards mathematics or a preference for traditional learning tools (Poçan et al., 2021), as supported by studies reporting moderate (Diri, 2021) or high (Horzum et al., 2014) acceptance levels. Gender was not a significant factor in mobile technology acceptance (Nikolopoulou, 2018; Nikolopoulou et al., 2020), while 12th-grade students showed higher "Performance Expectancy" and "Effort Expectancy" than lower grades. Interestingly, 10th-grade students were more socially influenced, and 9th-grade students perceived mobile technologies as more cost-effective. Regarding academic achievement, a significant difference was found only in "Hedonic Motivation," with higher-achieving students reporting greater enjoyment while using mobile technologies for mathematics (Han & Shin, 2016). A low but positive correlation was found between students' perceived self-regulation skills and mobile technology acceptance in mathematics. This correlation remained consistently low across gender, grade level, and academic achievement. It suggests that students who are capable of managing their learning are more inclined to accept and utilize mobile technology effectively (Liou & Kuo, 2014; Ngampornchai & Adams, 2016; Zare Bidaki et al., 2013).

However, the relatively moderate levels of both self-regulation and mobile technology acceptance may explain the weakness of this relationship. Moreover, students' attitudes toward mathematics could have also influenced this interaction. Therefore, fostering both self-regulation skills and positive attitudes toward educational technologies is essential for enhancing academic performance (Schunk & Ertmer, 2000).

Based on the results, hypotheses H1, H2b, H2c, H3, H4b, H4c, and H5 are supported, while hypotheses H2a, H4a, H6a, H6b, and H6c are not supported. Specifically, no significant differences were found based on gender, age, or academic achievement, while a low but positive relationship between self-regulation skills and mobile technology acceptance was observed.

This study offers significant contributions to both the theoretical literature and practical applications by examining the relationship between high school students' perceived self-regulation skills and their acceptance levels of mobile technology in mathematics learning. While existing studies in this field predominantly focus on university students, this research stands out as one of the few that investigates this relationship in the context of secondary education. By addressing this gap, the study provides a more comprehensive understanding of how individual learning skills interact with technology acceptance among adolescents. Moreover, the integration of the Unified Theory of Acceptance and Use of Technology (UTAUT-2) and self-regulation theory within the framework of this study offers a novel perspective to the literature, highlighting how self-regulatory capacities can influence technology adoption processes in educational settings.

In addition to its theoretical contributions, the study also provides several practical implications for educators, policymakers, and instructional designers. To ensure students can effectively benefit from mobile technologies in mathematics learning, it is essential to enhance their self-regulation skills. Therefore, teachers are encouraged to incorporate self-regulation-oriented instructional strategies into their lessons, especially when utilizing mobile technologies. Furthermore, the development of instructional materials and mobile learning applications that explicitly support students' self-regulation processes is recommended. From a policy perspective, there is a need for in-service training programs aimed at equipping teachers with the competencies required to integrate mobile technologies into their teaching practices effectively. By doing so, both students' academic performance and their positive attitudes towards technology can be fostered in a more holistic manner. Research can also be carried out for different variables theoretically supported in the future. The study participants consisted of only the students of one school through appropriate sampling. In the following studies, a larger group of participants with high representation power of the universe can be studied, including different types of schools (Science High School, Social Sciences High School, Vocational High School, Imam Hatip High School, etc.) and even different levels of education (primary school, secondary school, university, etc.). This study included only the screening method, but experimental and qualitative methods can also be used to obtain in-depth research results.

Compliance with Ethical Standards

Disclosure of potential conflicts of interest

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Research involving Human Participants and/or Animals

The ethics committee permissions were obtained with the letter dated 23.02.2022 and numbered 02/23 of the "Social and Human Sciences Scientific Research and Publication Ethics Committee of University Institute of Educational Sciences."

Lise Öğrencilerinin Algılanan Öz Düzenleme Becerilerinin Matematik Öğreniminde Mobil Teknoloji Kabul Düzeyleri ile İlişkisi

Özet:

Eğitimde mobil teknolojinin yaygınlaşmasıyla birlikte bireysel öğrenme ön plana çıkmış, bu da öğrencinin işini en iyi şekilde organize etmesini, yani öz düzenleme becerilerini geliştirmesini gerektirmiştir. Bu araştırmada lise öğrencilerinin algılanan öz düzenleme becerileri ile matematik öğrenmede mobil teknoloji kabul düzeyleri arasındaki ilişki incelenmiştir. Ayrıca araştırmada öğrencilerin matematik öğrenmede öz düzenleme becerileri ve mobil teknoloji kabul düzeyleri cinsiyet, sınıf düzeyi ve akademik başarı ortalamaları açısından incelenmiştir. Araştırmaya uygun örnekleme yöntemi ile belirlenen bir lisede öğrenim gören öğrenciler dahil edilmiş ve 752 öğrencinin verileri değerlendirilmiştir. Araştırmada veri toplama araçları olarak Öğrenci Bilgi Formu, Algılanan Öz Düzenleme Ölçeği ve Matematik Öğrenmede Mobil Teknoloji Kabul Ölçeği kullanılmıştır. Araştırmada ayrıca betimsel ve ilişkisel tarama yöntemleri kullanılmıştır. Araştırmaya göre lise öğrencilerinin algılanan öz düzenleme becerileri ile matematik öğrenmeye yönelik mobil teknoloji kabul düzeyleri arasında düşük düzeyde pozitif bir korelasyon vardır. Ayrıca öğrencilerin algılanan öz düzenleme becerileri ortalamanın üzerindedir ve mobil teknoloji kabul düzeyleri matematik öğreniminde ortalamaya yakındı.

Anahtar kelimeler: Lise öğrencileri, matematik, mobil öğrenme, mobil teknoloji kabulü, öz düzenleme.

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Research Article

AI-Generated STEM Activities: The Impact of the Activities on the Scientific Creativity of Gifted Students

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Abstract – This study aims to answer the questions: "Does the implementation of AI-generated STEM activities have an impact on students' levels of scientific creativity?" and "What are the students' views and experiences regarding AI- generated STEM activities?". The study group consists of 49 gifted 4th-grade students enrolled in a Science and Art Center in Bursa, Turkey during the 2023-2024 academic year. Utilizing a case study analysis, the research demonstrates that AI-generated STEM activities significantly enhance students' scientific creativity levels. Additionally, most students expressed positive views about the activities and stated that they developed their creativity, gained various skills and felt like engineers due to their involvement in design. The "Scientific Creativity Scale," adapted for use in Turkish context by Aktamış (2007), and a semi-structured interview form were employed in the research. This study highlights the potential of artificial intelligence in designing STEM activities and offers a new approach to develop students' scientific creative thinking skills.

Keywords: Artificial intelligence, STEM, gifted-students, scientific creativity.

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Introduction

STEM and Artificial Intelligence

Artificial intelligence (AI) is one of the most significant technologies in use today, and its impact is growing daily. The term "artificial intelligence" was first introduced in 1921 in a play by Czech writer K. Capec (Arslan, 2020), and since then, AI has continued to develop, being integrated into nearly every field, especially education. In their study, İşler and Kılıç (2021) discussed the various benefits of using AI in education and teaching. AI helps personalize learning by offering an educational experience tailored to each student's individual needs and learning styles. It also saves teachers time by providing tools that can perform certain tasks, such as preparing necessary materials and digitizing textbooks. Moreover, AI enables continuous assessment and feedback, allowing students to identify and fill gaps in their knowledge (Arnett, 2016). Through virtual reality and immersive environments, AI promotes active student engagement by offering interactive, three-dimensional worlds that enhance interaction with learning materials (Karsenti et al., 2019). Additionally, AI facilitates the easy collection and storage of student data, making it highly effective in the education of students with special needs and contributing to the accessibility of global classrooms for all learners (Woolf et al., 2013).

AI is increasingly being utilized in teaching, particularly in STEM (Science, Technology, Engineering, Mathematics) education (Linn et al., 2023; Xu & Ouyang., 2022). The primary goal of AI in STEM education is to enhance the quality of teaching and learning in STEM fields (Hwang et al., 2020). Integrating AI into STEM education offers various advantages, such as providing personalized and adaptive learning opportunities, helping teachers better understand students' learning behaviors, and automatically assessing STEM learning outcomes (Alabdulhadi & Faisal, 2021; Walker et al., 2014). AI is believed to enable more effective student-centered STEM education, potentially leading to better student achievement (Barkoczi et al., 2024; Triplett, 2023; Xu & Ouyang, 2022). Although this study uses AI-generated STEM content, both the focus of this study and research on the direct integration of artificial intelligence into STEM teaching practices remain limited. A review of the literature using both the keywords “artificial intelligence education” and “STEM” in the Web of Science and Google Scholar databases revealed 24 studies published between 2019 and 2024. Among them, Skowronek et al. (2022), Xu and Ouyang (2022), Kong et al. (2021), Hebebci (2023), Chang et al. (2023), and Triplett (2023) discussed the benefits of AI in learning STEM content, developing educational materials, evaluating student performance, and improving learning environments. Jang et al. (2022) developed a STEM-based AIED (Artificial Intelligence Education) program for primary school students aged K-6. Students have been tasked with researching topics such as ecosystem conservation and social integration of disadvantaged individuals, developing solutions to these issues using artificial intelligence, and programming AI models to propose solutions. Lin et al. (2021) discuss a STEM-based artificial intelligence learning approach for non-engineering undergraduate students. A three-week STEM-based artificial intelligence curriculum was implemented, and the results indicated a significant positive impact on students' perceptions of both artificial intelligence and teamwork. Körpeoğlu and Yıldız (2024) used "Adaptive Neural Network-Based Fuzzy Logic Model", created with the help of AI, to measure students' attitudes towards STEM and compare these with actual attitude scores.

In the study of Uğraş et al. (2024), it was revealed that teachers generally agreed on the benefits of integrating ChatGPT into early childhood STEM education. Teachers emphasized ChatGPT's significant role in providing instant feedback, offering personalized content suggestions, encouraging creativity, relating learning to real-life contexts, and increasing student motivation. According to the study by Zhai et al. (2023), AI enables time and labor savings in assessment processes in STEM education. It can analyze student learning in real-time, especially in complex tasks such as open-ended responses, modeling, and argumentation, and create a feedback loop. When used appropriately, AI technologies can provide a more equitable, effective, and personalized STEM education. In another study conducted by Sun et al. (2024), they provide concrete recommendations in their research for enhancing pre-service STEM teachers' willingness to integrate AI technologies into their teaching practices.

Previous studies have discussed the positive role of AI in STEM education, and they also highlight AI's potential in the process of designing educational activities. In other words, AI has the potential to assist teachers in lesson and activity planning (Çelik et al., 2022; Zawacki-Richter et al., 2019). For example, a study by Cooper (2023) examined the effectiveness of AI tools like ChatGPT in creating science education activities. The researchers suggest that the developed activities are consistent with effective pedagogical practices and can serve as supportive tools for teachers. Thus, artificial intelligence technologies have the potential to support teachers in lesson planning processes, making learning more effective and helping reduce teachers' workload. (Althuwaybi, 2020; Luckin et al., 2016). However, despite increasing interest in the integration of artificial intelligence into

STEM education, there remains a notable gap in the literature regarding its effectiveness, particularly in the context of designing activities tailored for gifted learners. The current body of research has largely focused on general applications, leaving implementation methods and student-specific impacts underexplored. Given the unique cognitive and emotional needs of gifted students, it is essential to investigate how AI-generated educational activities can address their learning potential more effectively. Therefore, this study aims to contribute to the field by examining the design, implementation, and outcomes of AI-driven STEM activities specifically developed for gifted learners, with the goal of informing future educational practices and policies.

STEM and Scientific Creativity

Creativity in science is defined by the term "scientific creativity." Scientific creativity refers to the ability to present or generate an original idea using existing knowledge. This ability often emerges when encountering a problem (Aktamış & Ergin, 2006). Additionally, scientific creativity is the ability to create original products with societal or personal value toward a specific goal using given information, or the potential capacity to produce such products. Furthermore, this process is based on scientific knowledge and skills (Hu & Adey, 2002).

In the literature, creativity is defined by its core features, such as problem-solving and product design (Kale, 2010), and encompasses scientific creativity. These features align with the goals of STEM education. STEM education is based on an interdisciplinary approach that integrates science, technology, engineering, and mathematics. Rather than merely transferring knowledge, STEM education aims to instill 21st-century skills such as creativity, problem-solving, product development, collaboration, and entrepreneurship (Voogt & Roblin, 2012). Through this, students are expected to develop alternative solutions to everyday problems by approaching them with a scientific perspective. Integrating creativity into STEM education is believed to not only enhance students' creative thinking abilities but also positively impact the success of STEM education (Kaplan Sayı, 2021).

Many studies on STEM and scientific creativity highlight the positive effects of STEM education on students at different levels. For instance, Kutru and Hasançebi (2024) reported that “Argumentation-Based Science Learning”, supported by STEM, enhanced creativity in 7th-grade students, while Asal Özkan and Sarıkaya (2023) found similar results in 4th-grade students through engineering design-based activities. Sarıçam (2019) examined creativity development in 6th-grade students through digital game-based applications, and Uğraş (2018) studied creativity development in 7th-grade students through STEM activities. Similarly, Rasul et al. (2018), Siew and Ambo (2018) and Zhang et al. (2024) emphasized that STEM activities supported creativity across various age groups. In their study, Eroğlu and Bektaş (2022) demonstrated the effectiveness of 5E-based STEM strategies in 9th-grade students.

In summary, the existing literature highlights the crucial role of STEM activities, conducted through various methods, in enhancing students' scientific creativity. Therefore, this study aims to examine the impact of AI-generated STEM activities on students' scientific creativity. It is hypothesized that, if the activity is a suitable STEM activity, it will increase students' scientific creativity.

Gifted Students and Scientific Creativity

Gifted students are defined as individuals who possess high-level abilities and skills in one or more areas (Philips, 2019). These students exhibit high potential in terms of creativity and problem-solving skills (Ercan Yalman & Çepni, 2021). Moreover, it is believed that above-average intelligence is required to demonstrate scientific creative performance (Hu & Adey, 2002). According to Hennessey (2004) gifted individuals possess the innate abilities to meet all the requirements of the scientific creativity process. Given these characteristics, it is reasonable to assume that gifted students possess a high level of scientific creativity. However, there is a need for more research on how to cultivate scientific creativity in these students, as it is crucial for both scientific advancement and their personal development. Due to their advanced cognitive abilities, such as creativity, gifted students require specialized educational approaches to meet their unique learning needs (Kaya & Mertol, 2022). These students benefit from educational environments and instructional methods that are specifically tailored to their developmental characteristics and intellectual potential (Baltacı, 2016). Moreover, gifted individuals, who can be described as advanced learners, are expected to play a significant role in the future scientific and technological progress of society (Keser & Kalender, 2016). These considerations underscore the necessity for further research focused on understanding and supporting the educational development of gifted students, particularly in ways that nurture their scientific creativity.

While some progress has been made, there is a clear need for further development and implementation of educational policies that cater to the unique needs of gifted students in Turkey (Cevher Kılıç, 2015). Research on scientific creativity and gifted students can contribute to the improvement of educational policies and practices. Such research can help us better understand the specific needs and potential of these students, enabling us to provide them with more suitable educational environments and programs. Bıçakçı and Baloğlu (2018) examined studies conducted in Turkey on the creativity skills of gifted students and they raised concerns about whether the programs and curricula designed for gifted students in Turkey are sufficient to cultivate creativity.

Camcı Erdoğan (2014) found that differentiated science and technology instruction based on scientific creativity increased the achievement, attitudes, and creativity of gifted students. Therefore, it is evident that enriched environments with diverse activities and approaches are essential for these students.

Ercan Yalman and Çepni (2021) concluded that gifted students lacked self-confidence in scientific creativity and scientific problem-solving. According to the researchers, creating motivating environments in the teaching process is crucial for students to develop self-confidence in creativity. Although these students are recognized for their superior creativity, it is predicted that educational environments supported by contemporary and innovative tools will enhance their scientific creativity. Cevher (2023) emphasized the need to support STEM-focused schools and faculties for gifted individuals and stated that innovative techniques and tools based on anomalies, challenging processes, and argumentation can be used to enhance scientific creativity.

In this study, gifted students were selected to participate in activities developed by artificial intelligence. There are several reasons for this. Primarily, these students are strong in problem-solving and creative thinking skills (Ercan Yalman & Çepni, 2021) and have high-level learning potential (Philips, 2019). For this reason, they may require more than standard programs and teaching methods (Renzulli, 2013). STEM activities developed by artificial intelligence can help further develop students' skills in these areas. Additionally, these activities can be personalized for each student and support their learning processes.

Purpose and Importance of the Research

The research aims to investigate the impact of STEM activities developed by artificial intelligence on the scientific creativity of gifted fourth-grade students, while also evaluating students' experiences and views throughout the process to gain a better understanding of AI's role in this context. To this end, the research question to be addressed is: "How successful is artificial intelligence in creating STEM activities for gifted students?" In this context, the following sub-problems will be examined:

1. Does the implementation of STEM activities generated by artificial intelligence have an effect on students' levels of scientific creativity?

2. What are students' opinions and experiences regarding STEM activities developed by artificial intelligence?

To the best of the author's knowledge, and in light of the researches discussed thus far, there appears to be a lack of studies, both domestically and internationally, on the role of artificial intelligence in designing activities and the impact of AI-generated STEM activities on scientific creativity. Additionally, although this is not the main focus of the study, no studies have been found in the domestic literature that encompass both artificial intelligence and scientific creativity; yet, one study exists in the international literature (Colton & Steel, 1999). This research discusses how artificial intelligence serves as a facilitator in generating new ideas, analyzing data, designing experiments, and conveying results in the context of scientific creativity.

This study is expected to contribute significantly to the literature by addressing critical gaps at the intersection of artificial intelligence, STEM education, and scientific creativity. More specifically, it aims to highlight how AI-generated STEM activities differ from traditional approaches in terms of personalization, adaptability, and cognitive challenge. These differences are particularly relevant for gifted learners, who require more complex, enriched, and stimulating educational experiences. By focusing on these distinctions, the study will provide valuable insights and practical guidance for researchers, educators, and policymakers interested in optimizing AI-based educational strategies to meet the advanced learning needs of gifted students.

Method

Research Design

This study employed an experimental design, specifically a one-group pretest-posttest design. In this design, a single group of participants is exposed to the intervention, and their performance is measured both before (pretest) and after (posttest) the implementation of the intervention (Frankell & Wallen, 2016).

Participants

The study group consists of 49 gifted 4th grade students attending a Science and Art Center (BİLSEM) in Bursa, Turkey during the 2023-2024 academic year. Convenience sampling was employed in this study. Convenience sampling is a practical and low-cost method that allows researchers to easily access participants (Yıldırım & Şimşek, 2008). 18 (36.7%) of the participants are girls and 31 (63.3%) are boys. Additionally, the majority (81%) attend public schools.

Data Collection Tools

Scientific Creativity Scale

The scale developed by Hu and Adey (2002) to measure students' scientific creativity skills and adapted into Turkish by Aktamış (2007) for 7th grade students. It consists of 6 open-ended questions. For example prompts and questions such as; "Please design an apple picking machine. Draw a picture, point out the name and function of each part." or 'If you invented a time machine, which time would you travel to and which scientific questions would you like to investigate?' are included in this scale. Asal (2020) applied this scale to the 4th grade level and calculated the Cronbach Alpha coefficient of internal consistency as 0.74. In this study, the alpha value was 0.70 for the pretest and 0.68 for the posttest. Although a reliability coefficient of .70 or higher is generally recommended, values slightly below .70 (e.g., .65–.69) can be considered acceptable, particularly when the number of items is limited (George & Mallery, 2003).

Interview

A semi-structured interview were conducted to obtain students' opinions about the activities. Students were asked about their feelings and thoughts during these activities, the difficulties they encountered and what they learned during the activity. The interviews lasted approximately between 5 and 11 minutes. During data analysis, inter-coder reliability was established. Two researchers independently coded a subset of the interview data, and discussed until a consensus was reached. The intercoder agreement rate was above 80%, which is considered (Miles & Huberman, 1994).

Implementation Process

After the Scientific Creativity Scale was applied to the students as a pre-test, the selected 3 activities were applied to the students for three weeks without any changes. Although scientific creativity is a multifaceted skill that typically develops over time, several studies have shown that short-term interventions can produce measurable gains. For example, a meta-analysis conducted Bi et al. (2020) demonstrated that even brief instructional interventions could significantly enhance students' scientific creativity.

In the following week, the same scale was applied as a post-test, followed by interviews in which students' opinions about the activities were obtained. The process is shown in Figure 1.

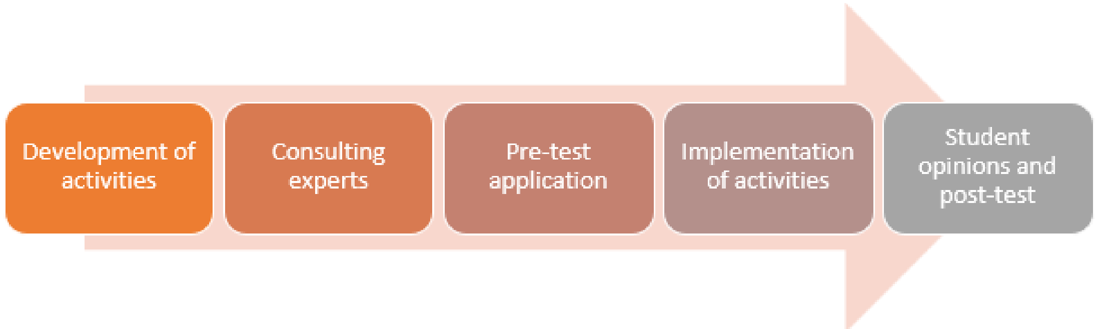

Figure 1 Implementation Process

Development of Activities

In line with the purpose of the study, the ChatGPT artificial intelligence robot was used to design the activities for the students. Firstly, some articles about scientific creativity, gifted individuals, Science and Arts and Centers and STEM subjects were entered into the artificial intelligence, and then, based on these texts and its own database, it was asked to design different STEM activities that could improve the scientific creativity of 4th grade gifted students (OpenAI, 2024). An example of the input prompt is presented in Figure 2.

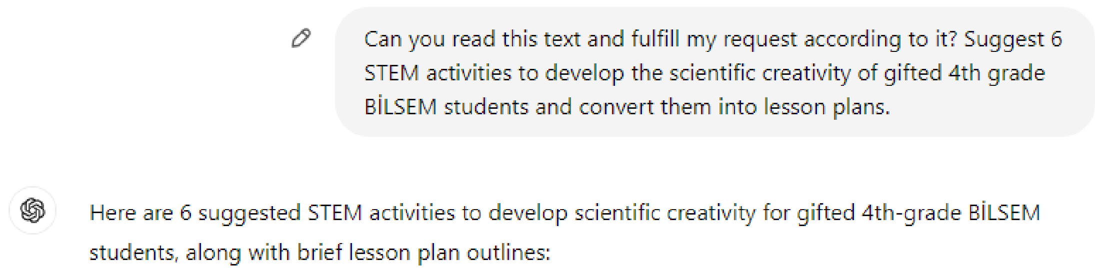

Figure 2 The Prompt Entered into ChatGPT

Three experts were consulted for these designed activities. The experts are individuals who work as science teachers in Science and Art Centers where gifted students are educated and who have doctoral level education in science education. In addition, the experts have various academic studies in the field of STEM. The experts were asked for their opinions about the appropriateness of the activities for gifted students, grade level and STEM, and they were mostly found to be appropriate for the students. However, since the purpose of this study is to examine the impact of AI-generated STEM activities as they are, no revisions or content changes were made based on expert feedback.

Implementation of Activities

Three activities were selected based on expert opinions and each activity was implemented for one week. The AI suggested version of the activities were presented in Appendix A. The description of the implemented activities and aims were presented in Table 1. In total, the implementation process lasted three weeks.

Table 1 The Description of the Implemented Activities

Activity name	Aim	Learning outcomes in the BİLSEM program	Number of hours
Engineering Inspired by Nature	To explore the concept of biomimicry and design innovative solutions inspired by nature.	1)Observes and analyzes structures and functions in nature. 2) Identifies problems and generates solutions. 3)Develops creativity and collaborative working skills."	40'+40'+40' (three class hours)
Sustainable House Design	To help students understand the concept of sustainability and use scientific principles to design a sustainable house.	1)Recognizes the concept of sustainability and relates it to daily life. 2)Explains the importance of renewable energy sources and eco-friendly practices. 3)Develops problem-solving skills through the design thinking process.	40'+40'+40' (three class hours)
Machine Design and Construction	To help students develop engineering skills and produce creative solutions to problems.	1)Explores the working principles of simple machines and relates them to daily life. 2)Develops problem-solving skills using the design thinking process. 3)Engages in productive collaboration by sharing different ideas. 4)Integrates engineering and creativity skills to solve a problem.	40'+40' (two class hours- as suggested by ChatGPT)

Activity 1: Engineering Inspired by Nature

The aim of this activity is for students to explore the concept of biomimicry and design innovative solutions inspired by nature. Sample designs of students for the activity are shown below.

Figure 3 Example of Design Created by Students_1: Insect Hunter Inspired by Insect Trap

Figure 4 Example of Design Created by Students_2: Safe Climbing Shoes Inspired by the Lizard

Figure 5 Example of Design Created by Students_3: Hedgehog-inspired Home Security Tool

Figure 6 Example of Design Created by Students_4: Fishing Gear Inspired by Octopus and Angler Fish

Activity 2: Sustainable House Design

The aim of this activity is to help students understand the concept of sustainability and design a sustainable house using scientific principles. Student design examples of the activity are presented below.

Figure 7 Examples of Sustainable House Designs Created by Students

Activity 3: Machine Design Construction

The aim of this activity is to improve the engineering skills of the students and to enable them to produce creative solutions to problems. Student design examples of the activity are presented below.

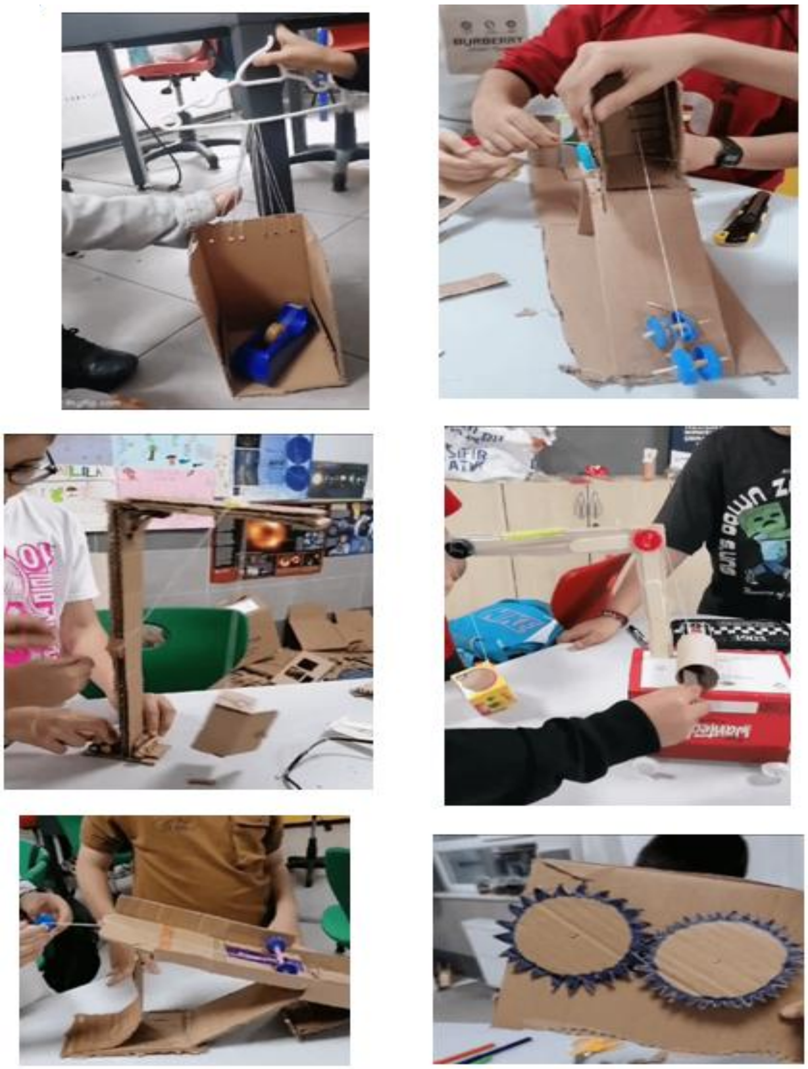

Figure 8 Examples of Machine Designs Created by Students

Data Analysis

For the first four questions of the Scientific Creativity Scale consisting of six open-ended questions, fluency, flexibility and originality scores were examined. For each answer produced 1 point (fluency score), for each different application suggested + 1 point (flexibility score), for each answer found in less than 5% of the participants 2 points, for each answer found in between 5% and 10% 1 point (originality score). In question 5, a maximum of 9 points for each method given (3 points for tools, 3 points for principle, 3 points for procedure), a total of 18 points if an answer suggests two perfect methods, plus 4 points for methods less than 5% of all answers, 2 points for 5% to 10%. In question 6, 3 points were awarded for each separate function of the machine, plus an originality score between 1 and 5 based on a comprehensive overall impression (Asal, 2020).

For example, 19 of the students responded with “test tube” to the question “Can you write what you can use an empty tin can for in the laboratory?” in part a of question 1.

Although each of the students received a "fluency score" of "1" point for giving a scientific answer, they did not receive an "originality score" for giving an answer that is common to most people. The student who wrote "sound transmission material" in the same question received "2" points for "originality" in addition to the fluency score because he gave an answer that is common in less than 5% of the students.

In the quantitative analysis of the data, normality analysis was performed to decide whether parametric or nonparametric tests should be applied. Skewness and kurtosis values, Q-Q Plot and histogram graphs were used for normal distribution. According to the normality analysis, the skewness and kurtosis values for the pre-test were .272 and -0.577, respectively, with standard errors of .340 and .668. For the post-test, the skewness was .206 and the kurtosis was .066, with the same standard errors (.340 and .668, respectively). Considering the distribution of the graphs and skewness and kurtosis values in the range of -2, +2 (George & Mallery, 2010), the distributions were accepted as normal. For this reason paired-sample T test, which is a parametric test, was used in the comparison of the mean scores of the students from the Scientific Creativity Scale in the pre-test and post-test.

The interviews were conducted one-on-one with the students after the activities were completed. Considering the age range of the students, it was observed that they generally preferred to give short answers. The answers given to the interview form were analyzed by MAXQDA 24 program for content analysis.

Findings

Findings Related to the First Research Question

The table obtained as a result of the statistical analysis of the research question "Is there a significant difference between the pre-test and post-test scores when the scientific creativity levels of the students are compared as a result of the implementation of STEM activities produced by artificial intelligence?" is as follows.

Table 2. Analysis Results Regarding the Pre-Test and Post-Test Scores of the Students' Scientific Creativity Levels

Scale	Test	N	M	SD	t	df	p
Scientific creativity	Pre-test	49	4.59	1.65	-6.928	48	<.001
	Post-test	49	6.19	1.97			

When the paired samples T-test results in Table 2 were examined, it was found that there was a significant difference in favor of the post-test scores in terms of students' scientific creativity scores after the activities ($t(48) = 6.928$, $p < .05$, Cohen's $d = .990 > 0.8$).

Findings Related to the Second Research Question

As a result of the content analysis of the answers received from the students as a result of the interviews within the scope of the research question "How are the opinions and experiences of the students about the STEM activities developed by artificial intelligence?", the opinions of the students about "what they learned from the STEM activities developed by artificial intelligence" were grouped under five main themes. A prominent theme was the enhancement of creative thinking. Most students reported that the activities were beneficial in enhancing their creativity. One student noted:

- " *These activities helped me improve my creativity and think in more diverse ways"*

Additionally, it was observed that students gave responses such as*:*

- *"I realized that I am very creative"*
- *"I was able to generate more creative ideas"*

Many students described how the activities helped them draw connections between natural phenomena and the process of creating new designs and inventions. For example, students provided responses such as the following:

- *"I found out that many innovations are based on ideas drawn from nature."*
- *"Each animal has different characteristics, and we can create various things by taking inspiration from animals."*
- *"It is very important to take inspiration from nature."*

Several students highlighted how the projects increased their understanding of sustainability. One participant explained:

- *"I now have a clearer understanding of what sustainability means."*

One of the students also expressed this idea by saying:

- *"I learned what a sustainable home includes and how to create related projects.'"*

Teamwork was another emergent theme. Some students appreciated the collaborative nature of the tasks, expressing that working in groups improved their communication and cooperation skills. For example, a student mentioned:

- *“I learned the meaning of the phrase 'strength comes from unity' through teamwork.”*

Last but not least, some students emphasized that they discovered the enjoyable and engaging aspect of science, noting that the activities made science feel more accessible and exciting. For example, a participant underlined that:

- “*I learned that science is very fun and interesting*.”

Another student stated the following:

- *“I liked science more.”*

During the activity, most students stated that they felt like engineers, describing their experience through four key themes. One of the most prominent themes that emerged was the process of designing. Several students associated engineering with the act of creating designs. In other words, thinking and designing how to do it before the application reminded them of the tasks of an engineer.

This was followed by the process of creating something new. Students described the excitement of developing original solutions and making unique connections between ideas, as reflected in statements like:

- “*I realized that I can create new inventions from some objects or materials, and that I can design something unique even with just two materials.”*

In addition, some students emphasized that working on a project made them feel like an engineer, and a few of them stated that making calculations contribute them feel like engineers.

Finally, when students were asked what the activities contributed to them, their responses revealed four main themes that reflected different dimensions of learning and development. The most prominent theme was skill development. Many students emphasized that the activities helped them improve their skills:

- *“Using hot glue and cutting cardboard improved my skills.”*
- *“Working with different materials to design objects enhanced my hands-on skills.”*

The second theme that emerged was social development. Several students pointed out that working collaboratively helped them strengthen their communication and teamwork skills:

- *“I learned to socialize a bit more with my friends.”*

- *"I got to know my friends better, and they got to know me better too."*

Another theme was the acquisition of knowledge. Some students stated that they learned new concepts related to science, technology, or sustainability through the activity process. Lastly, some students also expressed that they had a great time during the activities:

- *"I learned a lot and had fun."*
- *"The activities weren't challenging for me—in fact, I really enjoyed them."*

Results, Discussion and Suggestions

This study aimed to examine the impact of AI-generated STEM activities on the scientific creativity of gifted fourth-grade students, as well as to explore students' experiences and opinions regarding these activities. For this purpose, firstly, operational definitions related to STEM and gifted students were given to the AI and then it was asked to design STEM activities suitable for the target group. Expert opinion was taken about the designed activities and they were deemed appropriate for the student level. In line with the objective, the findings revealed a statistically significant increase in students' scientific creativity levels after the intervention, as demonstrated by the results of the paired-samples t-test ($t(48) = -6.928$, $p < .001$). The effect size (Cohen's $d = 0.99$) indicates a large effect, which is considered highly impactful in educational research (Cohen, 1988).

From a methodological standpoint, the convergence of quantitative and qualitative findings strengthens the internal validity of the study. The increase in scientific creativity scores is not only statistically significant but also meaningfully perceived by the students themselves. This consistency between numerical data and student experiences provides a robust case for the effectiveness of AI-generated STEM activities.

This finding supports existing literature emphasizing the positive effects of STEM education on creativity (Asal Özkan & Sarıkaya, 2023; Ercan Yalman & Çepni, 2021; Eroğlu & Bektaş, 2022; Kutru & Hasançebi, 2024; Renzulli, 2013). Moreover, in a meta-analysis conducted by Bi et al. (2020), short-term interventions were also shown to significantly enhance scientific creativity, with moderate effect sizes averaging around 0.6. Therefore, the high effect size found in this study suggests that AI-generated activities may offer an even more powerful intervention tool in this context.

In addition to the quantitative findings, student interviews provided deeper insights into their learning experiences. Many students reported that the activities helped them think more creatively, make original designs, and draw inspiration from nature. For example, themes such as *"feeling like an engineer," "learning from nature,"* and *"discovering science is fun"* emerged prominently. This not only reflects the students' cognitive engagement but also their affective connection to the subject matter.

The theme of *"feeling like an engineer"* was particularly striking. Students expressed that processes such as planning, designing, and solving problems made them feel like real engineers. This is consistent with findings by Lin et al. (2021), who emphasized that STEM-based AI interventions promote professional identity and teamwork among students. Similarly, students' recognition of nature as a source of innovation highlights the value of biomimicry in STEM learning (Chang et al., 2023; Rasul et al., 2018). By linking animal characteristics with product design, students demonstrated authentic engagement with scientific creativity.

Furthermore, the activities increased students' awareness of sustainability. Several students indicated that they had learned what it means to design an eco-friendly house and how renewable energy relates to daily life. These findings align with the goal of STEM education to cultivate environmentally responsible citizens (Walker et al., 2014).

Interview responses also indicate that students had positive views towards the activities and discovered the fun aspect of science. The statement of one of the students, "*I learned that science is very fun and science is very interesting,*" shows that STEM activities are effective not only in terms of academic gains but also in developing positive attitudes towards science. This finding is in accordance with the literature that STEM activities can increase student motivation and encourage interest in science (Eroğlu & Bektaş, 2022; Sarıçam, 2019). Finally, although most of the students stated that they did not have any difficulties during the activities, some students stated that they had difficulties. These difficulties were experienced in issues such as using materials and finding design ideas. It was observed that there was no difficulty in understanding the activity or content. This can be considered an indicator of the suitability of the activities for the students.

Another important finding is that students identified teamwork, skill development, and enjoyment as major outcomes of their participation. These non-academic gains reinforce the holistic value of STEM activities, which aim not only to build academic knowledge but also to develop 21st-century skills such as collaboration, problem-solving, and creativity (Voogt & Roblin, 2012).

Moreover, the positive outcomes of AI-generated content highlight the potential of such systems to democratize high-quality instructional design, especially for specialized populations such as gifted students. These learners require enriched and differentiated experiences (Kaya & Mertol, 2022; Renzulli, 2013), and AI offers a scalable method to meet those needs.

In conclusion, it can be stated that STEM activities developed by artificial intelligence can be integrated into educational environments. This study also emphasizes the role of AI in supporting the lesson planning processes for science courses and increasing the potential of the learning environment. According to a study by Ateş and Sungur Gül (2023), STEM education faces a range of complex challenges, including first-order barriers (time, resources, and support), second-order barriers (teacher beliefs), and third-order barriers (curriculum redesign). The emergence of these barriers as a source of concern for teachers inevitably influences their ability to incorporate STEM education into their classrooms or learning environment. They also found that STEM self-efficacy and STEM concerns have a positive and significant relationship. It is thought that the use of artificial intelligence will be a facilitating factor for teachers who have low self-efficacy perceptions in integrating STEM activities into their lessons and finding activities. In addition, considering the importance of lesson plans for science education and the fact that teachers cannot devote enough time to the planning process due to their workload and can face limited access to resources, and difficulties in curriculum adaptation (Ateş & Sungur Gül, 2023; Mon et al., 2016). AI support can facilitate this process for teachers. In parallel to this, Zawacki-Richter et al. (2019) and Çelik et al. (2022) state that artificial intelligence can help teachers design lessons or activities. AI technologies, such as ChatGPT, may serve as effective tools for reducing teachers' workload and generating developmentally appropriate, personalized, and creative STEM content (Althuwaybi, 2020; Luckin et al., 2016; Zawacki-Richter et al., 2019).

The results of this study indicate that the inclusion of AI-generated STEM activities in teacher education programs is essential. In-service training should be organized to help teachers understand how to utilize artificial intelligence in STEM planning processes. Furthermore, policy recommendations can be developed to promote the widespread implementation and curriculum integration of such practices in special education institutions, such as science and art centers.

However, several limitations must be acknowledged. First, although the "Scientific Creativity Scale" was adapted for younger students by Asal (2020), its original development was intended for seventh-grade students (Aktamış, 2007; Hu & Adey, 2002). While reliability coefficients were acceptable, the conceptual suitability of the questions for fourth graders may require further investigation. Additionally, the study was conducted with a relatively small, convenience sample drawn from a single Science and Art Center (BİLSEM) in Bursa, limiting the generalizability of the results. Moreover, considering the limited weekly instruction hours in BİLSEM compared to regular schools, spreading the implementation of the activities over a longer period in future studies may further enhance the reliability of the findings.

Future research should explore the long-term impacts of AI-generated STEM activities across different age groups and educational settings. Additionally, it is recommended that teachers' attitudes, efficacy beliefs, and cognitive readiness regarding AI-supported lesson planning be investigated. This can inform teacher training programs and policy-level decisions on AI integration in curricula.

It is also important to mention that as this study implemented a novel approach by using artificial intelligence to design STEM activities, reflections on the functionality and limitations of the method are critical. While the AI successfully generated activity drafts aligned with the operational definitions provided, expert evaluation was necessary to ensure educational appropriateness and coherence with pedagogical goals. Although the activities were found effective and engaging by students, it was observed that not all of the designed activities included learning outcomes and activity duration. This indicates that the prompts given to the AI play a crucial role, and that human intervention is necessary to improve the outputs. According to the authors The AI demonstrated potential in accelerating lesson planning; however, it could not fully replace teacher insight, especially in terms of emotional, cultural, and developmental appropriateness.

In summary, the study provides strong evidence that AI-generated STEM activities significantly enhance the scientific creativity of gifted fourth-grade students. The combination of quantitative and qualitative data underscores the cognitive, emotional, and social benefits of such interventions. While limitations regarding sample and tool suitability exist, the results point to promising applications of artificial intelligence in instructional design. As AI tools continue to evolve, their thoughtful integration into STEM education can offer enriched, personalized learning environments that foster creativity, innovation, and engagement particularly for gifted learners.

Compliance with Ethical Standards

Disclosure of potential conflicts of interest

The authors declare no conflict of interests with respect to the study.

Research involving Human Participants and/or Animals

This study was approved by the Uludağ University Research and Publication Ethics Committees and conducted in accordance with the ethical standards set by the relevant institutional and national regulations, including the approval of the Ministry of National Education.

Informed consent was obtained from all participants involved in the study.

Data availability

The data of this study are not publicly available due to confidentiality and privacy considerations. For further details regarding the dataset, please contact the corresponding author.

Yapay Zeka ile Geliştirilen STEM Etkinlikleri: Özel Yetenekli Öğrenciler için Önerilen Etkinliklerin Bilimsel Yaratıcılıkları Üzerine Etkisi

Özet:

Bu çalışma, "Yapay zeka tarafından oluşturulan STEM etkinliklerinin öğrencilerin bilimsel yaratıcılık düzeyleri üzerinde bir etkisi var mıdır?" ve "Öğrencilerin yapay zeka tarafından üretilen STEM etkinliklerine ilişkin görüşleri ve deneyimleri nelerdir?" sorularına yanıt aramaktadır. Araştırmanın çalışma grubunu, 2023-2024 eğitim-öğretim yılında Bursa'daki bir Bilim ve Sanat Merkezi'ne devam eden 49 özel yetenekli 4. sınıf öğrencisi oluşturmaktadır. Durum çalışması deseninin kullanıldığı bu araştırmada, yapay zeka tarafından geliştirilen STEM etkinliklerinin öğrencilerin bilimsel yaratıcılık düzeylerini anlamlı ölçüde artırdığı tespit edilmiştir. Ayrıca, öğrencilerin büyük bir çoğunluğu etkinliklere ilişkin olumlu görüşler bildirmiş, yaratıcılıklarının geliştiğini, çeşitli beceriler kazandıklarını ve tasarım sürecine dahil olmaları sebebiyle kendilerini mühendis gibi hissettiklerini ifade etmiştir. Araştırmada, Türkçeye Aktamış (2007) tarafından uyarlanan "Bilimsel Yaratıcılık Ölçeği" ile yarı yapılandırılmış görüşme formu kullanılmıştır. Bu çalışma, yapay zekânın STEM etkinliklerinin tasarımındaki potansiyelini ortaya koymakta ve öğrencilerin bilimsel yaratıcı düşünme becerilerinin geliştirilmesine yönelik yeni bir yaklaşım sunmaktadır.

Anahtar Kelimeler: Yapay zeka, STEM, özel yetenekli öğrenciler, bilimsel yaratıcılık.

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Appendix A

Activity-1

"Engineering Inspired by Nature"

Objective:

To explore the concept of biomimicry and design innovative solutions inspired by nature.

Materials:

- Books or videos about biomimicry and examples of nature-inspired designs
- Various building materials (paper, cardboard, craft sticks, etc.)
- Glue, scissors, markers

Activity Steps:

1. Start by introducing the concept of biomimicry and displaying examples of products or designs inspired by nature.
2. Discuss different natural phenomena such as animal adaptations or plant structures.
3. Invite students to identify a specific problem or need and design a solution inspired by nature.
4. Allow time for idea generation, prototype creation, and testing of the designs.
5. Have students present their designs, explain how nature inspired their ideas, and discuss the potential real-world applications.

Activity-2

Sustainable House Design

Objective:

To help students understand the concept of sustainability and use scientific principles to design a sustainable house.

Materials:

- Cardboard or construction materials (for model houses)
- Recycled materials (cardboard tubes, plastic bottles, etc.)
- Solar panels (optional)
- Rainwater collection systems (optional)
- Glue, tape, scissors
- Paint and brushes (optional)

Implementation:

1. Assign students the task of designing a sustainable house.
2. Students use the provided materials to design a house following sustainability principles. This design may include renewable energy sources such as solar power or rainwater harvesting systems.
3. Encourage students to consider aspects like energy efficiency, material usage, and waste management in their designs.
4. Once completed, students display their designs in the classroom or school and share them with other students.
5. During the exhibition, students discuss their designs and are evaluated based on their sustainability awareness and scientific thinking skills.

Activity-3

Machine Design and Construction

Objective:

To help students develop engineering skills and produce creative solutions to problems.

Materials:

- Used cardboard boxes
- Scissors
- Glue
- Colored markers
- Materials for simple machines such as gears, washers, and cranks (optional)

Lesson Plan:

Introduction (15 minutes):

Give a brief presentation about what machines are and provide examples of machines encountered in everyday life. Then, assign students the task of designing and building their own simple machines.

Design Phase (20 minutes):

Give students time to work with cardboard boxes and other materials to design their machines. Allow them to share different ideas and collaborate with one another.

Construction (30 minutes):

Give students time to bring their designs to life. Help when necessary, but encourage them to solve problems on their own as much as possible.

Presentation and Evaluation (15 minutes):

Have students present their designs in class and allow them to examine each other's work. Encourage them to discuss what worked, what didn't, and what they learned during the design process.

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Research Article

Virus Knowledge Test: A Validity and Reliability Study*

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Abstract - Viruses have caused and continue to cause many epidemics for centuries. During these epidemics, there are many examples that are misunderstood and applied among the public. People need to recognise these entities and take appropriate measures. In the teaching process in Türkiye, students learn about the virus for the first time in the 9th grade biology course. With this study, it is aimed to develop a test that can be used to determine the students' knowledge level about the virus subject. It is a descriptive survey study in which data related to variables are collected. 99 students studying in the 9th grade of a state high school in Karesi district of Balıkesir city participated in the pilot application on voluntary basis. The data obtained were analysed with item difficulty and item discrimination indices from classical item statistics. The finalised Virus Knowledge Test (VBT) was administered to 9th grade 165 students from different randomly selected two state high schools in Karesi. The Cronbach α reliability coefficient for the whole VBT was found to be 0.66. The fact that it is the first virus knowledge test with reliability and validity in the literature on the virus subject reveals the originality of the study.

Keywords: Virus, knowledge test, validity, reliability.

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Introduction

Viruses have been causing pandemics and epidemics for centuries (Spanish flu, avian flu, ebola, covid-19). Mankind is faced with a new epidemic disease every moment. For this reason, individuals need to learn to live with viruses and cope with the diseases they cause.

Viruses are the smallest organisms ranging in size from 20-300 nanometres (Simon, 2015). They have protein sheaths (capsid) that protect nucleic acids (RNA or DNA). The capsid has the ability to allow the virus to live outside the cell and enter new cells (Madigan et al., 2017; Simon, 2015; Şimşekli, 2015). The fact that viruses contain genetic material in the form of nucleic acid packaged in an organised structure is the reason why they are classified as living, while the fact that they are not in the cell structure and cannot reproduce on their own is the reason why they are classified as non-living (Simon et al., 2017). When viewed by people, viruses are known to be harmful according to general belief. However, contrary to popular belief, viruses also have benefits. For example, the development of the human placenta in the evolutionary process was thanks to viral proteins (Flint et al., 2022). Viruses have their own genomes, but are dependent on the host cell for energy, metabolic intermediates and protein synthesis. Viruses are necessarily intracellular parasites because they cannot replicate without a hostcell (Flint et al., 2022; Madigan et al., 2017; Simon et al., 2017). Antiviral drugs are used to prevent the virus from multiplying in the body as a result of infection. The foundation of antiviral drugs was laid in 1967. Over time, antiviral drugs have been produced against different virus types. Although new antiviral drugs are produced every day, a complete treatment cannot be found due to the high genetic diversity of viruses and their rapid evolution (Dar et al., 2019). Using the ability of viruses to transfer their genetic material to the host, scientists have worked especially on bacteriophages in the middle of the 20th century. With the development of recombinant DNA technology, viruses have started to be used in gene transfer to cells for therapeutic purposes in the fields of cancer and viral infection (Dar et al., 2019; Flint et al., 2022).

During the investigation of the relationship between bacteria and viruses, a new generation genome editing technique (CRISPRs) was discovered, which enables editing in the genome. With this technique, the desired genes can be silenced and the necessary nucleotides can be replaced. Recently, this technique has been frequently used for human pathogenic viruses (Dar et al., 2019). Due to the rapid evolution of viruses, treatment types are also developing rapidly. For example, in addition to traditional vaccines, mRNA vaccines, which have a history of about 35 years, have spread more widely in the last 15 years. With mRNA vaccines, mRNAs consisting of genetic codes of viruses that cause pathogenic effects are injected into the living body. It is then recognised by the immune system of the living being and antibody production is triggered. Unlike other vaccines, mRNA vaccines provide immunity without the risk of disease development by stimulating the living body for a certain period of time (Savaşçı & Gül, 2020). Viruses are used as vectors to carry the necessary genes to the living body. Although viral vectors provide high transfer during gene therapy, they can carry a limited size load (Baykara, 2016). There are also oncolytic viruses that can survive in tumour cells designed for cancer treatment. These viruses enable the elimination of tumour cells (Salman & Dinçkal, 2022). According to a news published in August 2024, the first phase trials of a vaccine named BNT116, developed by BioNTech to treat non-small cell lung cancer, were initiated in 7 countries including Türkiye. In this vaccine, mRNA model is used as in covid-19 vaccine (Euronews, 2024).

When the national literature is examined, there is only one study on the teaching of virus subject. In this study conducted by Dalgülge (2019), the effect of argumentation-based science learning approach on learning about bacteria and viruses with high school first-year students was examined. The number of studies on the teaching of virus, which is an extremely current and rapidly developing field of study, is insufficient. There are also misconception studies on virus in the literature. When these studies are examined, it is thought that viruses are thought to be living by some students and non-living by some students (Kurt & Ekici, 2013; Muzembo et al., 2022). In addition, there are the following statements about viruses containing a single type of genetic material: "It does not have DNA, it has RNA.", "Virus consists of RNA and protein sheath.". "Virus consists of DNA and sheath", "Viruses do not carry RNA". There is also a belief that the ribosome organelle is present in the structure of the virus (Kurt & Ekici, 2013). In the study conducted by Muzembo et al. (2022) in Africa, there are false beliefs that viruses are malicious and that they are an alien cell that negatively affects the immune system. It is thought that the virus is copied by its own department. The number of people who know that the vaccine is effective in preventing viral diseases is small (Muzembo et al., 2022). It is seen in many studies that the concept of bacteria and virus are used interchangeably (Büyük, 2017; Dumais & Hasni, 2009; Hürcan Gürler & Önder, 2014). It is not known that diseases such as influenza and flu are caused by viruses and it is widely believed that they are caused by bacteria (Büyük, 2017; Larson et al., 2009). Harmful microorganisms that cause diseases such as measles, polio, influenza, herpes, hepatitis B, AIDS, tuberculosis cannot be named (Hürcan & Gürler, 2014). It is stated that antibiotics are used for viral diseases (Büyük, 2017; Hürcan Gürler & Önder, 2014; Yüzbaşıoğlu & Atav, 2004). The concept of virus cannot be associated with daily life (Hürcan Gürler & Önder, 2014; İlkörücü- Göçmençelebi, 2009; Yüzbaşoğlu & Atav, 2004). It is thought that the immune system is formed as a result of virus infection (Dumais & Hasni, 2009). There is no thought that there may be virus particles in the air (Yağbasan & Gülçiçek, 2003). When foreign sources are examined, studies on the false beliefs of virus types such as Ebola and HIV among the public are found. These studies focus on the transmission types of diseases and religious beliefs (Bhagavathula et al., 2015; Kpanake et al., 2016). Saputri and Widyaningrum (2016) studied the misconceptions caused by the pictures in textbooks.

In Türkiye, the subject of virus is not included in primary and secondary school curricula. In the secondary school Biology course, the subject of virus is included in the "Living Worlds and Their Properties" unit at the 9th grade level. In Grade 11, the subject of lymph circulation in the "Circulatory System" unit, and in Grade 12, the subject of virus is mentioned in the "Genetic Code and Protein Synthesis" unit in the "Gene to Protein" unit. A student spends only 4 lesson hours with the virus subject during his/her entire secondary education life (Takmaz & Yılmaz, 2020).

In order for students to be successful in their daily lives, they need to be able to use the knowledge and skills gained at school in real life (Berberoğlu, 2006). In order to determine the current status of individuals in the teaching process, it is necessary to make measurement and evaluation and a knowledge test is needed (Erkuş, 2019, p. 82). Choosing the appropriate evaluation method for the teaching process is one of the most important factors that lead the student to success (Berberoğlu, 2006). Since students encounter the virus for the first time at an average age of 15, this process should be realised in a meaningful way. Knowledge/achievement tests are needed for the evaluation of the teaching.

The number of studies on test development in the studies on the virus subject is limited. In the study conducted by Dalgülge (2019), it was aimed to carry out argumentation-based teaching of bacteria and viruses, to determine and eliminate misconceptions. Pre and post knowledge tests were prepared by the researcher by taking expert opinion. In the study conducted by Hürcan and Önder (2014), with the concept test developed by taking expert opinion, students' associating the concepts of bacteria and viruses learned in the 7th grade science and technology course with daily life was determined. In this study by Mağden et al. (2003), in which the knowledge levels of high school senior students about AIDS were examined, question papers were prepared by experts in the field. The fact that these studies do not cover the 9th grade virus topic of secondary biology course curriculum MoNE (Ministry of National Education) (2018) and that validity and reliability analyses were not conducted creates a need for a virus knowledge test in the literature.

In this study a Virus Knowledge Test (VKT) was developed to be used in the measurement and evaluation stage of the topic's instructional process, in accordance with both the objectives and the teaching-learning (context-based learning) strategy suggested by the curriculum. The aim of this study is to prove the validity, reliability, item discrimination index and item difficulty index of the Virus Knowledge Test (VKT) and to prove the item quality.

Method

Research Design

Survey method is used in studies where data are collected to determine the characteristics of the universe such as ability, opinion, attitude, belief or knowledge. Survey studies in which only data on variables are collected are descriptive survey studies (Sezgin Selçuk, 2019, p.140-141). This study is also a descriptive survey research.

Participants

The population of this study consists of 9th grade high school students in Türkiye. The sampling method used in this study is the convenience sampling method, which selects individuals who are easily accessible and volunteer to participate in the study (Creswell et al.,2008). In the study, students studying in the 9th grade of a public high school in Karesi district of Balıkesir province took part. A total of 99 students (53 girls and 46 boys, 13-14 aged) participated in the pilot study and 165 students (90 girls and 75 boys, 13-14 aged) participated in the main study on a voluntary basis.

Development of the Data Collection Tool

There is a need for a virus knowledge test due to the limited time allocated to the virus subject in the secondary biology course curriculum (MoNE, 2018), and the lack of a knowledge test consisting of items suitable for authentic measurement and evaluation, which is compatible with the context-based learning approach on this subject in the literature. For this reason, a knowledge test consisting of 16 items was developed by taking into account the learning outcomes in the curriculum, the recommended teaching and learning activities and the misconceptions in the related literature. The following steps were followed in the development of the knowledge test:

Identification of Outcomes

The learning outcomes in the secondary biology curriculum MoNE (2018) were reviewed. The following acquisitions related to viruses were selected from the subject of "Living Organisms and Their Properties" in the "World of Living Things" unit at the ninth grade level:

> "9.3.2.3. Explains the general characteristics of viruses.
>
> a. The reasons why viruses are not included in biological classification categories are emphasised.
>
> b. The effects of viruses on human health are discussed through rabies, hepatitis, influenza, herpes and AIDS diseases. Precautions to be taken against viral diseases are emphasised.
>
> c. It is emphasised that viruses offer new opportunities for studies in the field of genetic engineering." (p.18)

Preparation of Knowledge Test Items and Obtaining Expert Opinions

Before preparing the items in the knowledge test on the virus topic, the misconceptions in the literature were reviewed. Since the target group was 9th grade, misconceptions at both secondary and high school levels were examined, and the misconceptions that individuals may bring from previous years and the misconceptions that may exist in their current position were taken into consideration. A item pool containing 16 items was created by blending the objectives selected from the curriculum, misconceptions in the literature, and the textbooks in the MoNE 9th Grade Biology (2022) textbook. Since the visuals used in the items were not among the existing visuals, drawings were made by the researchers when necessary. The relationship of the items with the subject acquisitions and misconceptions is given in Table 1.

Table 1 Outcome-Misconception-Item Relationship

Acquisition	Misconceptions and misunderstandings	Item number
9.3.2.3.a. The reasons why viruses are not included in biological classification categories are briefly stated.	- Viruses show living and non-living characteristics (Kurt & Ekici, 2013; Muzembo et al., 2022). - They do not have DNA, they have RNA (Kurt & Ekici, 2013). - The structure of the virus contains ribosome (Kurt & Ekici, 2013). - Virus consists of RNA and protein sheath (Kurt & Ekici, 2013). - Virus consists of DNA and sheath (Kurt & Ekici, 2013). - Viruses do not carry RNA (Kurt & Ekici, 2013). - Viruses are malicious (Muzembo et al., 2022). - The virus is replicated by its own part (Muzembo et al., 2022). - The concept of bacteria and virus are used interchangeably (Büyük, 2017; Dumais & Hasni, 2009; Hürcan Gürler & Önder, 2014).	Item 1 Item 2 Item 8 Item 16
9.3.2.3.b. The effects of viruses on human health are discussed through rabies, hepatitis, influenza, herpes, AIDS diseases. Precautions against viral diseases are emphasised.	- Influenza is caused by bacteria (no relationship has been established with the virus) (Larson et al., 2009). - It is not known that flu and cold are caused by viruses (Büyük, 2017). - It is thought that antibiotics are used for viruses (Büyük, 2017; Hürcan Gürler & Önder, 2014; Yüzbaşoğlu & Atav, 2004). - They cannot name harmful microorganisms that cause diseases such as measles, polio, influenza, herpes, hepatitis B, AIDS, tuberculosis (Hürcan & Gürler, 2014). - There is no thought that there may be virus particles in the air (Yağbasan & Gülçiçek, 2003). - It negatively affects the body's immune system (Muzembo et al., 2022). - The immune system is formed as a result of virus infection (Dumais & Hasni, 2009).	Item 3 Item 4 Item 6 Item 7 Item 10 Item 11 Item 12 Item 13 Item 14 Item 15
9.3.2.3.c. It is emphasised that viruses offer new opportunities for studies in the field of genetic engineering.	- The concept of virus cannot be associated with daily life (Hürcan Gürler & Önder, 2014; İlkörücü-Göçmençelebi 2009, Yüzbaşoğlu & Atav, 2004).	Item 5 Item 9

An Expert Opinion Form was prepared to facilitate the determination of the content validity of the knowledge test created by the researchers and to provide the opportunity to evaluate it on common criteria. In the expert opinion form, firstly, the purpose for which the knowledge test was prepared was stated. The acquisitions of the items were explained in writing. A section was prepared to include demographic information (gender, professional status, education level, field of expertise and duration of experience) of the experts. The table given in Table 2 was added under each item and the experts were asked to evaluate each item separately.

Table 2 Example of an Expert Opinion Chart

Item 1				
Feature	Suitable for	Must be reorganised	Should be excluded from the test	Recommendation
Outcome relationship				
Activity relationship				
Pedagogically appropriate				
Substance difficulty				
Item root				
The suitability of the written language in terms of grammar				
Understandability				
Carrying bias				
Page structure				
Post format				
Font size				
Your advice on the item				

The opinions and suggestions of five experts in the field were obtained by using an expert opinion form. Demographic information of the experts is given in Table 3. In line with the opinions expressed by these experts, necessary arrangements were made in the item by the researchers.

Table 3 Demographic Information of the Experts

	Gender	Occupational status	Education level	Area of expertise	Experience (years)
1	Woman	Assoc. Prof. Dr.	PhD	Measurement and evaluation in education	7
2	Male	Assoc. Prof. Dr.	PhD	Molecular systematics	14
3	Woman	Teacher	Master's degree	Biology education	37
4	Woman	Teacher	Bachelor's degree	Turkish language and literature	21
5	Male	Teacher	Bachelor's degree	Turkish language and literature	2

Pilot Application of VBT and Data Analysis

The prepared knowledge test was applied face-to-face to 99 students in a qualified high school located in Karesi district of Balıkesir city. During the pilot application, students were given 40 minutes. In the evaluation of the knowledge test, scoring criteria and answer key were created by the researchers. In Figure 1, answer keys for two items are given as an example.

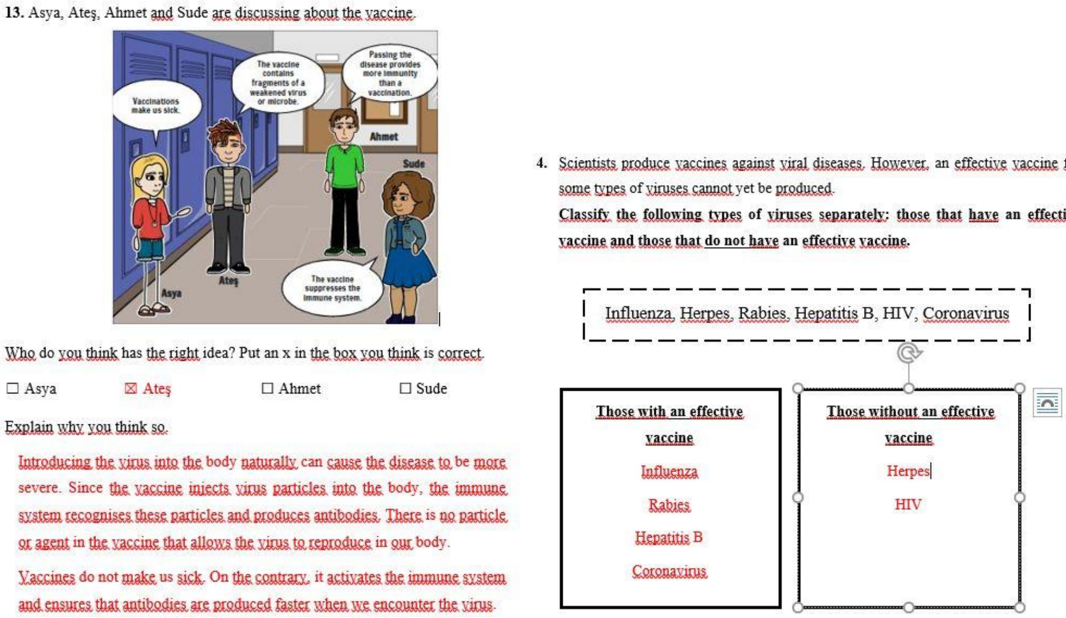

Figure 1 Example of Answer Key

Three different teachers were asked to evaluate the tests collected from the students using the answer key. The demographic information of the three teachers who made the scoring is given in Table 4.

Table 4 Demographic Information of the Raters

Rater	Occupational status	Education level	Area of expertise	Experience
Rater A	Teacher	PhD student	Biology education	11 years
Rater B	Teacher	Biology teacher	Biology education	9 years
Rater C	Teacher	PhD student	Biology education	5 years

To maintain scorer objectivity, they were asked to score by considering the answer key. The scoring criteria consisted of a binary system as true and false (coding as 0 and 1) was chosen for reliability analysis.

In order to measure inter-rater reliability, scoring was performed by 3 different raters and the inter-rater reliability coefficient was calculated by Pearson correlation (Table 5). The agreement between all raters was above .81, indicating that the inter-rater reliability was almost perfect (Landis & Koch, 1977). This emphasises the importance of the answer key and scoring criteria.

Table 5 Inter-Rater Reliability Coefficients

Rater	Rater A	Rater B	Rater C
Rater A	1	.864	.974
Rater B	.864	1	.945
Rater C	.974	.945	1

Since inter-rater reliability shows that the scoring does not change from one rater to another, the scores obtained were used to calculate item difficulty and item discrimination indices (Kutlu et al., 2009).

The data of this study were analysed with item difficulty and item discrimination indices from Classical Item Statistics (Koğar, 2021). The item difficulty index is calculated as the ratio of the number of correct answers to the item to the total number of students. It is classified as very easy between .80 -1.00, easy between .60 - .79, moderate between .40 - .59, difficult between .20 - .39, and very difficult between .00 - .19 (Crocker & Algina, 1986). Item discrimination index is the power to distinguish between an individual with a low score and an individual with a high score. It is calculated by correlation analysis and takes a value between -1 and +1 (Koğar, 2021; Şata, 2022). In the item discrimination index, .40 and above discriminates very well; .30 - .39 is used without correction; 20 - .29 is used with correction; .19 and below should be removed from the scale or revised (Crocker & Algina, 1986; Ebel, 1965).

According to the results of the data analysis, the revised VBT was finalised. The test, whose pilot study was completed in this way, was applied to 165 students from a different school at a similar level. The test data of 29 students who answered the test incompletely (leaving unanswered items) were not included in the analysis. Item analysis was performed on the obtained data and the reliability of the test was determined.

Validity and Reliability

A high-quality knowledge test should have high validity and reliability. Reliability is a prerequisite for validity. However, a test with high reliability may not be valid (Ercan & Kan, 2004). In the literature, expert opinion is used for test validity (Dalgülge, 2019; Hürcan & Önder, 2014; Mağden et al., 2003). As in this study, it is more accurate to look at the validity of the results obtained from the test and to analyse the items (Gönen et al., 2011). Validity types are content validity (the degree to which the scale serves the purpose), criterion validity (the relationship between the scores obtained from the scale and the criteria determined), construct validity (the pattern formed by interrelated items) and face validity (whether a test appears to measure what it's supposed to measure) (Ercan & Kan, 2004).

In this study, five experts in the fields of measurement and evaluation, molecular systematics, biology education, Turkish language and literature were asked to evaluate the items to determine content validity. The fact that all items of the VBT belong to the virus subject and cover the gains of MoNE (2018) shows that it provides construct validity. The instructions and items at the beginning of the test show that the test measures the level of knowledge about the virus subject.

There are many definitions of reliability (Erkuş et al., 2020): correlation between parallel tests (Crocker & Algina, 1986; Gulliksen, 1967; Lord & Novick, 1968); consistency of the scores of the same individuals taking the same test in different situations (Anastasi, 1976); internal consistency of the scores gained by an individual (Ghiselli et al., 1981); reproducibility of the result obtained from the instrument (Magnusson, 1967). Reliability is the state of being free from random errors, consistency and reproducibility of test scores (Gönen et al., 2011). Cronbach-Alpha method was preferred to measure the reliability of VBT. In addition, Pearson Correlation was used to determine the inter-rater reliability.

Findings

Item analysis was conducted to answer the question "What is the item difficulty index, item discrimination index and reliability of each item of VBT?". In this section, the findings of the pilot application and the implementation of VBT are given.

Item Difficulty and Item Discrimination Indices in Pilot Application of the Test

Difficulty and discrimination indices of the test items are given in Table 6. According to the item discrimination index (Crocker & Algina, 1986), items 1, 7, 8, 11 and 15 distinguish very well; items 5, 9, 12 and 14 are used without correction; item 16 is used with correction; item 2, 3, 4, 6, 10 and 13 should be revised.

Table 6 Item Difficulty and Item Discrimination Indices in the Pilot Study

Item	Item difficulty index (Pj)	Item difficulty level	Item discrimination index (r)	Item discrimination level
1	0.37	Difficult	0.42	Distinguishes very well
2	0.13	Very difficult	0.15	Should be reviewed
3	0.50	Medium level	0.15	Should be reviewed
4	0.23	Very difficult	0.07	Should be reviewed
5	0.31	Difficult	0.34	Used without correction
6	0.41	Medium level	0.13	Should be reviewed
7	0.32	Difficult	0.51	Distinguishes very well
8	0.22	Difficult	0.47	Distinguishes very well
9	0.14	Very difficult	0.32	Used without correction
10	0.22	Difficult	0.13	Should be reviewed
11	0.37	Difficult	0.55	Distinguishes very well
12	0.12	Very difficult	0.35	Used without correction
13	0.80	Very easy	0.18	Should be reviewed
14	0.11	Very difficult	0.30	Used without correction
15	0.08	Very difficult	0.47	Distinguishes very well
16	0.34	Difficult	0.29	Used by correction

According to the item difficulty index, items 2, 4, 9, 12, 14 and 15 were classified as very difficult; items 1, 5, 7, 8, 10, 11 and 16 as difficult; items 3 and 6 as medium; item 13 as very easy.

As a result of the pilot application, Cronbach α reliability coefficient for the whole test was determined as 0.58. According to the item discrimination level, the test was finalised after the 7 items, which were classified as should be revised and can be used with correction, were edited by the researchers.

Item Difficulty and Item Discrimination Indices of VBT

The difficulty and discrimination indices of the test items from the analysis of the data obtained by reapplication of the final version of VBT are given in Table 7. According to the item discrimination index (Crocker & Algina, 1986), items 3, 7, 10 and 13 were classified as very good discriminators; items 4, 5, 6, 9, 11, 14, 15 and 16 were classified as used without correction; items 1, 2, 8 and 12 were classified as used with correction.

Table 7 Item Difficulty and Discrimination Index of VBT

Item	Item difficulty index (Pj)	Item difficulty level	Item discrimination index (r)	Item discrimination level
1	0.85	Very Easy	0.20	Used by correction
2	0.06	Very difficult	0.21	Used by correction
3	0.07	Very difficult	0.43	Distinguishes very well
4	0.31	Difficulty	0.36	Used without correction
5	0.13	Very difficult	0.30	Used without correction
6	0.61	Easy	0.38	Used without correction
7	0.50	Medium Level	0.44	Distinguishes very well
8	0.10	Very difficult	0.23	Used by correction
9	0.29	Difficulty	0.36	Used without correction
10	0.44	Medium Level	0.41	Distinguishes very well
11	0.44	Medium Level	0.30	Used without correction
12	0.21	Difficulty	0.26	Used by correction
13	0.71	Easy	0.48	Distinguishes very well
14	0.19	Very difficult	0.32	Used without correction
15	0.12	Very difficult	0.37	Used without correction
16	0.51	Medium Level	0.38	Used without correction

According to the item difficulty index, items 2, 3, 5, 8, 14 and 15 were classified as very difficult; items 4, 9 and 12 as difficult; items 7, 10, 11 and 16 as medium; items 6 and 13 as easy; item 1 as very easy.

Cronbach α reliability coefficient for the whole VBT was found to be 0.66.

Conclusion and Suggestions

In order to develop the measurement tool, firstly, the learning outcomes in the secondary biology course curriculum MoNE (2018) were determined. Items of VBT were prepared by considering these acquisitions and misconceptions in the literature.

Good quality items allow students to create answers from their own point of view and produce original solutions to the problems they encounter during their daily experiences (Gülbetekin et al., 2019). They are effective in developing high-level thinking skills such as organising and synthesising information. Although it is thought to be easy to prepare, it is quite difficult to prepare a high quality item many of the drawings in the items in the VBT were made by the researchers with special programmes. Item contents were formed with data taken from daily life. The items were prepared in a way that students would think at a high level, form their own answers and organise their knowledge.

Expert opinions were taken to ensure the content validity of the prepared virus knowledge test. The pilot application of the test consisting of 16 items with content validity was carried out. The item difficulty index, item discrimination index and reliability of the VBT consisting of 16 items applied to 99 high school students in the pilot application and 165 high school students in the final application were examined. According to the results of the items difficulty index of the pilot application, 6 items were classified as very difficult, 7 items as difficult, 2 items as medium level, 1 item as easy. Item discrimination indices were determined as 5 items discriminate very well, 4 items are used without correction, 1 item is used with correction, 6 items should be revised. The Cronbach α reliability coefficient of the test in the pilot application was 0.58, indicating that it had low reliability. Considering these results, the test items were reviewed and reorganised by the experts.

According to the item difficulty index results obtained from the re-application of the edited version of the test, 6 items were classified as very difficult, 3 items as difficult, 4 items as medium level, 2 item as easy, 1 item as very easy. Item discrimination indices were determined as 4 items discriminate very well, 8 items are used without correction, 4 items are used with correction. The Cronbach α reliability coefficient of the VBT was 0.66, which indicates that the reliability is at a moderate level. The low number of items in the measurement tool may cause the reliability coefficient to be low (Kılıç, 2016). The high number of items categorised as very difficult and the high number of items requiring editing can be shown as factors that cause low reliability.

The fact that students think that long items are difficult reduces the rate of answering the questions (Koretz et al., 1993). It is thought that some of the items classified as very difficult in VBT are not answered by many students because they are too long. Long items require students to read and comprehend the text carefully and express their answers in writing, so the success rate of students in such exams is low (Temizkan & Sallabaş, 2011). During the implementation of VBT, it should be emphasised to the students that the long items should not scare them and that long items do not always mean that they are difficult. In today's national exams, long and interpretation-based items, which are called new generation, are used quite a lot. Students should overcome their prejudices against such items.

The most important disadvantage of items is scoring (Bahar et al., 2015). In this study, in order to make the scoring more reliable, scoring criteria were determined, an answer key was created and all students' first and second items were scored. The inter-rater reliability coefficient proves that the scoring is reliable. In this study, the importance of preparing the answer key in a very clear way was once again revealed.

When the obtained data were analysed, it was determined that VBT was valid and reliable for 9th grade high school students. This knowledge test can be used to measure the knowledge levels of students in the "World of Living Things" unit in which the virus subject is taught in biology courses.

In this study, a knowledge test on virus was introduced to the literature. VBT, which was developed to determine the effectiveness of teaching the subject and student achievement, will make a great contribution to the literature since it is the first study in the literature and the items are related to daily life.

Since the Covid-19 pandemic is a socio-scientific event that confronts individuals with scientific, ethical and moral dilemmas, it should be included in the curriculum to improve individuals' decision-making, scientific thinking and reasoning skills (Evren Yapıcıoğlu, 2020; Tyrrell & Calinger, 2020). The virus topic is included in the curriculum as the last unit and the last topic. It is necessary to teach such important socio-scientific subjects without interruption. The application of the developed VBT to a larger number of 9th grade students studying in Türkiye will contribute to increase the validity and reliability of the test.

Compliance with Ethical Standards

Disclosure of potential conflicts of interest

There is no conflict of interest to declare.

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CRediT author statement

All authors contributed equally to this work. The order of authorship has been arranged as agreed by all parties.

Research involving Human Participants and/or Animals

Since this study involved human participants, ethics committee permission was obtained.

Virüs Bilgi Testi: Geçerlik ve Güvenirlik Çalışması

Özet:

Virüsler yüzyıllardır birçok salgın hastalığa neden olmuş ve olmaya devam etmektedir. Bu salgınlar sırasında halk arasında yanlış anlaşılan ve uygulanan birçok örnek vardır. İnsanların bu varlıkları tanıması ve uygun önlemleri alması gerekmektedir. Türkiye'deki öğretim sürecinde öğrenciler virüsü ilk kez 9. sınıf biyoloji dersinde öğrenmektedir. Bu çalışma ile öğrencilerin virüs konusu ile ilgili bilgi düzeylerini belirlemede kullanılabilecek bir test geliştirilmesi amaçlanmıştır. Değişkenlere ilişkin verilerin toplandığı betimsel bir tarama çalışmasıdır. Pilot uygulamaya Balıkesir ili Karesi ilçesinde bulunan bir devlet lisesinin 9. sınıfında öğrenim gören 99 öğrenci gönüllülük esasına göre katılmıştır. Elde edilen veriler klasik madde istatistiklerinden madde güçlük ve madde ayırt edicilik indeksleri ile analiz edilmiştir. Son hali verilen Virüs Bilgi Testi (VBT), Karesi'den rastgele seçilen iki farklı devlet lisesinin 9. sınıflarında öğrenim gören 165 öğrenciye uygulanmıştır. VBT'nin tamamı için Cronbach α güvenirlik katsayısı 0.66 olarak bulunmuştur. Virüs konusunda literatürde güvenilirliği ve geçerliliği olan ilk virüs bilgi testi olması çalışmanın özgünlüğünü ortaya koymaktadır.

Anahtar kelimeler: Virüs, bilgi testi, geçerlik, güvenirlik.

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