

# Understanding by Design (UbD) Model in Mathematics Teaching and its Impact on Students

Özge Gürbüz<sup>a,\*</sup>, Nihal Yapıcı<sup>b</sup>

Received : 2 July 2025  
Revised : 17 February 2026  
Accepted : 19 April 2026  
DOI : 10.26822/iejee.2026.438

<sup>a</sup> **Corresponding Author:** Özge Gürbüz, Expert Mathematics Teacher, Ministry of Education, Türkiye.  
E-mail: ozgegurubuz@gmail.com  
ORCID: <https://orcid.org/0000-0001-7839-217X>

<sup>b</sup> Nihal Yapıcı, Department of Educational Sciences, Faculty of Educational Sciences, İbn Haldun University, İstanbul, Türkiye.  
E-mail: nihal.yapici@ihu.edu.tr  
ORCID: <https://orcid.org/0000-0002-1338-4467>

## Abstract

The purpose of this study was to examine the impact of Understanding by Design (UbD) model in mathematics teaching on students' creative thinking skills, cognitive flexibility, and learning retention. Employing a pre-test post-test control group quasi-experimental design, the study involved 40 seventh-grade students, with 20 in the experimental group and 20 in the control group, attending a public school in İstanbul, Türkiye. While mathematics lessons were conducted using unit plans developed with the UbD instructional design model in the experimental group, no changes were made to the teaching approach in the control group. Data collection tools included the Torrance Creative Thinking Test, Cognitive Flexibility Scale, and a mathematics follow-up test. Data analysis involved Mann-Whitney U Test and Wilcoxon Signed Ranks Test. The results revealed a significant difference favoring the experimental group in terms of creative thinking skills, cognitive flexibility, and learning retention. These results suggest that UbD model in teaching plans can serve as valuable tools in enhancing creative thinking, cognitive flexibility, and learning retention.

## Keywords:

Understanding By Design, Creative Thinking, Cognitive Flexibility, Learning Retention.

## Introduction

Learning mathematics is crucial and indispensable in all facets and stages of life, as it fosters advanced skills such as problem-solving, communication, and creative, autonomous, and analytical thinking (Surya et al., 2017). In traditional mathematics teaching, teachers often emphasize abstract mathematical concepts and formulas, which may sometimes be presented with fewer concrete examples (Schoenfeld, 2022). Students are then tasked with reproducing this information through given exercises. However, Kilcan (2005) states that the most important purpose of mathematics is to develop the thinking skills that people possess since they were born to the world. The effectiveness of mathematics courses, designed to cultivate skills like logical, communication, creative, and critical thinking—crucial for problem-solving in daily life, is questionable within a traditional classroom setting where the teacher holds exclusive control (Stigler & Hiebart, 2009). The notion of 21st-century skills, a relatively new concept in the literature, encapsulates a framework outlining the skills



www.iejee.com  
ISSN: 1307-9298

2026 Published by KURA Education & Publishing.  
This is an open access article under the CC BY-NC-ND license. (<https://creativecommons.org/licenses/by/4.0/>)

that children need to be equipped with as they are prepared for the world they inhabit. To keep pace with evolving global conditions and even to drive change, it is imperative to nurture individuals capable of comprehending their era, analyzing societal needs innovatively, and embracing lifelong learning as a lifestyle. Achieving these goals necessitates aligning the education system with the acquisition of 21st-century skills (Sholihah et al., 2017; Uçak & Erdem, 2020).

### *Problems in Traditional Mathematics Teaching*

Mathematics holds significant importance for improving students' cognitive capabilities and communication skills, both of which are vital for their everyday lives. However, most students struggle to develop an interest in mathematics, find it difficult to succeed in, and view it as abstract and unengaging. For some students, mathematics is a feared and hated subject (Huda et al., 2021). The challenges in mathematics education, such as insufficient concretization, lack of differentiation according to students' learning styles, and underutilization of necessary tools and materials, are widely recognized in the literature (Biber & Bakırcı, 2023; Filiz, 2023; Vitale et al., 2014). In education, the need for interactive methods where the learner is active, and the teacher is in a guiding position is increasingly evident in mathematics teaching as well (Hayati et al., 2024). Students struggle to learn subjects because they find it challenging to mentally visualize abstract concepts (Cao et al., 2021). For this reason, teachers should use various materials in their lessons to concretize abstract concepts.

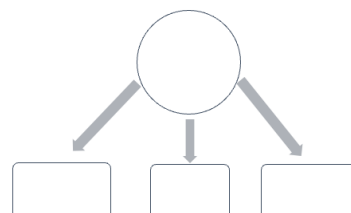
### *The Need for Innovative Approaches*

Altun and Yurtseven (2019, p. 17) state that "The teacher is not just someone who mechanically follows a pre-set script in the classroom; rather, they are the primary orchestrator who crafts the script based on the classroom's atmosphere and dynamics, engages with their students in enacting the script, and assesses the resulting outcomes." This perspective signifies a process of acquiring a new identity and adopting a different perspective. In the construction of this new identity, there is a need for qualified professional development processes and the enhancement of teachers' design skills (Garet et al., 2001). Among the areas contributing to teachers' professional development are subject knowledge, planning and instructional skills, assessment competency, classroom management, and addressing individual differences in learning. The concept that emerges from the combination of these knowledge and skills is instructional design and there are numerous instructional design models that can be used while crafting the learning environment (Belay et al., 2022; Risnanosanti et al., 2023). Understanding by Design (UbD) is among these instructional design models.

### *The Understanding by Design (UbD) Model*

The novel viewpoint introduced by UbD empowers teachers to shift from merely delivering pre-existing knowledge to students in a standardized format, enabling them to enhance both the teaching process and students' learning experiences, fostering active engagement in the learning journey (Yurtseven, 2016). From this perspective, learning retention is deeply connected to meaningful learning, as students are more likely to retain knowledge when they can actively apply it across different contexts. The ability to seamlessly transfer and utilize knowledge in various real-world situations demonstrates not only retention but also a deeper understanding, reinforcing the importance of instructional strategies that promote both long-term memory and practical application (Andrews et al., 2023). Moreover, the conveyance of content in teaching evolves from a fundamental objective to being a tool (Wiggins & McTighe, 2011). UbD stands as an instructional design framework emphasizing the cultivation of the learning retention and the transfer of knowledge to new environments through a backward design approach. The key aspects of this approach are setting goals that students can achieve, selecting evidence that demonstrates their achievement, and structuring activities accordingly (Altun & Yurtseven, 2019). Unlike traditional models where the learning plan takes precedence and the content delivery is prioritized, UbD puts strong emphasis on aspects such as students' inclination toward transfer of knowledge, their capacity to foster learning retention, and the emergence of evidence throughout the learning journey. UbD encourages students to investigate big ideas and find answers to essential questions, which improves higher-order thinking and the capacity to apply taught concepts across disciplines. The UbD framework excels at supporting creative thinking and cognitive flexibility. This model is frequently demanding in the sense that it encourages students to analyze, synthesize, and evaluate material and this promotes divergent and convergent thinking. Compared to other instructional design models that often emphasize content coverage and standardized assessments, UbD offers a structured yet flexible approach that is consistent with the goals of 21st-century skills, especially by promoting critical thinking, creativity, and problem-solving (Aristanti & Fatayan, 2024; Lai, 2023).

**Figure 1.**  
*Study Framework*



UbD possesses distinguishing features that set it apart from other design models, including the big idea, essential questions, understanding, and transfer. As outlined by Wiggins and McTighe (2005), big ideas are impactful statements that are both memorable and centered on the core of the subject matter. Essential questions, introduced at the onset of each unit, prompt students to seek answers based on the information they acquire throughout the unit, serving to ignite students' curiosity. Furthermore, they constitute a pivotal component of UbD, capable of dispelling any misconceptions that may have previously taken root in students through the responses provided during the learning process. Essential questions, characterized by criteria such as avoiding binary yes-or-no responses and not being readily sourced from a singular origin, also play a crucial role in motivating students and nurturing their capacity for creative thinking. Another fundamental aspect of UbD is understanding and transfer (Altun & Yurtseven, 2019). To effectively apply their existing knowledge to novel scenarios, individuals must first establish learning retention in their current knowledge base. A pedagogical approach centered on learning retention equips students with skills applicable throughout their educational journey, fostering their capacity for critical thinking and inquiry rather than focusing solely on short-term exam success (McTighe, Seif & Wiggins, 2004). In essence, transfer refers to students' ability to utilize the knowledge and skills acquired in school through their own cognitive abilities, both within and beyond academic settings and in unfamiliar contexts (Azaryahu et al., 2023; Wiggins & McTighe, 2007). From this perspective, it can be deduced that the transfer component lays the groundwork for learning retention among students.

In recent years, various cognitive skills such as analytical, critical, creative, lateral, reflective, and collaborative thinking have gained prominence in academic research and educational policies worldwide. Among these, creative thinking plays a pivotal role in fostering diverse thinking skills (Ritter & Mostert, 2016). It can be viewed that creative thinking skill, in this context, serves as a comprehensive task encompassing other high-level thinking skills. As highlighted by Evans et al. (2023), nurturing curiosity in lessons fosters students' inclination towards inquiry, prompting them to delve deeper into the questions that pique their interest. Research emphasizes the importance of nurturing creative thinking skills, particularly in educational contexts, to establish supportive settings that foster children's creativity (Kalogeratos et al., 2023; Khotinets & Shihsova, 2023; Nurjanah et al., 2024; Sari et al., 2021). Moreover, creative thinking is increasingly valued in the 21st century, underlining its significance in personal and professional realms (Misechko & Lytnyova, 2022). Various researchers have proposed that creativity comprises four core dimensions: fluency, flexibility, originality (authenticity), and elaboration (enrichment)

across diverse disciplines (Fisher, 1995; Rawlinson, 1981; Torrance, 1962). Creativity is essential for generating innovative solutions and outcomes, recognized as a metacognitive process that drives inventive problem-solving (Jung, 2013).

Various subjects have been linked to problem-solving skills, among which cognitive flexibility stands out. An individual who excels in problem-solving, a cognitive process, is also anticipated to demonstrate cognitive flexibility. Students' progress in mathematics learning hinges not only on their problem-solving skills but also on their cognitive flexibility (Taş & Deniz, 2018). Cognitive flexibility refers to an individual's capacity to restructure their own knowledge and respond adaptively to significantly changing situational demands (Martin & Rubin, 1995; Spiro et al., 1988). Drawing from these insights, Taş and Deniz (2018) have characterized cognitive flexibility as the ability to adopt different perspectives and the confidence in generating alternative solutions. In light of these definitions, flexibility and enrichment are observable within the dimensions of creative thinking skills inherent in cognitive flexibility. Flexibility entails embracing diverse viewpoints, exhibiting creativity in various forms, while enrichment involves delving into the intricacies of varied perspectives and evaluating them meticulously, all integral aspects of cognitive flexibility. Bilgin (2009) underscored the resemblance between cognitive flexibility and problem-solving skills, noting that both involve the exploration of diverse solutions. This observation highlights the significant and interconnected nature of cognitive flexibility and problem-solving skills. Individuals with high cognitive flexibility exhibit ease in making unexpected adjustments, while those with limited cognitive flexibility tend to resist change and encounter challenges (Mones & Massonnié, 2022). From this perspective, cognitive flexibility can be perceived as the capacity to adjust to varying circumstances, transition between different ideas, and approach diverse problems with multifaceted strategies. It encompasses the ability to alter response patterns, learn from mistakes, develop alternative strategies, allocate attention effectively, and process copious amounts of information simultaneously. Conversely, individuals lacking cognitive flexibility or possessing limited cognitive flexibility rely on rigid behavioral patterns and struggle to adapt to changes in sequence (Orakçı, 2021; Spiro et al., 1988).

Mathematics stands out as one of the most effective avenues for nurturing creative thinking skills, serving as a fundamental tool applicable in various facets of life and decision-making processes (Ibrahim et al., 2024). Hence, there exists a robust correlation between mathematics and creative thinking skills, which complement each other synergistically (Kim et al., 2016). By prioritizing and emphasizing the

problem-solving process, creativity can be fostered and observed during real-world problem-solving endeavors (Basadur et al., 2014). Implementing the UbD model in mathematics instruction entails designing and structuring lessons to facilitate students' comprehension and application of mathematical concepts. These plans offer significant advantages by also promoting and enhancing students' creative thinking capabilities. Within this framework, the UbD affords students the opportunity to cultivate problem-solving, critical thinking, and analytical skills. Engaging with and resolving real-world problems in mathematics classes contributes to the development of students' creative thinking skills. The emphasis on 'understanding' advocated by the UbD model encourages students to explore problems from diverse perspectives, fostering the discovery of innovative solutions (Wiggins & McTighe, 2005).

### Rationale and Significance of the Study

Mathematics education is vital for helping students develop key skills like problem-solving, communication, and analytical thinking. Yet, traditional teaching methods often fall short, as they focus heavily on memorization and abstract concepts, leaving little room for creativity, adaptability, or meaningful connections to real-life situations. Research has shown the importance of cause-and-effect reasoning in math (Thuneberg et al., 2018), integrating 21st-century skills into teaching (Azaryahu et al., 2023), using effective instructional materials (Kul et al., 2018), and employing strategies to boost student success (Gürbüz et al., 2022). Still, there's a noticeable lack of studies that explore how 21st-century skills can be developed or how learning can be retained using innovative, design-focused teaching methods. One promising approach is Understanding by Design (UbD), a framework that flips the traditional way of planning lessons by starting with the desired learning outcomes and working backward to create activities that help students achieve those goals. This method encourages deeper understanding and helps students apply what they've learned to new situations. However, research on how UbD affects creativity, cognitive flexibility, and learning retention is still limited. Filling this gap is especially important for mathematics, a subject often seen as difficult but uniquely suited to foster creativity and adaptability—two skills that are crucial for thriving in today's rapidly changing world. This study addresses that challenge by examining how using UbD in math instruction impacts students' creative thinking, cognitive flexibility, and ability to retain knowledge. It also compares these results to traditional teaching methods, aiming to shed light on how innovative teaching approaches can better prepare students to meet the demands of the 21st century. In this regard, the purpose of this study was to examine the impact of Understanding by Design

(UbD) model in mathematics teaching and its effects on students' creative thinking skills, cognitive flexibility, and learning retention. The research questions were outlined as follows:

1. What is the impact of the Understanding by Design (UbD) model on students' creative thinking skills in mathematics?
2. What is the impact of the Understanding by Design (UbD) model on students' cognitive flexibility in mathematics?
3. What is the impact of the Understanding by Design (UbD) model on students' learning retention in mathematics?

## Method

### Research Model

This study employed a quasi-experimental design with pre-test and post-test control groups to investigate the impact of UbD model in mathematics teaching on students' creative thinking skills, cognitive flexibility, and learning retention. While quasi-experimental studies do not involve randomization, they can still provide valuable insights into the impact of educational interventions. By comparing outcomes between groups that receive the intervention and those that do not, researchers can draw conclusions about the effectiveness of the intervention on the measured outcomes (Creswell, 2012). In this study, two pre-existing classes were designated as the experimental and control groups. Measurements were collected from both groups before and after the intervention to examine changes attributable to the UbD-based math instruction (Büyükoztürk et al., 2013). The research model can be found in Table 1.

**Table 1**  
*Research Model*

Group	Pre-Tests	Intervention	Post-Tests
Experimental Group	Creative Thinking Test 1 Cognitive Flexibility Scale 1 Math Follow-Up Test 1	UbD-Based Math Instruction	Creative Thinking Test 2 Cognitive Flexibility Scale 2 Math Follow-Up Test 2
Control Group	Creative Thinking Test 1 Cognitive Flexibility Scale 1 Math Follow-Up Test 1	Traditional Math Instruction	Creative Thinking Test 2 Cognitive Flexibility Scale 2 Math Follow-Up Test 2

As seen in Table 1, the study included an instructional intervention, and pre and post-tests for both the experimental and control groups. The experimental group received UbD-Based Math Instruction, while the control group followed traditional math instruction. Both groups were assessed before and after the intervention using Creative Thinking Tests, the Cognitive Flexibility Scale, and the Math Follow-Up

Test to measure changes in learning outcomes.

### Participants

The participants consisted of a total of 40 seventh-grade students, 20 of which were experimental and 20 of which were control students, enrolled in a public secondary school in Istanbul, Türkiye. Within the experimental group, 55% were female and 45% were male, in the control group, the gender distribution was 53% female and 47% male. The convenience sampling technique was used since the first researcher's students were included in the study, making it easier to access and involve participants and it ensured the feasibility and practicality of the study. The experimental and control groups were formed based on the principle of neutrality, ensuring that both groups had comparable academic achievement levels during the selection process.

### Measures

Torrance Creative Thinking Test Verbal A and B forms, Torrance Creative Thinking Test Figural A and B forms, Cognitive Flexibility Scale and Mathematics Follow-Up Tests were used to collect the data in the study.

**Torrance Test of Creative Thinking.** The Torrance Test of Creative Thinking was published by Torrance (1966) and The Turkish equivalence, validity, and reliability studies for the test were conducted by Aslan (1999), affirming its validity and reliability in the Turkish context. Reliability assessments included test-retest and internal consistency calculations, yielding Cronbach's alpha correlation coefficients ranging between .89 and .86 for primary education. The test comprised verbal and figural subtests in two separate parallel forms, A and B. Each form consisted of 10 activities, with 7 in the verbal form and 3 in the figural form. Verbal tasks encompassed activities such as asking questions, estimating reasons, estimating results, product development, unusual uses, unusual questions, and achievement tests. The figural tasks involved picture construction, picture completion, and lines/circles tests, respectively. Following studies by Torrance and Ball (1984), new scoring criteria were established for the figural tests, resulting in two sets of scores: Norm-Resistant and Criterion-Resistant. Norm-resistant scores included originality, fluency, abstractness of titles, enrichment, and resistance to premature closure, whereas criterion-resistant scores consisted of thirteen categories, including emotional expression, story expression, movement or activity, expressiveness of titles, synthesis of incomplete figures, synthesis of lines, unconventional visualization, internal visualization, extending or crossing boundaries, humor, richness of imagination, colorfulness of imagination, and fantasy. The verbal form A booklet and figural form A booklet were administered as pre-tests, while the verbal form B booklet and figural form B booklet

were administered as post-tests. Scoring of the administered Torrance Tests of Creative Thinking was conducted using a scoring guide. The scoring guide included a compilation of sentences that students might write (approximately 75-100 sentences) and specified the points that could be obtained for each sentence. Scoring for the figural forms was based on sub-dimensions such as fluency, originality, abstractness of titles, enriching details, resistance to premature closure, and creative strengths list.

**Cognitive Flexibility Scale.** Developed by Martin and Rubin (1995), Çelikkaleli (2014) studied the validity and reliability of the Turkish version of the Cognitive Flexibility Scale. The scale was a 6-point Likert-type measurement tool with responses ranging from 1 (strongly disagree) to 6 (strongly agree). The scale included items related to understanding the problem solving and cognitive flexibility levels of the participants. Following the adaptation study, the 11-item Turkish version of the scale, originally comprising 12 items, demonstrated a unidimensional structure that aligned with both exploratory (EFA) and confirmatory factor analysis (CFA) results. In reliability studies, internal consistency coefficients in three different samples were obtained as .74, .73 and .75 respectively.

**Mathematics Follow-Up Tests.** Follow-up tests were created and administered by the first researcher before and after the intervention to assess students' learning retention levels. These follow-up tests were designed based on the learning outcomes outlined in the unit plans. Initially, a pre-test encompassing all the learning outcomes for the semester was administered to two separate groups just before the intervention process. The multiple-choice test consisted of 20 questions and was scored on a scale of 100. The second follow-up test, administered after the implementation process was completed, served as a post-test for two distinct groups. Like the pre-test, the post-test contained 20 multiple-choice questions, with scores measured on a 100-point scale. Since the test was prepared by the teacher, steps were taken to ensure its validity and reliability. To ensure content validity, initial item pools of questions were generated based on the learning outcomes specified in the curriculum for both tests. Three mathematics education experts independently reviewed each item for relevance, alignment with the curriculum, cognitive level, and linguistic clarity. Revisions were made based on their feedback, and overlapping or irrelevant items were removed from tests. Before the implementation, each test underwent a pilot study with separate groups of students who were not included in the main study to evaluate clarity, difficulty level, and consistency. The item difficulty and discrimination indexes were calculated. Item difficulty ratings varied from .40 to .78, indicating a moderate overall difficulty level, while item discrimination values ranged from .32 to .67, meeting suggested levels

for classroom assessment tools. Items falling below acceptable limits were revised or replaced prior to final administration. Internal consistency reliability was examined using Cronbach's alpha. The pilot study yielded an alpha coefficient of .81, and the final version produced an alpha of .84 in the main study, indicating good reliability.

### Data Analysis

The Mann-Whitney U Test and Wilcoxon Signed Ranks Test were employed to analyze the data due to the small sample size and non-parametric nature of the data distribution. These methods are appropriate for comparing pre-test and post-test scores within and between groups.

### Procedure

As part of the study, official approval was obtained from the school administration where the intervention took place, as well as ethics committee approval from the researchers' affiliated university. Subsequently, two separate classrooms were set up, each assigned to either the experimental or control group. Throughout the semester, continuous evaluations were conducted to monitor the progress of the experimental process and ensure its effectiveness.

For the experimental group, seven unit plans were crafted in accordance with the UbD instructional design model. For each unit, Stage 1 identified the desired learning outcomes aligned with the national mathematics curriculum; Stage 2 specified acceptable evidence of learning, including performance tasks and formative assessments; and Stage 3 outlined the detailed learning experiences and instructional activities. To strengthen creative thinking and cognitive flexibility, the lessons incorporated open-ended tasks, problem-based activities, and structured games that required reasoning, flexible thinking, and multiple-solution exploration. The lesson plans included specially designed materials, such as manipulatives, graphic organizers, learning stations, and reflective worksheets. The researcher-teacher prepared all necessary resources (e.g., task cards, visual prompts, digital applets, and problem scenarios) and ensured their availability before each session. To enrich the cultivation of creative thinking skills and cognitive flexibility among students, specific components tailored to these aspects were integrated into the lesson plans. Careful selection of games and activities aimed at nurturing creative thinking and cognitive flexibility ensued to meet these objectives. Furthermore, supplementary materials and resources essential for the smooth execution of these activities were identified, prepared, and made readily accessible by the researchers.

To illustrate the instructional process, the unit on "Polygons" included a 150-minute lesson implemented as follows:

1. Hook / Warm-Up (10 minutes): To spark students' curiosity and interest, the lesson began by introducing the "big idea." The big idea was discussed together with the students. For the polygons unit, the big idea was introduced by showing students an image of a shape composed of many overlapping triangles and asking, "How many triangles do you think are in this figure?" a discussion environment was created based on students' responses.

2. Exploration Task (50 minutes): First, the questions "What is a polygon?", "Where do we encounter polygons in our daily lives?", "How do we define a polygon?", and "Is every shape in geometry a polygon?" were presented to the students, and a brainstorming session was conducted to collect their ideas. The purpose of this stage was to assess students' prior knowledge and eliminate any misconceptions they held. Using the fishbowl (Aquarium) discussion technique, students expressed their thoughts on statements that were open to debate or closely related to possible misconceptions. Sample questions included:

*"Is a rhombus a regular polygon?"*

*"Can we draw a polygon with infinitely many sides?"*

*"How do we calculate the sum of the interior angles of a polygon?"*

*"Can a polygon be drawn using only two line segments?"*

*"Does a triangle have a diagonal?"*

The teacher asked these questions in an order aligned with the unit outcomes. Using students' responses, the topic was taught systematically, and misconceptions were addressed.

3. Concept Development (30 minutes): The activity "Create Your Cubism Artwork" was implemented. The Six Thinking Hats technique was used during this activity. Students were asked to research the influence of Cubism in artwork. Then, examples of Picasso's Cubist paintings were shown in class. Each student was given one of the six hat colors and asked to create their own artwork in the Cubist style, ensuring that the polygon types learned in the lesson were prominently used in their drawings. Afterwards, students presented their artwork and explained their perspectives based on the color of their hat. The goal of using the Six Thinking Hats technique was to develop students' creativity, multi-dimensional thinking, and decision-making skills.

4. Performance Task (50 minutes): The performance task titled “What If Countries Had Polygon Shapes?” was carried out. Students examined the world map and the borders of countries and then redesigned these borders so that each country would become a polygon (based strictly on the polygon rules discussed in class—for example, all polygons must have straight edges, and every polygon must be a closed shape). In this task, students assumed the role of map engineers who highly value art. They presented their performance task to an audience consisting of their classmates and teacher. While creating their redesigned maps, students were free to use all types of polygons they had learned (such as concave or convex polygons). Throughout the task, the teacher served as a guide, and students kept a project journal in which they documented and planned their process. A rubric prepared by the teacher beforehand was used to assess students’ performance.

5. Reflection (10 minutes): Finally, a summary activity titled “What Did We Learn?” was conducted to review the unit. Students completed a brief reflection card focusing on how they used flexible reasoning during

the activity. Table 2 demonstrates examples about the linking of learning outcomes to UbD-based tasks and types of thinking:

These examples demonstrate how UbD stages were operationalized through authentic, inquiry-driven, and creativity-enhancing learning activities. While the experimental group engaged in lessons structured as described above, the control group followed the school’s standard mathematics curriculum using traditional direct instruction, textbook-based practice, and routine exercises. No UbD-specific activities, open-ended tasks, or creativity-focused materials were used.

Following the comprehensive preparations for the experimental process, pre-tests were administered to gauge students’ baseline levels, after which the planned implementations commenced. Throughout the implementation period, rigorous attention was devoted to ensuring that the activities effectively elicited creative thinking and cognitive flexibility, thereby fostering a vibrant and captivating learning environment for the students.

**Table 2**

*Examples about learning outcomes, UbD-based tasks, and types of thinking*

Unit Name	Learning Outcome	UbD-Integrated Activity	Type of Thinking Targeted
1. Ratio and Proportion	Students understand that the constant of proportionality in direct proportion is obtained by dividing one quantity by another.	“MiniaWorld 3D Virtual Tour” activity	Creative thinking: • Enrichment • Flexibility Cognitive flexibility: • Ability to view from different perspectives
2. Percentages	Students understand that concepts such as discount, increase, inflation, and decrease become easier to interpret when expressed using percentages.	“Silent Cinema with Percentages” activity	Creative thinking: • Fluency • Flexibility Cognitive flexibility: • Awareness and use of alternative options
3. Lines and Angles	Students understand that angles are the fundamental factor in the construction of all structures—small or large, simple or magnificent—worldwide.	“Let My Bicycle Describe Me” activity	Creative thinking: • Originality • Richness Cognitive flexibility: • Transferability of knowledge to new contexts
4. Polygons	Students understand that a polygon cannot be drawn with two line segments, and that at least three line segments are required for a closed shape.	“What If Countries Had Polygon Shapes?” activity	Creative thinking: • Richness • Fluency Cognitive flexibility: • Moving away from narrow and rigid viewpoints
5. Circle and Disk	Students state that the filled interior of a circle is a disk, and that the region between the arms of a central angle is a sector of the disk.	“Alternative Mandala: Slices from Nature” activity	Creative thinking: • Originality • Enrichment Cognitive flexibility: • Transferability of knowledge

**Results**

Determining the readiness levels of the experimental and control groups before the implementation is important for the healthier conduct of the research. As such, initially, the pre-test scores of both groups in verbal creativity, figural creativity, cognitive flexibility, and learning assessments were compared using the Mann-Whitney U Test. Table 3 displays the pre-test scores of students in verbal creativity, Table 4 shows the pre-test scores of students in figural creativity, Table 5 outlines the pre-test scores of students in cognitive flexibility, and Table 6 illustrates the pre-test scores of students in the learning assessment, based on the results of the Mann-Whitney U Test.

**Table 3**  
*Results of Mann-Whitney U Test Regarding Verbal Creativity Pre-test Scores*

	N	Average Rank	Total Rank	U	p	Effect Size (r)
Experimental Group	20	16.95	339.00	129.00	.055*	0.30
Control Group	20	24.05	481.00			

\* p>0.05

Table 3 presents the results regarding the Mann-Whitney U test conducted on the verbal creativity scores of the students participating in the study to determine whether there was a difference in verbal creativity pre-test scores between the experimental and control groups. The analysis revealed that there was no significant difference in the pre-test scores of verbal creativity between the experimental and control groups ( $U = 129.00, p > 0.05, r = 0.30$ ).

**Table 4**  
*Results of Mann-Whitney U Test Regarding Figural Creativity Pre-test Scores*

	N	Average Rank	Total Rank	U	p	Effect size (r)
Experimental Group	20	19.95	399.00	189.00	.76*	0.04
Control Group	20	21.05	421.00			

\* p>0.05

The results of the Mann-Whitney U Test concerning the pre-test scores of students' figural creativity are displayed in Table 4. The analysis indicated that there was no significant difference in figural creativity pre-test scores between the experimental and control groups ( $U = 189.00, p > 0.05, r = 0.04$ ).

**Table 5**  
*Results of Mann-Whitney U Test Regarding Cognitive Flexibility Pre-Test Scores*

	N	Average Rank	Total Rank	U	p	Effect size (r)
Experimental Group	20	18.52	370.50	160.50	.28*	0.17
Control Group	20	22.48	449.50			

\* p>0.05

The results of the Mann-Whitney U test regarding the cognitive flexibility scores of the students involved in the study are shown in Table 5, examining whether there were variations in the cognitive flexibility pre-test scores between the experimental and control groups. According to the analysis, there was no notable distinction in cognitive flexibility pre-test scores between the experimental and control groups ( $U = 160.50, p > 0.05, r = 0.17$ ).

**Table 6**  
*Results of Mann-Whitney U Test Regarding Learning Pre-Test Scores*

	N	Average Rank	Total Rank	U	p	Effect size (r)
Experimental Group	20	20.88	417.50	192.50	.83*	0.03
Control Group	20	20.13	402.50			

\* p>0.05

Table 6 presents the results of the Mann-Whitney U test regarding the learning scores of the students participating in the research, examining whether the learning pre-test scores differed between the experimental and control groups. The analysis revealed that there was no significant difference in learning pre-test scores between the experimental and control groups ( $U = 192.50, p > 0.05, r = 0.03$ ).

**Results Regarding the First Research Question**

To answer the first research question, which was stated as "What is the impact of the Understanding by Design (UbD) model on students' creative thinking skills in mathematics?", the pre-test and post-test scores of students from the Torrance Test of Creative Thinking Test were compared.

**Table 7**  
*Results of the Mann-Whitney U Test Regarding Verbal Creativity Post-Test Scores*

	N	Average Rank	Total Rank	U	p	Effect size (r)
Experimental Group	20	30.50	610.00	0.00	.00*	0.85
Control Group	20	10.50	210.00			

\* p<0.05

Table 7 displays the results concerning the distinction in post-test scores for verbal creativity between the experimental and control groups. The analysis indicated a significant difference in verbal creativity post-test scores between the experimental and control groups ( $U = 0.00, p < 0.05$ ). Furthermore, a large effect was found in favor of the experimental group ( $r = 0.85$ ), indicating strong gains in verbal creativity. In other words, the post-test scores for verbal creativity were markedly higher in the experimental group compared to the control group, indicating a notable impact of the intervention on enhancing verbal creativity skills.

**Table 8**  
Results of the Mann-Whitney U Test Regarding Figural Creativity Post-Test Scores

	N	Average Rank	Total Rank	U	p	Effect size (r)
Experimental Group	20	29.35	587.00	23.00	.00*	0.75
Control Group	20	11.65	233.00			

\* p<0.05

Table 8 presents the results regarding the difference in figural creativity post-test scores between the experimental and control groups of the students participating in the research. The analysis revealed that there was a significant difference in figural creativity post-test scores between the experimental and control groups ( $U = 23.00, p < 0.05$ ) and a significant and large effect favored the experimental group ( $r=0.75$ ). In other words, it was found that figural creativity post-test scores favored the experimental group.

**Table 9**  
Results of the Wilcoxon Signed Ranks Test for Experimental Group Verbal Creativity Pre-Test and Post-Test Scores

Pre-Test – Post-Test	N	Average Rank	Total Rank	Z	p	Effect size (r)
Positive Rank	18	10.83	195.00	-3.36	.01*	0.75
Negative Rank	2	7.50	15.00			
Equal	0					

\*p < 0.05

Table 9 illustrates the results of the Wilcoxon Signed Ranks Test aimed at assessing the potential difference between the pre-test and post-test scores for verbal creativity within the experimental group. The examination unveiled a statistically significant difference between the pre-test and post-test scores ( $Z = -3.36, p < 0.05$ ) and there was a large effect size ( $r = 0.75$ ). This difference favored the post-test outcomes, suggesting a significant enhancement in the verbal creativity scores of students following the group interventions.

**Table 10**  
Results of the Wilcoxon Signed Ranks Test for Verbal Creativity Pre-Test and Post-Test Scores of the Control Group

Pre-Test – Post-Test	N	Average Rank	Total Rank	Z	p	Effect size (r)
Positive Rank	0	0.00	0.00	-3.92	.00*	0.88
Negative Rank	20	10.50	210.00			
Equal	0					

\*p<0.05

Results of the Wilcoxon Signed Ranks Test for Verbal Creativity Pre-Test and Post-Test Scores of the Control Group are presented in Table 10. The analysis revealed that there was a statistically significant difference between the pre-test and post-test scores ( $Z=-3.92, p<0.05$ ) and the effect size was large ( $r=0.88$ ). This difference occurred in favor of the pre-test.

**Table 11**  
Results of the Wilcoxon Signed Ranks Test for the Pre-Test and Post-Test Scores of Figural Creativity of the Experimental Group

Pre-Test – Post-Test	N	Average Rank	Total Rank	Z	p	Effect size (r)
Positive Rank	17	11.71	199.00	-3.51	.00*	0.79
Negative Rank	3	3.67	11.00			
Equal	0					

\*p<0.05

Table 11 displays the outcomes of the Wilcoxon Signed Ranks Test assessing the pre-test and post-test scores of figural creativity within the experimental group. The analysis uncovered a statistically significant difference between the pre-test and post-test scores with a large effect size ( $Z = -3.51, p < 0.05, r = 0.79$ ). This difference favored the post-test scores. In other words, the figural creativity scores of the students in the experimental group significantly increased after the interventions.

**Table 12**  
Results of the Wilcoxon Signed Ranks Test for the Pre-Test and Post-Test Scores of Figural Creativity of the Control Group

Pre-Test – Post-Test	N	Average Rank	Total Rank	Z	p	Effect size (r)
Positive Rank	0	0.00	0.00	-3.92	.00*	0.88
Negative Rank	20	10.50	210.00			
Equal	0					

\*p<.05

As seen in Table 12, the Wilcoxon Signed Ranks Test was conducted to determine if there was a significant difference between the pre-test and post-test scores of figural creativity for the students in the control group. The statistical analysis revealed a significant difference in the ranks' means with a large effect size ( $Z = -3.92, p < 0.05, r = 0.88$ ). This difference favored the pre-test scores.

**Results Regarding the Second Research Question**

To answer the second research question, stated as "What is the impact of the Understanding by Design (UbD) model on students' cognitive flexibility in mathematics?", the pre-test and post-test scores of students from the Cognitive Flexibility Scale were compared.

**Table 13**  
Results of the Mann-Whitney U Test Regarding Cognitive Flexibility Post-Test Scores

	N	Average Rank	Total Rank	U	p	Effect size (r)
Experimental Group	20	30.10	602.00	8.00	.00*	0.82
Control Group	20	10.90	218.00			

\*p<0.05

Table 13 displays the analyses of the Mann-Whitney U test regarding the cognitive flexibility scores of the participating students. According to the analyses, there was a significant difference in cognitive flexibility post-test scores between the experimental and control groups with a large effect size ( $U = 8.00, p < 0.05, r = 0.82$ ). In other words, cognitive flexibility post-test scores favored the experimental group.

**Table 14**  
Results of the Wilcoxon Signed-Rank Test for Experimental Group Cognitive Flexibility Pre-Test and Post-Test Scores

Pre-Test – Post-Test	N	Average Rank	Total Rank	Z	p	Effect size (r)
Positive Rank	20	10.50	210.00	-3.92	.00*	0.88
Negative Rank	0	0.00	0.00			
Equal	0					

\*p<.05

Table 14 illustrates the results of the Wilcoxon Signed-Rank Test for the pre-test and post-test scores of cognitive flexibility in the experimental group. The analysis indicated a statistically significant difference between the pre-test and post-test averages with a large effect size ( $Z = -3.92, p < 0.05, r = 0.88$ ). This difference favored the post-test. In other words, the cognitive flexibility scores of the experimental group students significantly increased after the group interventions.

**Table 15**  
Results of the Wilcoxon Signed-Rank Test Regarding Control Group Cognitive Flexibility Pre-Test and Post-Test Scores

Pre-Test – Post-Test	N	Average Rank	Total Rank	Z	p	Effect size (r)
Positive Rank	18	10.36	186.50	-3.76	.00*	0.84
Negative Rank	1	3.50	3.50			
Equal	1					

\*p<.05

Table 15 displays the outcomes of the Wilcoxon Signed-Rank Test conducted to determine whether there was a significant difference between the cognitive flexibility pre-test and post-test scores of the control group students. According to the analysis, there was a statistically significant difference between the pre-

test and post-test means with a large effect size ( $Z = -3.76, p < 0.05, r = 0.84$ ). This difference occurred in favor of the post-test. In other words, the cognitive flexibility scores of the students in the control group significantly increased after the group interventions.

### Results Regarding the Third Research Question

To answer the third research question, "What is the impact of the Understanding by Design (UbD) model on students' learning retention in mathematics?", the pre-test and post-test scores of students from the mathematics course follow-up test were compared.

**Table 16**  
Results of the Mann-Whitney U Test Regarding Learning Retention Post-Test Scores

	N	Average Rank	Total Rank	U	p	Effect size (r)
Experimental Group	20	26.00	520.00	90.00	.03*	0.47
Control Group	20	15.00	300.00			

\*p<0.05

Table 16 displays the results of the Mann-Whitney U test regarding the learning retention scores of the students involved in the study. The analysis indicated a notable distinction in learning post-test scores between the experimental and control groups with a medium effect size ( $U = 90.00, p < 0.05, r = 0.47$ ). In other words, it was found that learning retention post-test scores favored the experimental group.

**Table 17**  
Results of the Wilcoxon Signed Ranks Test Regarding Pre-Test and Post-Test Scores of the Experimental Group for Learning Retention

Pre-Test – Post-Test	N	Average Rank	Total Rank	Z	p	Effect size (r)
Positive Rank	20	10.50	210.00	-3.94	.00*	0.88
Negative Rank	0	0.00	0.00			
Equal	0					

\*p<.05

As can be seen in Table 17, the analysis regarding pre-test and post-test scores of the experimental group for learning retention revealed a statistically significant difference between the pre-test and post-test averages with a large effect size ( $Z = -3.94, p < 0.05, r = 0.88$ ). This difference favored the post-test scores, indicating that the learning retention scores of the experimental group significantly increased after the group interventions.

**Table 18**

*Results of the Wilcoxon Signed Ranks Test Regarding Pre-Test and Post-Test Scores of the Control Group for Learning Retention*

Pre-Test – Post-Test	N	Average Rank	Total Rank	Z	p	Effect size (r)
Positive Rank	11	9.86	108.50	-.55	.58*	0.12
Negative Rank	8	10.19	81.50			
Equal	1					

\* $p > .05$

The Wilcoxon Signed Ranks Test was conducted to determine if there was a significant difference between the pre-test and post-test scores obtained from the learning retention test by the students in the control group. As seen in Table 18, the analysis revealed that there was no statistically significant difference between the mean scores of the pre-test and post-test and the effect size was small ( $Z = -.55$ ,  $p > 0.05$ ,  $r = 0.12$ ).

## Discussion

The study demonstrated that UbD model in mathematics teaching had a positive impact on students' creative thinking skills, cognitive flexibility, and learning retention. The experimental group showed significantly higher post-test scores compared to the control group in all three areas, indicating the effectiveness of these interventions. These findings highlight the potential of UbD model to enhance critical cognitive and creative skills in secondary school mathematics education. The results support the integration of UbD principles into teaching practices to improve student outcomes and suggest further research to validate these benefits across diverse educational settings and extended timelines.

A further analysis of the learning–teaching experiences adopted in the experimental group could provide basis for understanding these positive findings. Performance tasks, real life problem scenarios, concept maps construction and model development were some of the activities in which students were involved during the UbD intervention program in this study to enable them to apply mathematical concepts in reality. Essential questions and big ideas supported learners to think deeply conceptually, while intentionally constructed formative assessments prompted them to explain their thinking, challenge assumptions, and further develop their ideas. In addition, the learning environment situated students as problem-solvers and designers rather than consumers of knowledge passively waiting to be filled. Over time, hands-on materials, group-based investigations, and opportunities for diverse solution paths supported creativity and cognitive flexibility as students were constantly asked to create alternatives, consider

options and justify decisions. These specific aspects of the practice of UbD – in particular, a focus on transfer, authentic tasks, and student agency – led directly to the significant gains in creative thinking, cognitive flexibility and learning retention found with students participating in experimental group.

The UbD instructional design model holds significant importance in enabling students to engage in various actions such as designing, exhibiting, deriving, modeling, illustrating, narrating metaphorically, storytelling, constructing, producing original products, inventing, imagining, and role-playing, thus contributing to the demonstration of their creativity during math classes. The UbD-based activities initiated in the experimental group in this study certainly helped produce these gains, and a clear cause-effect relationship can therefore be drawn between the instruction and its effects. Throughout the whole intervention, students used concrete materials, created models, formulated their own questions and reflected in classroom discussions that were organized based on big ideas and essential questions. These activities enabled students to reflect on the problems from several viewpoints, generate new solutions and progressively elaborate upon them. Since the instructional design constantly placed students in a needful position for designing, reasoning, representing and evaluating while operating the dynamic models, only through independent practicing their creative thinking power could be strengthened instead of simply exposure to. In the control group, in contrast, opportunities pertained to direct explanation and procedural exercises. As a result, the fact that the control group achieved lower creativity scores reflects in their limited chances to conceptualise or develop other concepts or come up with unique ideas.

A creative learning environment is essential for children to demonstrate their creative thinking skills. Learning environments where children interact with each other the most, when designed accordingly, will facilitate the development of their creative abilities (Fan & Cai, 2020). Moreover, it is important to provide a learning environment where students are active, can apply what they have learned to real-life situations, and can acquire long-term knowledge and skills, as opposed to traditional and memorization-based learning (Som et al., 2016). Considering that traditional teaching methods were applied in the control group, it was observed that control group students experienced disengagement from classes, submitted their assignments late and carelessly, and their interest and attendance in classes decreased over time. This situation is thought to have affected the students' post-test results. From this perspective, it can be said that UbD's unique learning approach, encouraging curiosity, interaction, and active learning experiences, contributes to the creative thinking skills of the experimental group students.

The higher average post tests results in the experimental group can be understood by examining how students were engaged during learning. UbD-based lessons were always learner-active lessons: students engaged in collaborating tasks to solve problems; they discussed aloud alternative ways to solve them and give reasons for it with their classmates; they compared representations of mathematical entities. In addition to promoting deeper understanding, the structured opportunities for dialogue and collaboration stimulated students' consideration of multiple perspectives—a strong predictor both of creativity and cognitive flexibility. Concrete examples provided for students helped them understand abstract ideas, which in turn supported stronger understanding and enabled more consistent retention of information. Thus, the better performance of the experimental group is not merely an effect but instead a natural consequence of participatory, interactive and meaning-centred learning processes integrated in the UbD framework.

The emergence of cognitive flexibility depends on two types of interaction: the interaction of several cognitive mechanisms and the interaction of sensory-motor mechanisms, cognition, and context over developmental time. Comprehensive and integrated cognitive flexibility is highly beneficial and important in encouraging students to engage in effective problem-solving and creativity (Lonescu, 2012). Cognitive flexibility holds significant importance in the education of students, shaping them into individuals capable of navigating life successfully, adapting to new circumstances and changes, fostering curiosity, productivity, creativity, and innovation. It entails the capacity to alter response patterns, derive lessons from errors, devise alternative approaches, manage attention effectively, and handle substantial information simultaneously (Gabrys et al., 2018). This is because cognitive flexibility focuses on the transfer of knowledge and the use of knowledge in different learning environments after initial learning situations (Braem & Egner, 2018; Tello-Ramos et al. 2019). The UbD model in mathematics teaching conducted in the scope of the research contributed to the development of the mentioned skills in lessons within the framework of cognitive flexibility. Flexible learning processes, where information can be used from different perspectives and alternative solutions to problems are sought, provide valuable contributions to the development of such skills.

The fundamental concept of transfer, emphasized by the UbD instructional design model, highlights areas where students can transfer what they have learned to independent and new learning environments, corresponding to their needs for lasting understanding or learning. For a teacher to determine whether their students have genuinely learned and comprehended

the material, they need to pay attention to certain actions during the application process, such as explaining, expressing, convincing, predicting, proving, synthesizing, evaluating, transforming, judging, suggesting, utilizing, making decisions and choices, investigating reasons, comparing, distinguishing similarities and differences, drawing conclusions, making connections, being aware, self-assessing, and empathizing (Altun & Yurtseven, 2019). A teaching process based on enduring understanding not only contributes to students' success in short-term exams but also helps them acquire skills they can use throughout their educational lives, enhancing their critical thinking and questioning abilities (McTighe et al., 2004). In this context, the studies conducted within the scope of the current study may have had a positive impact on the learning retention levels of the experimental group students.

"Schools may perceive themselves as ambitious when striving to achieve uniformity among all students, yet they fail to recognize that educational systems promoting homogeneity inadvertently label themselves as dull institutions that overlook the unique differences among students." (Altun & Yurtseven, 2019, p. 22). However, in the 21st century, to adapt to changing world conditions and even to influence change, it is necessary to raise individuals who understand the era they live in well, can analyze the needs of the society they are in, think innovatively, and have made lifelong learning a lifestyle. Undoubtedly, all of these are possible through adapting educational systems to impart 21st-century skills. Among these skills, creative thinking skills contribute to versatile skills such as demonstrating originality and creativity in the workplace, developing new ideas that will benefit others, being open and adaptable to new and different perspectives, and providing concrete and useful assistance with creative ideas in areas where innovation is developing. On the other hand, cognitive flexibility will enable individuals to be aware of their alternatives before deciding on their actions, be flexible in adapting to situations, and feel competent when they are flexible in situations where they can be flexible.

The study's findings align with similar research outcomes in the literature, underscoring the effectiveness of UbD model in enhancing students' critical thinking, skills, and knowledge retention. Bodur and Yurtseven (2021) highlighted how using UbD model in creative drama activities improve student engagement and skills, while Alper and Deryakulu (2008) showed significant gains in cognitive flexibility, achievement, and learning retention through web-based problem-based learning. Gürbüz et al. (2022) demonstrated positive impacts on academic success and learning retention in mathematics, supporting the benefits of UbD model. Additionally, findings from the

studies conducted by Gül, Altun, and Yücel-Toy (2021) revealed that during the implementation process, the UbD model's fundamental components, such as big ideas, essential questions, and transfer expressions, significantly facilitated students' comprehension and transfer of knowledge by encouraging them to think critically and question the subject matter. In another study, Lai (2023) examined the integration of the UbD-Internet of Things (UbD-IoT) education framework with design thinking and computational thinking, demonstrating its effectiveness in enhancing students' problem-solving abilities and deeper thinking skills and found out that the UbD framework had a critical role in fostering cognitive flexibility. Lastly, Çelikman-Hanratty and Eveyik-Aydın (2023) aimed to investigate the effectiveness of UbD in English as a Foreign Language (EFL) instruction. They found out that it promoted creative instructional designs that supported contextual learning, ultimately enhancing creativity and adaptability among learners.

### Conclusion

The results demonstrate the value of embedding UbD model in teaching mathematics to develop students' creativity, cognitive flexibility, and learning retention. This study provides evidence supporting the adoption of UbD model in designing the instruction secondary school mathematics teaching. Future research would be well-advised to investigate the long-term impact of UbD on diverse student populations as well as cross-disciplinary exploration of its effectiveness to validate and expand its value in education.

### Limitations

Despite the positive outcomes, several limitations should be noted. Firstly, the small sample size (N=20 per group) limits the extent to which the findings can be generalized, as a larger sample might yield more reliable data. Although the pre-test comparisons indicated no significant differences between the groups, the relatively small sample size may have reduced the statistical power of these tests. Future research should aim to address these limitations by incorporating larger sample sizes and diverse educational settings. As a second limitation, the duration of the study might be mentioned as it may not adequately reflect the long-term impacts of the UbD model on students' creative thinking, cognitive flexibility, and learning retention. Future studies can integrate longitudinal designs to validate and extend the findings. Finally, the study was conducted in a specific educational setting, which may limit the applicability of the results to other contexts or subjects. Future research should consider expanding the study to include a broader range of educational settings or subjects to enhance the applicability of the results. By diversifying the contexts in which similar research is conducted, researchers can better understand how

findings may vary across different environments and populations.

### Acknowledgements

We would like to express our sincere gratitude to the students who participated in this study.

### Author contributions

O.G.: writing the original draft, implementation, data collection, data analysis, interpretation of the data. N.Y.: conceptualization, research design, writing the original draft, review and editing, data curation.

### Funding

This research received no external funding.

### Data availability

The dataset used in this research is available upon request.

### Competing interests

The authors declare no competing interests.

### References

- Aiym, Y., Galiya, K., Ademi, B., Adilet, M., Kamshat, Z., & Gulmira, K. (2022). Development of the logical thinking of future mathematics teachers through the use of digital educational technologies. *Cypriot Journal of Educational Sciences*, 17(6), 2001-2012. <https://doi.org/10.18844/cjes.v17i6.7548>.
- Aksu, G. & Koruklu, N. (2015). Determination the effects of vocational high school students' logical and critical thinking skills on mathematics success. *Eurasian Journal of Educational Research*, 15(59), 181-206. <https://doi.org/10.14689/ejer.2015.59.11>.
- Alper, A. & Deryakulu, D. (2008). The effect of cognitive flexibility on students' achievement and attitudes in web mediated problem based learning. *Education and Science*, 33(148), 49-63.
- Altun, S., & Yurtseven, N. (2019). *Tasarımcı öğretmen UbD el kitabı (Designer Teacher: Handbook of UbD)*. Asos Publication.
- Andrews, D., Lieshout, E. v., & Kaudal, B. B. (2023). How, where, and when do students experience meaningful learning?. *International Journal of Innovation in Science and Mathematics Education*, 31(3). <https://doi.org/10.30722/ijisme.31.03.003>.

- Aristanti, A. P. & Fatayan, A. (2024). The effect of the ubd-based problem based learning model on the critical thinking skills of grade iv students in ipas subject at elementary school. *Mimbar Sekolah Dasar*, 11(2), 268-280. <https://doi.org/10.53400/mimbar-sd.v11i2.71794>.
- Aslan, E. (1999). *Adaptation of Torrance Test of Creative Thinking*, Washington D. C: *International Conference on Test Adaptation Proceedings*. George Town University.
- Azaryahu, L., Broza, O., Cohen, S., Hershkovitz, S., & Adi-Japha, E. (2023). Development of creative thinking patterns via math and music. *Thinking Skills and Creativity*, 47 (101196), 1-13. <https://doi.org/10.1016/j.tsc.2022.101196>.
- Basadur, M., Gelade, G., & Basadur, T. (2014). Creative problem-solving process styles, cognitive work demands, and organizational adaptability. *The Journal of Applied Behavioral Science*, 50(1), 80-115. <https://doi.org/10.1177/0021886313508433>.
- Belay, S., Melesse, S., & Seifu, A. (2022). Elevating teachers' professional capital: effects of teachers' engagement in professional learning and job satisfaction, awi district, ethiopia. *SAGE Open*, 12(2), 1-15. <https://doi.org/10.1177/21582440221094592>.
- Biber, A. Ç. & Bakırcı, D. (2023). The awareness of prospective mathematics teachers on the mathematics curriculum. *International Journal of Educational Studies in Mathematics*, 10(3), 180-189. <https://doi.org/10.17278/ijesim.1258227>.
- Bilgin, M. (2009). Some variables predicting cognitive flexibility. *Çukurova University Faculty of Education Journal*, 3(36), 142-157. <https://doi:10.14687/jhs.v13i3.3975>.
- Bodur, Z. T. & Yurtseven, N. (2021). An investigation of the reflections of UbD-based creative drama activities on students in English lessons. *Journal of Education for Life*, 35(1), 88-103. <https://doi.org/10.33308/26674874.20213512>.
- Braem, S. & Egner, T. (2018). Getting a grip on cognitive flexibility. *Current Directions in Psychological Science*, 27(6), 470-476. <https://doi.org/10.1177/0963721418787475>.
- Büyükköztürk, Ş., Çakmak, E. K., Akgün, Ö. E., Karadeniz, Ş. & Demirel, F. (2013). *Scientific research methods*. Pegem Academy.
- Cao, Q., Png, B. T., Cai, Y., Cen, Y., & Xu, D. (2021). Interactive virtual reality game for online learning of science subject in primary schools. 2021 *IEEE International Conference on Engineering, Technology & Education (TALE)*. <https://doi.org/10.1109/tale52509.2021.9678916>.
- Creswell, J. W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research*. Pearson Education, Inc.
- Çelikkaleli, Ö. (2014). The validity and reliability of the cognitive flexibility scale. *Education and Science*, 39(176), 339-346. <https://doi.org/10.15390/EB.2014.3466>.
- Çelikman-Hanratty, G. Ç. & Eveyik-Aydin, E. (2023). Designing units with the ubd framework to teach english as a foreign language: Benefits and challenges. *Sakarya University Journal of Education*, 13(3), 435-455. <https://doi.org/10.19126/suje.1277604>.
- Evans, N. S., Burke, R., Vitiello, V., Zumbunn, S., & Jirout, J. J. (2023). Curiosity in classrooms: An examination of curiosity promotion and suppression in preschool math and science classrooms. *Thinking Skills and Creativity*, 49(10133), 1-11. <https://doi.org/10.1016/j.tsc.2023.101333>.
- Fan, M. & Cai, W. (2020). How does a creative learning environment foster student creativity? an examination on multiple explanatory mechanisms. *Current Psychology*, 41(7), 4667-4676. <https://doi.org/10.1007/s12144-020-00974-z>.
- Filiz, T. (2023). Teacher opinions on the process of preparing, implementing, and evaluation of an individualized education program for primary school mathematics courses. *The Universal Academic Research Journal*, 5(3), 254-269. <https://doi.org/10.55236/tuara.1353213>.
- Fisher R. (1995). *Teaching children to think*. Stanley Thornes.
- Gabrys, R. L., Tabri, N., Anisman, H., & Matheson, K. (2018). Cognitive control and flexibility in the context of stress and depressive symptoms: The cognitive control and flexibility questionnaire. *Frontiers in Psychology*, 9(2219). <https://doi.org/10.3389/fpsyg.2018.02219>.
- Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, 38(4), 915-945. <https://doi.org/10.3102/00028312038004915>.

- Gül, M., Altun, S. ve Yücel-Toy, B. (2021). Impact of understanding by design (UbD) on the students cognitive and affective development: A study on the history of revolution and kemalism course. *Van Yüzüncü Yıl University The Journal of Social Sciences Institute*, 51, 123-152. <https://dergipark.org.tr/en/download/article-file/1678196>.
- Gürbüz, Ö., Kahya-Koçak, F., & Yurtseven, N. (2022). UbD temelli gelişimsel yaklaşım uygulamalarının matematik dersi öğrenci başarısına etkisinin incelenmesi. *Milli Eğitim Dergisi*, 51(233), 581-601. <https://doi.org/10.37669/milliegitim.791938>.
- Hayati, R., Asmayanti, A., & Prima, W. (2024). Revitalizing math education: unveiling the impact of holistic mathematics education based "sistem among" in elementary classrooms. *Al-Ishlah: Jurnal Pendidikan*, 16(2). <https://doi.org/10.35445/alishlah.v16i2.4926>.
- Huda, N., Wahyuni, T. S., & Fauziyah, F. D. (2021). Students' perceptions of online mathematics learning and its relationship towards their achievement. *Advances in Social Science, Education and Humanities Research*, 529, Proceedings of the International Conference on Engineering, Technology and Social Science (ICONETOS 2020) <https://doi.org/10.2991/assehr.k.210421.077>.
- Ibrahim, Khalil, I. A., & Prahmana, R. C. I. (2024). Mathematics learning orientation: Mthematical creative thinking ability or creative disposition?. *Journal on Mathematics Education*, 15(1), 253-276. <https://doi.org/10.22342/jme.v15i1.pp253-276>.
- Jung, R. E. (2013). The structure of creative cognition in the human brain. *Frontiers in Human Neuroscience*, 7(330), 1-13. <https://doi.org/10.3389/fnhum.2013.00330>.
- Kalogeratos, G., Anastasopoulou, E., Tsagri, A., Tseremegklis, C., & Asimakopoulou, S. (2023). Enhancing creativity in the school environment. a narrative examination. *Technium Education and Humanities*, 6, 84-97. <https://doi.org/10.47577/teh.v6i1.10223>.
- Khotinets, V. & Shishova, E. (2023). Cultural and educational environment in the development of younger schoolchildren's creative potential. *Frontiers in Psychology*, 14. <https://doi.org/10.3389/fpsyg.2023.1178535>.
- Kılcan, F. (2005). *The Effect of thematic instruction based on the students' achievements throughout the teaching of measurement at sixth grade of elementary schools*. (Unpublished Master's Thesis). Marmara University Educational Sciences Institute, İstanbul, Türkiye.
- Kim, M. K., Roh, I. S., & Cho, M. K. (2016). Creativity of gifted students in an integrated math-science instruction. *Thinking Skills and Creativity*, 19, 38-48. <https://doi.org/10.1016/j.tsc.2015.07.004>.
- Kul, Ü., Çelik, S., & Aksu, Z. (2018). The impact of educational material use on mathematics achievement: a meta-analysis. *International Journal of Instruction*, 11(4), 303-324. <https://doi.org/10.12973/iji.2018.11420a>.
- Lai, Y. H. (2023). Learning efficacy of understanding by design-internet of things (ubd-iot) education integrated with design thinking and computational thinking. *Library Hi Tech*, 42(2), 730-747. <https://doi.org/10.1108/lht-01-2023-0002>.
- Lonescu, T. (2012). Exploring the nature of cognitive flexibility. *New Ideas in Psychology* 30(2), 190-200. <https://doi.org/10.1016/j.newideapsych.2011.11.001>.
- Martin, M. M. & Rubin, R. B. (1995). A new measure of cognitive flexibility. *Psychological Reports*, 76, 623-626. <https://doi.org/10.2466/pr0.1995.76.2.623>.
- McTighe, J., Seif, E., & Wiggins, G. (2004). You can teach for meaning. *Educational Leadership*, 62(1), 26-30.
- Misechko, . & Lytnyova, T. (2022). From critical thinking – to creativity: steps to understanding. *Zhytomyr Ivan Franko State University Journal. edagogical Sciences*, 2(109), 5-15. [https://doi.org/10.35433/pedagogy.2\(109\).2022.5-15](https://doi.org/10.35433/pedagogy.2(109).2022.5-15).
- Mones, P. & Massonnié, J. (2022). What can you do with a bottle and a hanger? Students with high cognitive flexibility give more ideas in the presence of ambient noise. *Thinking Skills and Creativity*, 46(101116), 1-17. <https://doi.org/10.1016/j.tsc.2022.101116>.
- Nurjanah, N. E., Yetti, E., & Sumantri, M. S. (2024). Developing creative thinking in preschool children: a comprehensive review of innovative. *European Journal of Educational Research*, 13, 1303-1319. <https://doi.org/10.12973/eu-jer.13.3.1303>.
- Orakçı, Ş. (2021). Exploring the relationships between cognitive flexibility, learner autonomy, and reflective thinking. *Thinking Skills and Creativity*, 41(100838), 1-13. <https://doi.org/10.1016/j.tsc.2021.100838>.
- Rawlinson, J.G. (1981). *Creative thinking and brainstorming*. Routledge. <https://doi.org/10.4324/9781315259000>.

- Risnanosanti, R., Susyla, D., Suyuthie, H., Mursalin, M., Naziev, A., Koklu, O., & Salcedo, A. (2023). Development of teacher professionalism in inquiry learning through learning community. *Electronic Journal of Education, Social Economics and Technology*, 4(1), 22-29. <https://doi.org/10.33122/ejeset.v4i1.80>.
- Ritter, S. M. & Mostert, N. M. (2017). Enhancement of creative thinking skills using a cognitive-based creativity training. *Journal of Cognitive Enhancement*, 1(3), 243-253. <https://doi.org/10.1007/s41465-016-0002-3>.
- Sari, N. P., Setiawan, M. A., & Makaria, E. C. (2021). Can science develop creativity in early children?. *Advances in Social Science, Education and Humanities Research. Proceedings of the 2nd Progress in Social Science, Humanities and Education Research Symposium (PSSHRS 2020)*. <https://doi.org/10.2991/assehr.k.210618.040>.
- Schoenfeld, A.H. (2022). Why are learning and teaching mathematics so difficult?. In Danesi, M. (eds). *Handbook of Cognitive Mathematics*. Springer. [https://doi.org/10.1007/978-3-030-44982-7\\_10-1](https://doi.org/10.1007/978-3-030-44982-7_10-1).
- Sholihah, F., Inganah, S., & Effendi, M. M. (2017). Analysis of critical thinking skills by homeschooling's students in solving mathematical problem. *Mathematics Education Journal*, 1(2), 41. <https://doi.org/10.22219/mej.v1i2.4628>.
- Som, İ., Türkan, A., & Altun, S. (2016). Design of Introduction to Educational Sciences course using UbD: The evaluation of prospective teachers' achievement, attitudes and opinions about the course. *International Journal of Social Sciences and Education Research*, 2(4), 1341-1351. <https://doi.org/10.24289/ijsser.279009>.
- Spiro, R. J., Feltovich, P. J., Jacobson, M. J., & Coulson, R. L. (1988). Cognitive flexibility theory: Advanced knowledge acquisition in ill-structured domains. A Reading Research and Education Center Report. University of Illinois at Urbana.
- Stigler, J. & Hiebert, J. (2009). Closing the teaching gap. *Phi Delta Kappan*, 91(3), 32-37. <https://doi.org/10.1177/003172170909100307>.
- Surya, E., Putri, F. A., & Mukhtar, M. (2017). Improving mathematical problem-solving ability and self-confidence of high school students through contextual learning model. *Journal on Mathematics Education*, 8(1), 85-94. <https://doi.org/10.22342/jme.8.1.3324.85-94>.
- Taş, S. & Deniz, S. (2018). Prediction concerning the learned helplessness about mathematics of the 8th grade students: Problem-solving skills and cognitive flexibility. *Turkish Journal of Computer and Mathematics Education*, 9(3), 581-617. <https://doi.org/10.16949/turkbilmat.415087>.
- Tello-Ramos, M. C., Branch, C. L., Kozlovsky, D. Y., Pitera, A. M., & Pravosudov, V. V. (2019). Spatial memory and cognitive flexibility trade-offs: to be or not to be flexible, that is the question. *Animal Behaviour*, 147, 129-136. <https://doi.org/10.1016/j.anbehav.2018.02.019>.
- Thuneberg, H. M., Salmi, H. S., & Bogner, F. X. (2018). How creativity, autonomy and visual reasoning contribute to cognitive learning in a STEAM hands-on inquiry-based math module. *Thinking Skills and Creativity*, 29, 153-160. <https://doi.org/10.1016/j.tsc.2018.07.003>.
- Torrance, E. P. (1966). *Torrance tests of creative thinking—norms technical manual research edition—verbal tests, forms A and B—figural tests, forms A and B*. Personnel Pres. Inc.
- Torrance, E. P., Ball, O. E. (1984). *Torrance tests of creative thinking. streamlined (revised) manual*. Bensenville, IL: Scholastic Testing Service.
- Uçak, S. & Erdem, H. H. (2020). On the skills of 21st century and philosophy of education in terms of searching a new aspect in education. *Uşak University Journal of Educational Research*, 6(1), 76-93. <https://doi.org/10.29065/usakead.690205>.
- Vitale, J. M., Black, J. B., & Swart, M. I. (2014). Applying grounded coordination challenges to concrete learning materials: a study of number line estimation. *Journal of Educational Psychology*, 106(2), 403-418. <https://doi.org/10.1037/a0034098>.
- Wiggins, G. & McTighe, J. (2005). *Understanding by design*. Association for Supervision and Curriculum Development.
- Wiggins, G. & McTighe, J. (2007). *Schooling by design: Mission, action and achievement*. Association for Supervision and Curriculum Development.
- Wiggins, G. & McTighe, J. (2011). *The understanding by design guide to creating high-quality units*. Association for Supervision and Curriculum Development.
- Yurtseven, N. (2016). *The investigation of the reflections of action research based Ubd implementations on teachers and students in EFL teaching* (Unpublished Doctoral Thesis). Yıldız Technical University Social Sciences Institute, İstanbul, Türkiye.