Kastamonu Education Journal, 2025, Vol. 33, No:3, 572-584
doi: 10.24106/kefdergi.1748663

| Research Article / Araştırma Makalesi |

The Impact of Design-Based Research Method Science Activities on Middle School Students' Creative and Critical Thinking Skills: A Classroom Experimental Study

Tasarım Tabanlı Araştırma Yöntemi ile Hazırlanan Fen Etkinliklerinin Ortaokul Öğrencilerinin Yaratıcı ve Eleştirel Düşünme Becerilerine Etkisi: Sınıf İçi Deneysel Uygulama Çalışması

Adem YILMAZ[1]

Keywords

1. Tasarım Tabanlı Araştırma
2. Deneysel Uygulama
3. Fen Eğitimi
4. Yaratıcı Düşünme
5. Eleştirel Düşünme

Anahtar Kelimeler

1. Design-Based Research
2. Experimental Implementation
3. Science Education
4. Creative Thinking
5. Critical Thinking

Received/Başvuru Tarihi
24.03.2024

Accepted / Kabul Tarihi
25.07.2025

Abstract

Purpose: The purpose of this study is to investigate the effect of science activities prepared through the design-based research (DBR) method on middle school students' creative and critical thinking skills.

Design/Methodology/Approach: A quasi-experimental design was employed. The study group consisted of 80 middle school students in Kastamonu, Turkey, randomly assigned to experimental and control groups. Design-based science activities were applied in the experimental group, while the control group followed traditional science instruction. Data were collected through pre-tests and post-tests using the Marmara Creative Thinking Dispositions Scale and Marmara Critical Thinking Dispositions Scale.

Findings: Results indicated significant improvements in creative and critical thinking dispositions of students in the experimental group compared to the control group. The DBR activities provided students with active problem-solving opportunities, enhancing their ability to generate creative ideas and critically evaluate their work.

Highlights: The study highlights that the design-based research approach in science education is more effective than traditional teaching methods in enhancing creative and critical thinking skills. It is recommended for educators and curriculum developers to integrate DBR-driven activities into educational programs.

Öz

Çalışmanın amacı: Bu çalışmanın amacı, tasarım tabanlı araştırma yöntemiyle hazırlanan fen etkinliklerinin ortaokul öğrencilerinin yaratıcı ve eleştirel düşünme becerilerine olan etkisini incelemektir.

Materyal ve Yöntem: Araştırma, yarı deneysel desen kullanılarak gerçekleştirilmiştir. Kastamonu ilinde öğrenim gören 80 ortaokul öğrencisi rastgele seçilerek deney ve kontrol gruplarına ayrılmıştır. Deney grubunda tasarım tabanlı fen etkinlikleri uygulanırken, kontrol grubu geleneksel fen öğretimine devam etmiştir. Uygulama öncesi ve sonrası Marmara Yaratıcı Düşünme Eğilimleri Ölçeği ve Marmara Eleştirel Düşünme Eğilimleri Ölçeği kullanılarak veri toplanmıştır.

Bulgular: Araştırma sonucunda, deney grubundaki öğrencilerin yaratıcı ve eleştirel düşünme eğilimlerinde kontrol grubuna kıyasla anlamlı düzeyde daha fazla gelişim gösterdiği belirlenmiştir. Tasarım tabanlı etkinliklerin öğrencilere aktif problem çözme fırsatları sunduğu ve bu süreçte yaratıcı fikir üretme ile eleştirel değerlendirme becerilerini geliştirdikleri gözlenmiştir.

Önemli Vurgular: Araştırma bulguları, tasarım tabanlı araştırma yönteminin fen eğitiminde yaratıcı ve eleştirel düşünme becerilerini geliştirmede geleneksel yöntemlerden daha etkili olduğunu ortaya koymaktadır. Bu bağlamda, eğitimciler ve program geliştiricilere tasarım tabanlı etkinliklerin eğitim programlarına entegrasyonu önerilmektedir.

[1] **Corresponded Author,** Kastamonu University, Faculty of Education, Division of Science Education, Kastamonu, Türkiye, https://orcid.org/0000-0002-1424-8934

Citation/Alıntı: Yılmaz, A. (2025). The Impact of Design-Based Research Method Science Activities on Middle School Students' Creative and Critical Thinking Skills: A Classroom Experimental Study, *Kastamonu Education Journal, 33*(3), 572-584. doi: 10.24106/kefdergi.1748663

INTRODUCTION

In the 21st century, rapid advancements in technology, science, and globalization have made it imperative for individuals to be equipped with high-level cognitive skills such as creative thinking and critical thinking (National Science Teaching Association [NSTA], 2013). In an era where information is abundant and challenges are complex, mere content knowledge is not sufficient; students need to develop the ability to generate innovative solutions and make well-reasoned decisions (Bybee, 2010; Trilling & Fadel, 2009). Consequently, modern educational frameworks emphasize creative and critical thinking among the core "21st-century skills," alongside communication, collaboration, and other key competencies (National Research Council [NRC], 2010; Partnership for 21st Century Skills [P21], 2009). These skills are considered essential not only for academic success but also for enabling students to adapt and contribute effectively to today's knowledge-based and rapidly changing society. Science education plays a pivotal role in fostering 21st-century skills. Quality science instruction inherently provides a context for students to engage in problem solving, critical thinking, and information literacy, thereby helping them develop broadly applicable thinking habits. The U.S. National Research Council and the Partnership for 21st Century Learning have highlighted that science education reform and 21st-century skills share complementary goals: while science education seeks to promote deep understanding through active inquiry, 21st-century skills initiatives focus on cultivating adaptable, innovative thinkers prepared for the modern workforce (NSTA, 2013). Indeed, exemplary science education can offer rich opportunities for students to hone skills like critical thinking and creativity in tandem with scientific content mastery. Equipping learners with these skills has a dual benefit: it prepares a well-qualified future workforce and also endows individuals with life skills that enhance their personal decision-making and success in daily life. In summary, creative and critical thinking have emerged as universal educational priorities in the 21st century, regarded as indispensable for learners to navigate complex information, innovate, and participate meaningfully in civic life (Organisation for Economic Co-Operation and Development [OECD], 2018).

Science Education and Cognitive Skills at the Middle School Level

At the middle school level, science education is crucial not only for imparting scientific knowledge but also for developing students' cognitive skills. In Türkiye, the science curriculum begins in 3rd grade and continues through middle school (5th–8th grades), aiming to foster scientific literacy from an early age (Ministry of National Education [MoNE], 2018). The 2018 revised Science Curriculum in Türkiye explicitly emphasizes moving beyond rote learning of facts to focus on cultivating students' higher-order thinking skills. Among its objectives, the curriculum highlights the development of students' creative thinking, critical thinking, problem-solving, and decision-making abilities through science learning experiences (MoNE, 2018; NRC, 2010). In particular, new elements such as *Engineering and Design Applications* in the curriculum encourage students to apply scientific concepts by designing innovative solutions or products, thereby integrating opportunities for creativity within science lessons. Science classes inherently engage students in scientific process skills, providing a natural avenue for exercising advanced thinking. Activities like making observations, asking questions, formulating hypotheses, designing experiments, collecting data, and drawing conclusions train students to think both analytically and critically. For instance, in attempting to solve a scientific problem, a student begins by posing questions and hypothesizing (applying critical analysis to define the problem), then conducts experiments to gather evidence and interprets the results. Throughout this investigative process, students employ critical thinking to evaluate data and validate their hypotheses, and simultaneously use creative thinking to devise hypotheses and imagine explanations for their observations. In fact, scientists themselves rely on both creative and critical thinking when seeking solutions to scientific problems; they generate novel ideas and approaches, then rigorously test and refine them (Aguilera-Hermida, 2020). Thus, science education offers students the chance to "think like a scientist," integrating imaginative idea generation with evidence-based reasoning, which in turn nurtures both creative and critical faculties. Historically, however, science instruction has not always realized this dual potential. Traditional science teaching methods often centered on content delivery and memorization, giving relatively little attention to developing students' critical thinking. Many education systems, including Türkiye's in past decades, have been critiqued for focusing on factual recall in science classes at the expense of inquiry and reasoning skills. In recent years, educational reforms and updated curricula have aimed to address this gap by enriching science lessons with inquiry-based and student-centered activities that target skills like questioning, investigation, and creativity (MoNE, 2018). As Hacıoğlu and Kutru (2021) noted, science learning environments are seen as a prime opportunity to cultivate individuals who can keep up with scientific and technological advancements and who possess creative thinking abilities. This shift reflects a growing recognition that science education is not solely about learning scientific facts; it is equally about laying the foundation for scientific thinking, innovative problem-solving, and a critical mindset in students. By engaging with scientific content through experimentation and problem-solving, middle school students can concurrently develop cognitive skills that will serve them across disciplines and in real-world contexts.

Design-Based Research Method in Education and Its Connection to Science Teaching

The Design-Based Research (DBR) method is an innovative research approach in education that blends theoretical inquiry with practical implementation. Known in Turkish as "Tasarım Tabanlı Araştırma (TTA) Yöntemi," DBR involves researchers systematically designing educational interventions and studying their impact in real-world settings. The fundamental process of DBR consists of developing a solution or intervention (such as a set of learning activities or a curriculum unit) to address a specific educational problem, implementing this intervention in an authentic context (e.g., a classroom), and then iteratively refining the design based on empirical findings. Unlike one-off experiments, DBR is characterized by iterative cycles of design, enactment, analysis, and redesign. In each iteration, data on how the intervention affects learning are collected and analyzed, and the insights gained are used to improve the intervention in the next cycle (Collins, 1992; Wang & Hannafin, 2005). This iterative refinement continues until the educational innovation meets both its practical goals and generates sufficient data to allow researchers to draw conclusions about learning processes and outcomes. A hallmark of design-based research is the close collaboration between researchers and practitioners (teachers). In DBR, researchers often work hand-in-hand with classroom teachers to develop and implement interventions, ensuring that the innovations are feasible and relevant to everyday teaching practice. This collaboration allows for immediate identification and resolution of issues that arise during implementation, making the research process responsive and grounded in classroom reality (Design-Based Research Collective, 2003). By bridging the gap between theory and practice, DBR serves as a conduit for producing knowledge that is both scientifically valid and educationally useful. The approach aims to yield practical solutions for educators while simultaneously contributing to theory by uncovering design principles and refining learning theories based on what works (or doesn't work) in practice. In fact, the literature notes that a key goal of DBR is to develop new theories or frameworks for understanding learning and instruction that emerge from successful designs. In other words, through the DBR process, researchers seek to generate empirically grounded insights into how and why a particular educational innovation succeeds, thus informing broader educational research and practice.

Design-based research methodology emerged in the 1990s (Collins, 1992) as "design experiments" and has since gained traction in various fields of education. In the context of science education, DBR has been widely adopted to design and test innovative teaching approaches aimed at improving student engagement and understanding. For example, in science education literature, a DBR-oriented pedagogical approach is sometimes referred to as "design-based science" (Fortus et al., 2005; Vattam & Kolodner, 2006), which involves students using their scientific knowledge to develop an artifact or solve a real-world problem through design. In such approaches, students might be given a challenge (e.g., design a water filtration system or build a model rocket) that requires them to apply scientific concepts in a creative way. As they work on the design task, they engage in inquiry: they test their prototypes, observe outcomes, troubleshoot issues, and iteratively improve their designs. This process mirrors professional scientific and engineering practices and, importantly, situates learning in a meaningful problem-solving context. DBR in science education thus often produces curriculum interventions that are project-based or problem-based, where learning happens as students design and create, rather than passively absorb information. The role of DBR in education is significant because it allows researchers to tackle the complexity of learning environments head-on. Traditional experimental methods attempt to isolate variables to determine cause-effect relationships, but learning in classrooms is influenced by an interplay of many factors (student background, teacher practices, social dynamics, etc.) (Baron & Daniel-Allegro, 2019). DBR embraces this complexity by treating the classroom as a holistic "learning ecology" to be improved and studied simultaneously. By implementing and refining interventions in situ, DBR acknowledges emergent variables and adapts to them, yielding findings that are directly applicable to practice. In science classrooms, this might mean that a DBR study not only measures test score gains from a new teaching method but also observes how student motivation, classroom discourse, and practical constraints interact with the method. The knowledge gained is thus context-sensitive and immediately relevant to practitioners. Over time, DBR studies in science education have contributed to our understanding of effective strategies, such as how to integrate technology in science labs or how to sequence inquiry activities for optimal learning (Barab & Squire, 2004; Sandoval, 2014). In summary, design-based research is a contemporary and powerful approach in science education research, enabling the development of effective instructional practices and providing deep insights into student learning by iteratively testing and refining educational designs in real classrooms.

Creative and Critical Thinking Skills: Definitions and Educational Relevance

Creative thinking and critical thinking are two interrelated higher-order thinking skills that are prominently valued in modern education. Creative thinking is typically defined as the capacity to produce novel and useful ideas or products. This definition emphasizes two key aspects: originality (novelty) and appropriateness or value (usefulness). For instance, psychology professor Michael Mumford summarized the consensus in creativity research by stating, *"creativity involves the production of novel, useful products"* (Mumford, 2003, p.110). Similarly, Sternberg amd Sternberg (2011) noted that creativity yields *"something original and worthwhile*" (Sternberg & Sternberg, 2011). E. Paul Torrance (1966) described creativity as a process that involves becoming aware of problems or gaps in knowledge, identifying difficulties, searching for possible solutions, testing and retesting these solutions, and finally communicating the results. Despite varying formulations, most definitions converge on the idea that creative thinking enables individuals to approach situations in innovative ways and generate outcomes that are not only new but also effective or valuable. In an educational context, creative thinking might manifest when a student comes up with an original hypothesis for a science experiment, devises an unconventional method to solve a math problem, or composes an imaginative story in language arts. This skill is crucial because it drives innovation and adaptability; students who think creatively are better prepared to tackle novel challenges and contribute original ideas in their future careers and daily lives.

Critical thinking, on the other hand, refers to the process of analyzing, evaluating, and synthesizing information in a disciplined and logical manner to guide one's beliefs or actions. A widely cited definition by Ennis (1991) describes critical thinking as "reasonable, reflective thinking focused on deciding what to believe or do." Likewise, Facione (1990) defines it as purposeful, self-regulatory judgment which entails interpretation, analysis, evaluation, and inference, as well as explanation of the evidential and conceptual bases of one's decisions. In simpler terms, critical thinking involves skills such as analysis (breaking down complex information into parts), evaluation (assessing the credibility and relevance of information or arguments), and inference (drawing logical conclusions). A critical thinker carefully considers evidence, questions assumptions, identifies biases, and thinks through the implications of decisions. In education, fostering critical thinking means encouraging students to not just accept information at face value, but to question, investigate, and reason (Geitz & de Geus, 2019). For example, a critically thinking student in a science class will examine data from an experiment and consider whether the data truly support the conclusion, or a student in a social studies class will evaluate the credibility of different sources before forming an opinion on a historical event. Critical thinking is essential for enabling students to become independent learners and informed citizens. It empowers them to make reasoned decisions in everyday life, from scrutinizing the validity of news articles to solving complex problems in the workplace (Halpern, 2013).

Both creative and critical thinking are crucial in education because they correspond to the demands of the contemporary world (Ayyıldız & Yılmaz, 2023). Creativity is often called the engine of innovation – economies and societies thrive on individuals who can devise new solutions and drive progress. Teresa Amabile and colleagues have highlighted creativity as a critical skill for the workforce of the future, noting that companies across fields prioritize employees who can think outside the box to spur innovation (Amabile & Pratt, 2016). In science and technology, creative thinking leads to breakthroughs and new inventions; in everyday life, it enables people to adapt to change and find alternatives when faced with obstacles. Critical thinking, likewise, is fundamental for navigating the information-rich and often complex societal landscape of today. It allows individuals to discern truth from misinformation, to participate in reasoned discourse, and to make decisions that are rational and evidence-based. As Yacoubian (2015) argues, incorporating aspects of the Nature of Science and socioscientific issues in schooling is important because it links science learning to critical thinking, helping students learn to make informed decisions on issues that affect society (Santos, 2017). For example, on topics like climate change or public health, critical thinking enables students to weigh scientific evidence, understand the interplay of scientific and ethical considerations, and come to well-founded positions. In democratic societies, citizens with strong critical thinking skills are better equipped to engage in debates, understand public policies, and vote or act in ways that align with informed judgment rather than ignorance or bias. It is important to note that creative and critical thinking are not opposing skills, but rather complementary processes in thinking and problem-solving. Creativity involves generating ideas, while critical thinking involves judging ideas; effective problem solving and decision making typically require both. In a complex task, one often cycles between divergent thinking (brainstorming multiple possibilities) and convergent thinking (critically narrowing down options and selecting the best course). Educational psychologists often view these two skills as part of an "integrated thinking" model (Baum-Combs, Cennamo & Newbill, 2009). For instance, when students engage in a project-based learning activity, they use creative thinking to propose various project ideas or hypotheses, and then apply critical thinking to test their hypotheses or evaluate which idea is most feasible. Over the course of such an activity, learners must regulate their thought process—maintaining an open mind to new ideas while also applying logical criteria to refine those ideas. Therefore, modern pedagogical approaches aim to cultivate both creative and critical thinking in tandem, recognizing that a well-developed thinker needs to be inventive yet also judicious. By encouraging students to brainstorm and then analyze, to create and then critique, educators help students build a robust thinking repertoire that prepares them for complex real-life tasks.

Impact of Design-Based Research (Design-Focused) Interventions on Creative and Critical Thinking

Existing research suggests that learning environments structured around design principles – often developed through design-based research – can have positive effects on students' creative and critical thinking skills. Educational interventions prepared using the DBR approach usually involve students in active problem-solving and creation, which inherently engages their creativity and critical reasoning. Studies have documented that when students participate in design-based learning activities in science, they often show improvements in creative thinking. For example, Azizan and Shamsi (2022) investigated an online design-based learning experience with undergraduate science students and found that this approach enhanced students' creativity, allowing them to "think outside the box". Participants reported that having to develop an artifact to solve a real-life problem encouraged them to generate more original ideas and approach problems more imaginatively. Similarly, Joordens et al. (2012) note that design-based learning scenarios can boost students' imaginative capacity and creative engagement by placing them in open-ended problem contexts where innovative thinking is required. These findings support the notion that giving students the challenge and freedom to design solutions leads to measurable gains in creative thinking skills such as fluency (producing many ideas) and flexibility (producing diverse ideas) (Azizan & and Shamsi, 2022). In tandem, research indicates that critical thinking skills are also bolstered by design-oriented science activities. When students are involved in design tasks, they must not only invent ideas but also continually evaluate and refine those ideas, which is a form of critical thinking in action. For instance, during a design project, students often present their creations or solutions to peers and instructors, defend their design decisions, and respond to feedback or questions. This process requires them to articulate reasoning, consider counter-arguments, and justify their choices with evidence, thereby exercising and improving their critical thinking. Doppelt (2006) and Zhang et al. (2021) found in their studies on design-based science learning that having students present and defend their design projects led to significant enhancements in their critical thinking and problem-solving abilities. In these studies, students who engaged in design-and-defense activities became more adept at argumentation – they learned to provide logical justifications for how their design meets certain criteria or solves the problem, reflecting growth in critical analysis skills. Moreover, such activities often demand that students troubleshoot design flaws or optimize solutions, which involves a cycle of identifying weaknesses (critical evaluation) and improving the design (creative problem-solving). Through these experiences, students practice evidence-based reasoning and learn to view their own work through a critical lens, asking "What works? What doesn't? And why?". In short, design-centric learning experiences tend to treat creativity and critical thinking as intertwined: students use creativity to propose ideas and critical thinking to test and refine those ideas, leading to improvement in both skill sets. The synergy between design-based approaches and higher-order thinking has been articulated in theoretical models as well. Baum-Combs, Cennamo and Newbill (2009) proposed a conceptual model linking design-based learning environments to the development of creative and critical thinking. In their model, the problem space (where a learner defines and analyzes the problem) and the solution space (where the learner ideates and prototypes solutions) overlap in a cyclic process, and the student continually engages in self-regulation to monitor and adjust their approach. In practice, this means a student might repeatedly alternate between divergent phases (brainstorming design ideas) and convergent phases (critiquing and selecting ideas to implement). The model underscores that design thinking lies at the heart of both creative and critical thought – design is a unique form of problem-solving with no predetermined correct answer, requiring the generation of original ideas as well as the evaluation of those ideas against constraints and criteria. Hence, a well-designed educational activity grounded in DBR principles inherently fosters an environment where students must employ creative generation of ideas and critical judgment continuously. The relationship between critical thinking, creative thinking, and design is presented in Figure 1.

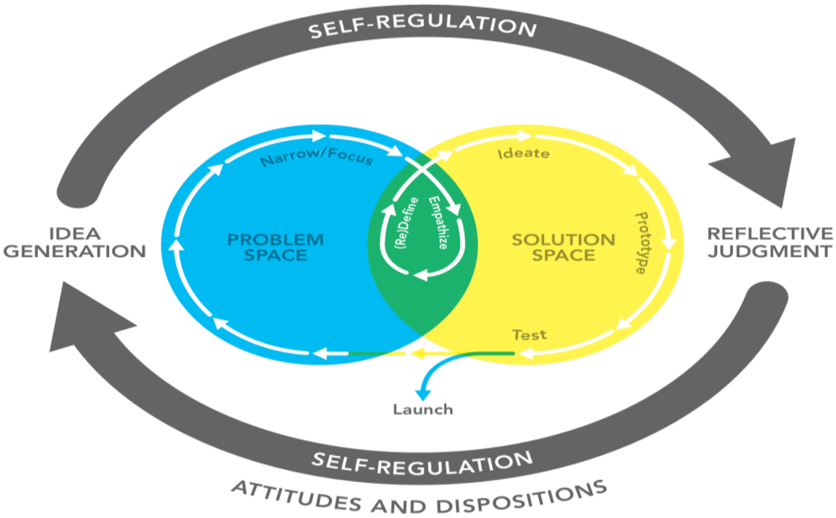

Figure 1. Number of Theses Written by Year (URL-1, 2025)

In summary, design-based research interventions in science education – such as science activities crafted through iterative design and implemented in classrooms – tend to create a learning experience that is conducive to both creativity and critical thinking. The hands-on, minds-on nature of these activities means that students are not passively receiving information; instead, they are actively creating and critiquing knowledge. Research to date shows that students immersed in such environments are able to propose more innovative ideas and also evaluate those ideas more thoroughly compared to students in more traditional settings (Azizan & Shamsi, 2022; Yılmaz, 2021). They learn to embrace failure as feedback, viewing setbacks in their design as prompts to think harder or differently – a disposition characteristic of both creative resilience and critical open-mindedness. Consequently, design-based learning activities help students practice the full cycle of thinking: from conception of an idea to its execution and evaluation. These experiences strengthen their ability to approach any complex task with both a creative spark and a critical eye.

Significance and Objectives of the Research

Despite the promising findings in the literature, there is a noticeable gap when it comes to studies focusing on the impact of design-based research (DBR) driven science activities on middle school students' creative and critical thinking skills, particularly in the Turkish context. Many existing studies internationally have been conducted at the high school or undergraduate level, or they have focused on outcomes like content learning and attitude rather than explicitly on thinking skills. Middle school is a formative period for cognitive development; thus, examining interventions at this stage can provide insight into how early engagement with design-based learning might influence students' thinking trajectories. This research aims to address the gap by investigating the effect of science activities prepared using the design-based research method on the creative and critical thinking skills of middle school students in Türkiye. In doing so, it seeks to contribute both to the local educational literature and to the broader understanding of how design-oriented pedagogy can support 21st-century skills in younger learners. The significance of this study can be articulated in several ways: Firstly, it will empirically evaluate to what extent the goals of the 2018 Turkish science curriculum regarding creative and critical thinking can be achieved through an innovative methodological approach (DBR-designed activities). This provides valuable feedback on curriculum implementation and the effectiveness of pedagogical innovations in reaching desired skill outcomes. Secondly, by implementing a design-based research approach in actual middle school classrooms and measuring its impact, the study will yield insights into the practical benefits and challenges of this approach at the middle school level. Specifically, it will shed light on whether such DBR-informed interventions measurably enhance students' creative and critical thinking in our local context, aligning with what has been observed elsewhere. Thirdly, the findings are expected to offer guidance to educators and curriculum developers. If the design-based science activities are found to significantly improve students' thinking skills, teachers may be encouraged to integrate more design-oriented projects and inquiry in their teaching, and curriculum developers might allocate more space for these approaches in educational programs. Ultimately, verifying the efficacy of DBR-based activities in improving critical and creative thinking can inform evidence-based decisions in teaching practice and educational policy.

In line with these aims, the research hypothesizes that students who participate in science activities developed through the design-based research method will show greater improvement in creative thinking (e.g., ability to generate original ideas, flexibility in thought) and critical thinking (e.g., ability to analyze information, evaluate arguments) compared to students experiencing traditional instruction. This expectation is supported by prior studies, which have demonstrated notable gains in creativity and critical reasoning following design-based interventions (Fortus et al., 2005; Raber, 2015; Ayyıldız & Yılmaz, 2021). By testing this hypothesis, the study will provide empirical evidence on the effectiveness of DBR-based pedagogy for skill development. The research will employ appropriate measures (such as creativity tests, critical thinking assessments, observational rubrics, etc.) to quantify changes in these skills, along with qualitative observations to understand how students engage with the design tasks. The mixed-method approach will enrich the findings, revealing not just if improvement occurs, but also how the design activities facilitate or hinder the thinking processes of students. In conclusion, this study is poised to offer meaningful contributions by evaluating a novel approach to science teaching in the context of cultivating crucial 21st-century skills. The insights gained are expected to advance the literature at the intersection of middle school science education and skill development, an area that stands to benefit from more research. If successful, the study will provide a model for integrating design-based research methods into regular classroom practice and demonstrate their value in enhancing student outcomes beyond content knowledge. Such evidence can inspire and inform educators, helping to shape science instruction that produces not only knowledgeable students but also innovative and critical thinkers prepared for the challenges of the future.

In this study, the following sub-problems were investigated:

1) Is there a significant difference between the pre-test and post-test results of the creative thinking tendencies of students in the control group?
2) Is there a significant difference between the pre-test and post-test results of the creative thinking tendencies of students in the experimental group?
3) Is there a significant difference between the pre-test results of the creative thinking tendencies of students in the experimental and control groups?
4) Is there a significant difference between the post-test results of the creative thinking tendencies of students in the experimental and control groups?
5) Is there a significant difference between the pre-test and post-test results of the critical thinking tendencies of students in the control group?
6) Is there a significant difference between the pre-test and post-test results of the critical thinking tendencies of students in the experimental group?
7) Is there a significant difference between the pre-test results of the critical thinking tendencies of students in the experimental and control groups?
8) Is there a significant difference between the post-test results of the critical thinking tendencies of students in the experimental and control groups?

METHOD

This study was conducted using a quasi-experimental design, one of the quantitative research methods. Specifically, a pretest-posttest control group design was employed (Büyüköztürk et al., 2016). In this study, the independent variable is the implementation of design-based science activities, while the dependent variables are students' creative thinking and critical thinking dispositions. The experimental group was exposed to design-based science activities, whereas the control group continued with the traditional science curriculum. Pretest and posttest measurements were conducted to compare changes in creative and critical thinking dispositions between the groups.

Study Group

The study group consisted of middle school students enrolled in a public school affiliated with the Ministry of National Education in Kastamonu, Türkiye. The random sampling method was used to select participants (Creswell & Poth, 2018), who were then assigned to experimental (n=40) and control (n=40) groups, resulting in a total sample size of 80 students. The following criteria were considered in selecting the sample:

- Students were in 7th grade.
- Their scientific process skills were at a comparable level.
- They had no prior experience with design-based learning models.

Participants were randomly assigned to experimental and control groups to ensure balance in terms of age, gender, and academic achievement.

Implementation Process

The research was conducted over a 6-week period within an educational program. Students in the experimental group participated in design-based science activities for two hours per week. These activities involved STEM-based design projects, problem-solving science tasks, and engineering applications requiring creativity. Table 1 presents the implementations conducted in the experimental and control groups.

Table 1. Implementation Process for Experimental and Control Groups

Week	Experimental Group (Design-Based Science Activities)	Control Group (Traditional Instruction)
1st Week	Introduction to scientific problem-solving and design thinking	Traditional science lessons
2nd Week	Simple engineering design: Bridge-building activity	Teacher-centered instruction
3rd Week	Experimental design activity on liquids and gases	Lecture-based teaching and Q&A
4th Week	Sustainability and ecosystem-based design project	Conventional classroom activities
5th Week	Scientific modeling and problem-solving STEM activities	Textbook and lesson materials
6th Week	Evaluation and presentation of all activities	In-class test and summary lessons

Before and after the implementation, the scales measuring critical and creative thinking dispositions were administered as pre-tests and post-tests to both the experimental and control groups, and the obtained data were compared. Figure 2 contains images related to the implementation process.

Figure 2. Images Related to the Implementation Process

Data Collection Instruments

Two different validated scales were used to collect data:

Marmara Critical Thinking Dispositions Scale (MCTDSa)

- Developed to measure students' critical thinking skills (Özgenel & Çetin, 2018).
- 5-point Likert-type scale with 6 sub-dimensions and 28 items.

Marmara Creative Thinking Dispositions Scale (MCTDSb)

- Developed to assess students' creative thinking tendencies (Özgenel & Çetin, 2017).
- 5-point Likert-type scale with 6 sub-dimensions and 25 items.

In this study, data were collected using two validated and reliable instruments: the Marmara Critical Thinking Dispositions Scale (MCTDSa) and the Marmara Creative Thinking Dispositions Scale (MCTDSb). The MCTDSa was developed by Özgenel and Çetin (2018). This scale consists of 28 items structured on a five-point Likert scale and encompasses six sub-dimensions: reasoning, reaching judgment, searching for evidence, searching for the truth, open-mindedness, and systematicity. The scale explains 56.35% of the total variance, and its overall internal consistency, as measured by Cronbach's alpha, is .91. The construct validity of the scale was established through exploratory and confirmatory factor analyses, while its reliability was further supported by test-retest procedures and comparisons between upper and lower 27% groups.

The Marmara Creative Thinking Dispositions Scale (MCTDSb), also developed by Özgenel and Çetin (2017), is another psychometrically sound instrument designed to assess general creative thinking dispositions. The scale comprises 25 items and six sub-dimensions: innovation search, courage, self-discipline, inquisitive, doubt, and flexibility. It is also based on a five-point Likert-type format. The scale accounts for 55.90% of the total variance and has a Cronbach's alpha coefficient of .87, indicating high internal consistency. Construct validity was confirmed via exploratory and confirmatory factor analyses, and test-retest reliability was supported by a significant correlation coefficient ($r = .88$; $p < .001$). This scale provides a reliable measure for assessing creative thinking dispositions.

These instruments were administered as both pretests and posttests, allowing for an analysis of changes in students' creative and critical thinking dispositions.

Data Analysis

In the analysis of the data obtained in this study, the first step was to examine whether the data followed a normal distribution. Normality tests indicated that the data were normally distributed. Accordingly, parametric tests were preferred to evaluate the effect of the experimental intervention. An independent samples t-test was conducted to determine the differences between the pre-test and post-test scores of the experimental and control groups. Additionally, Pearson correlation analysis was employed to examine the relationship between students' creative and critical thinking dispositions. All statistical analyses were performed using the SPSS software package, and the significance level was set at .05.

Validity and Reliability Studies

The validity and reliability of the data collection instruments used in the study were previously established by Özgenel and Çetin (2017; 2018). However, in this research, the researcher took several additional precautions to reinforce the validity and reliability of the data and ensure the accuracy of the results. First, a pilot study was conducted to confirm the appropriateness of the scales for the target population. The clarity of the items and the instructions was tested through feedback received from the participant group. Furthermore, prior to the administration of the instruments, students were provided with detailed explanations regarding how to complete the scales, and participation was based on informed consent in compliance with ethical principles.

FINDINGS

The first sub-problem of the research was stated as: *"Is there a significant difference between the pre-test and post-test results of the creative thinking tendencies of students in the control group?"* to address this question, an independent samples t-test was conducted, and the results for the control group are presented in Table 2.

Table 2. Pre-Test and Post-Test Results of the Control Group

Creative Thinking Tendencies	N	$\bar{X}$	SD	T	Df	*p*
Pre-Test	40	65.25	1.26	6.151	78	.001*
Post-Test	40	86.27	3.21			

***p≤ .05**

When the pre-test and post-test results of the control group regarding creative thinking tendencies were examined, a statistically significant difference was found in favor of the post-test scores [$t_{(78)}=6.151$; $p=.001<.05$]. As shown in Table 2, the mean score of the control group increased from 65.25 (SD = 1.26) in the pre-test to 86.27 (SD = 3.21) in the post-test. This result indicates that even within the control group, which continued with traditional instruction, there was a significant improvement in students' creative thinking tendencies over the course of the study.

The second sub-problem of the research was stated as: *"Is there a significant difference between the pre-test and post-test results of the creative thinking tendencies of students in the experimental group?"* to address this question, an independent samples t-test was conducted, and the results for the experimental group are presented in Table 3.

Table 3. Pre-Test and Post-Test Results of the Experimental Group

Creative Thinking Tendencies	N	X̄	SD	T	Df	p
Pre-Test	40	67.39	1.01	8.223	78	.000*
Post-Test	40	102.33	4.23			

***p≤ .05**

When the pre-test and post-test results of the experimental group regarding creative thinking tendencies were examined, a statistically significant difference was found in favor of the post-test scores [$t_{(78)}$=8.223; *p*=.000<.05]. As seen in Table 3, the mean score of the experimental group increased substantially from 67.39 (SD = 1.01) in the pre-test to 102.33 (SD = 4.23) in the post-test. This result suggests that the design-based science activities implemented in the experimental group had a significant positive effect on enhancing students' creative thinking tendencies.

The third sub-problem of the research was stated as: *"Is there a significant difference between the pre-test results of the creative thinking tendencies of students in the experimental and control groups?"* to address this question, an independent samples t-test was conducted, and the results for the experimental and control group are presented in Table 4.

Table 4. Pre-Test Results of the Experimental and Control Groups

Creative Thinking Tendencies	N	X̄	SD	T	Df	p
Experimental	40	67.39	1.01	-0.652	78	.062
Control	40	65.25	1.26			

***p≤ .05**

When the pre-test scores of the experimental and control groups regarding creative thinking tendencies were compared, no statistically significant difference was found between the groups [$t_{(78)}$=−0.652; *p*=.062>.05]. As shown in Table 4, the experimental group had a mean score of 67.39 (SD = 1.01), while the control group had a mean score of 65.25 (SD = 1.26). These results indicate that both groups were at a comparable level in terms of creative thinking tendencies before the intervention, thus supporting the internal validity of the study by ensuring group equivalence at the baseline.

The fourth sub-problem of the research was stated as: *"Is there a significant difference between the post-test results of the creative thinking tendencies of students in the experimental and control groups?"* to address this question, an independent samples t-test was conducted, and the results for the experimental and control group are presented in Table 5.

Table 5. Post-Test Results of the Experimental and Control Groups

Creative Thinking Tendencies	N	X̄	SD	T	Df	p
Experimental	40	102.33	4.23	4.546	78	.000*
Control	40	86.27	3.21			

***p≤ .05**

When the post-test scores of the experimental and control groups regarding creative thinking tendencies were compared, a statistically significant difference was found between the groups [$t_{(78)}$=4.546; *p*=.000<.05]. As presented in Table 5, the experimental group had a post-test mean score of 102.33 (SD = 4.23), while the control group had a mean score of 86.27 (SD=3.21). This result indicates that the design-based science activities implemented in the experimental group significantly enhanced students' creative thinking tendencies compared to those in the control group.

The fifth sub-problem of the research was stated as: *"Is there a significant difference between the pre-test and post-test results of the critical thinking tendencies of students in the control group?"* to address this question, an independent samples t-test was conducted, and the results for the control group are presented in Table 6.

Table 6. Pre-Test and Post-Test Results of the Control Group

Critical Thinking Tendencies	N	X̄	SD	T	Df	p
Pre-Test	40	77.23	2.01	5.185	78	.000*
Post-Test	40	109.23	4.01			

***p≤ .05**

When the pre-test and post-test scores of the control group regarding critical thinking tendencies were compared, a statistically significant difference was found in favor of the post-test scores [$t_{(78)}$=5.185; *p*=.000<.05]. As shown in Table 6, the control group's mean pre-test score was 77.23 (SD = 2.01), while the post-test mean increased to 109.23 (SD = 4.01). This result indicates that the traditional instructional process also contributed to a significant improvement in students' critical thinking tendencies.

The sixth sub-problem of the research was stated as: *"Is there a significant difference between the pre-test and post-test results of the critical thinking tendencies of students in the experimental group?"* to address this question, an independent samples t-test was conducted, and the results for the experimental group are presented in Table 7.

Table 7. Pre-Test and Post-Test Results of the Experimental Group

Critical Thinking Tendencies	N	$\bar{X}$	SD	T	Df	*p*
Pre-Test	40	79.22	2.02	4.937	78	.002*
Post-Test	40	122.53	3.71			

***p≤ .05**

When the pre-test and post-test scores of the experimental group regarding critical thinking tendencies were compared, a statistically significant difference was found in favor of the post-test scores [$t_{(78)}$=4.937; *p*=.002<.05]. As presented in Table 7, the experimental group's mean pre-test score was 79.22 (SD = 2.02), while the post-test mean increased to 122.53 (SD = 3.71). This result indicates that the design-based science activities implemented in the experimental group significantly improved students' critical thinking tendencies.

The seventh sub-problem of the research was stated as: *"Is there a significant difference between the pre-test results of the critical thinking tendencies of students in the experimental and control groups?"* to address this question, an independent samples t-test was conducted, and the results for the experimental and control group are presented in Table 8.

Table 8. Pre-Test Results of the Experimental and Control Groups

Critical Thinking Tendencies	N	$\bar{X}$	SD	T	Df	*p*
Experimental	40	79.22	2.02	0.334	78	.096
Control	40	77.23	2.01			

***p≤ .05**

When the pre-test scores of the experimental and control groups regarding critical thinking tendencies were compared, no statistically significant difference was found between the groups [$t_{(78)}$=0.334; *p*=.096>.05]. As shown in Table 8, the mean pre-test score of the experimental group was 79.22 (SD = 2.02), while that of the control group was 77.23 (SD = 2.01). This result indicates that both groups were at a similar level in terms of critical thinking tendencies prior to the intervention, supporting the equivalence of the groups at baseline.

The eighth sub-problem of the research was stated as: *"Is there a significant difference between the post-test results of the critical thinking tendencies of students in the experimental and control groups?"* to address this question, an independent samples t-test was conducted, and the results for the experimental and control group are presented in Table 9.

Table 9. Post-Test Results of the Experimental and Control Groups

Critical Thinking Tendencies	N	$\bar{X}$	SD	T	Df	*p*
Experimental	40	122.53	3.71	9.231	78	.000*
Control	40	109.23	4.01			

***p≤ .05**

When the post-test scores of the experimental and control groups regarding critical thinking tendencies were compared, a statistically significant difference was found in favor of the experimental group [$t_{(78)}$=9.231; *p*=.000<.05]. As shown in Table 9, the experimental group's mean post-test score was 122.53 (SD = 3.71), while the control group's mean score was 109.23 (SD = 4.01). This result indicates that the design-based science activities implemented in the experimental group significantly enhanced students' critical thinking tendencies compared to those in the control group.

DISCUSSION, CONCLUSION AND RECOMMENDATIONS

This study revealed that science activities designed through Design-Based Research (DBR) methodology significantly enhance middle school students' creative and critical thinking skills. The findings align with and confirm existing literature, underscoring the value of DBR-driven interventions in education (Azizan & Shamsi, 2022; Doppelt, 2006; Zhang et al., 2021).

For the first and second sub-problems, significant improvements were identified separately within both the control and experimental groups regarding students' creative thinking dispositions. However, the experimental group demonstrated a markedly higher increase, likely due to the problem-oriented nature of the design-based activities, which allowed students to actively engage with real-world problems. This aligns with the findings of Fortus et al. (2005), suggesting that DBR activities motivate students and increase their confidence in creative problem-solving. Furthermore, Geitz and de Geus (2019) emphasized that the student-centered and inquiry-driven characteristics of DBR contribute directly to enhancing creativity, such as originality and flexibility. The third sub-problem indicated no significant difference between the experimental and control groups in their pre-test creative thinking scores, demonstrating initial equivalence between groups and strengthening the study's internal validity.

Regarding the fourth sub-problem, the post-test scores of the experimental group were significantly higher than those of the control group. This outcome strongly indicates that design-based science activities are more effective in promoting creative thinking skills than traditional instructional methods, a result consistent with prior research highlighting that design processes inherently foster innovative idea generation (Amabile & Pratt, 2016).

The fifth and sixth sub-problems revealed significant improvements in critical thinking dispositions in both the control and experimental groups separately. The improvement in critical thinking is attributable to the nature of the activities, requiring students to question, hypothesize, analyze data, and make evidence-based decisions. Similar findings have been consistently reported by Santos (2017) and Yacoubian (2015), reinforcing the role of analytical inquiry in promoting critical thinking development. The seventh sub-problem indicated no significant differences in critical thinking pre-test scores between experimental and control groups, confirming again the initial equivalence of the groups (Yılmaz, Uysal & Nacar, 2024).

The eighth sub-problem demonstrated a significant advantage for the experimental group's critical thinking post-test scores. DBR activities inherently facilitate critical reasoning through structured argumentation and iterative evaluation processes, which aligns with Baum-Combs, Cennamo, and Newbill's (2009) assertion that design-based learning environments nurture systematic critical thinking.

The outcomes of this study clearly demonstrate that science activities developed through Design-Based Research methodology significantly enhance middle school students' creative and critical thinking skills compared to traditional teaching methods. The practical and problem-centered nature of these activities effectively encouraged students to engage in authentic problem-solving tasks, stimulating their creativity and critical thinking. These findings, consistent with international literature (Azizan & Shamsi, 2022; Fortus et al., 2005; Zhang et al., 2021), validate the effectiveness of DBR methodologies in Turkish educational contexts. Consequently, it is recommended that educators and curriculum developers integrate DBR-driven activities to foster students' essential 21st-century cognitive skills.

Based on the findings of this research, the following recommendations are presented:

1. *Integration of DBR in Science Education:* Science curricula, particularly at the middle school level, should be enriched with design-based activities that explicitly aim to improve creative and critical thinking skills.
2. *Professional Development for Teachers:* Professional training programs should be provided to enable teachers to understand and effectively implement DBR methodologies in their classrooms, enhancing both their confidence and instructional skills.
3. *Broadening the Scope of Research:* This study was conducted in a single school in Kastamonu, Türkiye. Future studies should involve larger and more diverse samples from different geographic and socio-economic contexts to increase generalizability.
4. *Longitudinal Studies:* Further research should investigate the long-term impacts of DBR interventions on students' creative and critical thinking skills to determine sustained effectiveness over extended periods.
5. *Interdisciplinary Applications:* Research should also focus on integrating design-based learning activities with other disciplines such as mathematics, technology, or engineering to investigate the effects of interdisciplinary education on cognitive skill development.
6. *Qualitative Investigations:* Future studies should incorporate qualitative research methodologies, including student interviews and classroom observations, to gain deeper insights into how students perceive and experience the learning processes inherent in design-based activities.

Declaration of Conflicting Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author received no financial support for the research, author-ship, and/or publication of this article.

Statements of publication ethics

I hereby declare that the study has not unethical issues and that research and publication ethics have been observed carefully.

Researchers' contribution rate

In this research, all processes were carried out by the author himself.

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