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Research Article

Addressing Misconceptions Regarding Force and Energy through Cognitive Conflict Activities

Bilişsel Çelişki Temelli Etkinliklerle Kuvvet ve Enerji ile İlgili Kavram Yanılgılarının Giderilmesi

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Abstract

This study examined the effectiveness of cognitive conflict-based activities and curriculum-based activities, as well as the interaction between instructional treatment and instructor, in improving seventh-grade students' conceptual understanding and in addressing their misconceptions concerning force and energy. This quasi-experimental factorial design study involved 58 seventh-grade students (27 boys and 31 girls) from two elementary schools during the second semester of the 2018–2019 academic year. The experimental groups participated in cognitive conflict-based activities, whereas the control groups received instruction through activities derived from the national science textbook. Seven cognitive conflict-based activities, structured around identifying misconceptions, generating contradictions, and clarifying scientific concepts, were developed by the researchers. Data were collected using the three-tier Force and Energy Misconceptions Test. Scores for scientific knowledge and misconceptions were computed, and a two-way ANOVA was performed to assess the effects of the instructional treatments and instructors. Additional analyses were conducted to compare the percentage of each misconception in the pre- and post-tests. The results indicated that, compared with curriculum-based activities, cognitive conflict-based activities significantly improved students' conceptual understanding scores. The results also showed that, compared with curriculum-based activities, cognitive conflict-based activities significantly reduced students' misconceptions. No significant interaction was found between the type of instructional treatment and the instructor. Overall, the findings highlight the effectiveness of cognitive conflict-based activities in promoting conceptual understanding and addressing misconceptions regarding force and energy.

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Abstract

Bu çalışmada, bilişsel çelişki temelli etkinlikler ile müfredat temelli etkinliklerin etkililiği ve ayrıca öğretim türü ile uygulayıcı arasındaki etkileşim, yedinci sınıf öğrencilerinin kuvvet ve enerji konularındaki kavramsal anlayışlarını geliştirme ve kavram yanılgılarını giderme açısından incelenmiştir. Yarı deneysel desenle yürütülen bu çalışma, 2018–2019 akademik yılının ikinci döneminde iki ayrı ortaokuldan toplam 58 yedinci sınıf öğrencisini (27 erkek, 31 kız) kapsamaktadır. Deney gruplarında bilişsel çelişki temelli etkinlikler uygulanırken, kontrol gruplarında öğretim Fen Bilgisi Ders Kitabı'nda yer alan etkinliklerle yürütülmüştür. Araştırmacılar tarafından, kavram yanılgılarının belirlenmesi, çelişki oluşturulması ve bilimsel kavramların açıklığa kavuşturulması olmak üzere üç aşamada yapılandırılmış yedi bilişsel çelişki temelli etkinlik geliştirilmiştir. Veriler üç aşamalı Kuvvet ve Enerji Kavram Yanılgıları Tanı Testi ile toplanmıştır. Bilimsel bilgi ve kavram yanılgısı puanları hesaplanmış ve öğretim türü ile uygulayıcının etkilerini değerlendirmek amacıyla iki yönlü ANOVA analizleri gerçekleştirilmiştir. Ayrıca her bir kavram yanılgısının ön test ve son test yüzdelerini karşılaştırmak için ek analizler yapılmıştır. Bulgular, bilişsel çelişki temelli etkinliklerin, müfredat temelli etkinliklere kıyasla öğrencilerin kavramsal anlayış puanlarını anlamlı düzeyde artırdığını göstermiştir. Sonuçlar ayrıca, müfredat temelli etkinliklerle karşılaştırıldığında bilişsel çelişki temelli etkinliklerin kavram yanılgılarını anlamlı düzeyde azalttığını ortaya koymuştur. Öğretim türü ile uygulayıcı arasındaki etkileşim açısından ise anlamlı bir fark bulunmamıştır. Genel olarak, bulgular bilişsel çelişki temelli etkinliklerin kuvvet ve enerji konularındaki kavramsal anlamayı geliştirmede ve kavram yanılgılarını gidermede etkili olduğunu göstermektedir.

Introduction

Science, technology, engineering, and mathematics (STEM) fields are critical to today's world for economic development, technological advancement, and social welfare (Holmes et al., 2018; Iwuanyanwu, 2020; Marginson et al., 2013). However, one of the important factors that limit success in these fields is the misconceptions, which are common among students (Liu & Fang, 2016), refers to students' thoughts that challenge with accepted scientific theories (Eryılmaz, 2002). Research shows that, especially in basic disciplines such as physics, chemistry, and mathematics, students learn many basic concepts incompletely or incorrectly, which has negative effects on their academic achievement and problem-solving skills (Liu & Fang, 2016; Smith et al., 1993; Toka & Aşkar, 2002) that have a high priority on a learner's mastery in STEM fields (Iwuanyanwu, 2020). Based on this reason, pedagogical strategies recognizing and addressing these misconceptions are needed to encourage a deeper conceptual understanding (Anggoro et al., 2019; Uwamahoro et al., 2021).

The physics education literature reveals that students experience significant difficulties in conceptual understanding due to the abstract nature of concepts (Docktor & Mestre, 2014; Legendre, 1997; Ramma et al., 2017). These concepts can conflict with students' daily life experiences, and such confusion paves the way for permanent misconceptions (Bahtaji, 2023; Brookes & Etkina, 2009; Docktor & Mestre, 2014; Duit & Treagust, 1995; Vosniadou & Skopeliti 2014; Wancham et al., 2023). Studies on fundamental physics concepts such as force and energy in particular show that students have difficulty in achieving meaningful learning on these topics (eg. Brookes & Etkina,

2009; Galili & Lehavi, 2003; Megalakaki & Thibaut, 2016; Özkan & Umdu Topsakal, 2021; Vosniadou et al., 2001; Yürümezoğlu et al., 2009). For instance, students often maintain unscientific thoughts such as energy "running out" (Besson & De Ambrosis, 2014; Megalakaki & Thibaut, 2016; Nordine et al., 2011) or force providing continuous "motion" (Liu & Fang, 2016; Palmer, 1997; Sadanand & Kess, 1990). However, the concept of force and energy are not only foundational knowledge in the field of physics (Bahtaji, 2023) but also key components of STEM education that students have to deeply understand, devoid of misconceptions, to facilitate effective learning in physics (Thibaut et al., 2018; Wancham et al., 2023). This backdrop necessitates a development of effective teaching techniques that assure conceptual understanding and eliminate misconceptions (Halim et al., 2014).

Misconceptions related to physics concepts such as force and motion are often attributed to students' prior experiences. On the other hand, these misconceptions may also develop during instruction as they try to interpret terminology of science (Graham et al., 2013). The conceptual change theory's view, which suggests that scientific knowledge replaced previous naïve conceptions (Posner et al., 1982) challenges with this perspective. Instructional methods that center on the delivery of correct information do not address misconceptions, limiting the ability of students to construct a comprehensible understanding of scientific concepts. According to Gönen (2008), these misconceptions are getting tough to be replaced and rooted deeply at higher education, when they are not taken into consideration effectively at the elementary or middle school level. There are many studies showing the resistance of certain misconceptions toward conventional instruction (Resbiantoro et al., 2022; Mestre, 1991). On the contrary, instructional methodologies that take misconceptions intentionally into account have been promoting conceptual change more effective than the conventional ones (Eryilmaz, 2002; Neidorf et al., 2020). Teaching methods such as conceptual change texts and cognitive conflict, especially when combined with opportunities for students to reflect on their thinking, have been shown to help students make significant improvements in their understanding of concepts (Duit & Treagust, 2003).

Different instructional strategies are widely used to remediate misconceptions. Concept cartoons, analogies, and conceptual change texts belong to these strategies whose success fundamentally centers on their ability to encourage the cognitive perturbation required for knowledge reorganization. Besides, they may encourage students to think deeply and keep up focusing on specific problems. So, to foster the required "disequilibrium" for conceptual reorganization, involvement of a cognitive conflict stage is crucial.

Fisher (2022) has shown that contemporary literature emphasizes cognitive conflict strategies having an essential role in encouraging collaboration, reformulation, and metacognitive awareness. Moreover, these well-thought-out steps make students concentrate on offering and evaluating their own conceptual frameworks (Brod, 2021).

Based on this aspect, the current study employs seven specifically developed cognitive conflict-based activities to address misconceptions in the seventh-grade curriculum.

Based on the previous research on cognitive-conflict as a part of conceptual change, this study examines the effect of cognitive conflict-based classroom activities on students' conceptual understanding of force and energy. By focusing on middle school science instruction, the study aims to contribute to the literature by exploring how structured cognitive conflict can help remediate persistent misconceptions. Accordingly, the research addresses the following questions:

1. Is there a significant difference in post-test scores between 7th grade students taught using cognitive conflict-based activities and those taught using curriculum-based activities in terms of their misconceptions about force and energy concepts?

2. Is there a significant interaction between instructor and instructional method on the remediation of 7th grade students' misconceptions regarding force and energy?

Misconceptions on Force and Energy

Students enter the classroom with pre-existing knowledge and intuitions acquired from their past life experiences and previous courses in physics (Canlas, 2019). When prior knowledge contradicts scientific notions, it displays as misconceptions and profoundly impacts the learning process (Neidorf et al., 2020). Research in physics education indicates that students have widespread and persisting misconceptions, particularly about the concepts of force and energy (Galili & Lehavi, 2003; Küçük et al., 2005; Megalakaki & Thibaut, 2016; Özkan & Umdu Topsakal, 2021; Siantuba et al., 2023; Yürümezoğlu et al., 2009).

The misconception that "heavier objects incline more rapidly in free fall" is common on the subject of force (Gunstone & White, 1981; Halloun & Hestenes, 1985). Similarly, the notion that gravity is absent on the Moon and gravitation varies significantly over short distances (Özkan & Umdu Topsakal, 2021) are among the common misconceptions on force. Therefore, students who have similar thoughts believe that mass varies based on location and the forces affecting the apple and the Moon are distinct. Furthermore, some students believe that gravity's force varies with an object's vertical motion or acts regularly in the direction of motion (Wells et al., 2020).

The misconception that "force implies motion" is another common one among students. They also believe that a continuous force is required for an object to move. Therefore, students perceive moving objects as subject to a net force. Similarly, they identify stationary objects not receiving a force (Bayraktar, 2009; Clement, 1982; Gilbert & Zylbersztajn, 1985; Minstrell, 1982). These conceptions might be due to existing interpretions of the philosophy of "impetus." Some students, for instance, contend that gravitational force becomes relevant only after an item relinquishes its "impetus" after

being projected upward (Gunstone & White, 1981; Minstrell, 1982; Whitaker, 1983). In some instances, students erroneously assume that circular motion necessitates a circular impulse, reflecting a pre-Newtonian perspective (Caramazza et al., 1981; McCloskey & Kohl, 1983).

A number of misconceptions regarding the force of friction are held by students, including the notions that "friction always opposes motion," "impedes motion," or "continuously alters the object's direction" (Özkan & Umdu Topsakal, 2021). In addition, the idea that the relationship between speed and force is known to be directly proportionate is widely held (Wells et al., 2020).

Students also have challenges in comprehending the idea of energy compared to that of force. Studies indicate that students often see energy as a resource that is used, diminished, or expended; they hold the belief that motionless things lack energy (Chabalengula et al., 2012; Megalakaki & Thibaut, 2016; Nordine et al., 2011; Watts & Zylbersztajn, 1981; Yürümezoğlu et al., 2009). Young children often identify energy with life, movement, and activity, believing it exists only in living entities or energy-storing items, such as batteries (Ioannides & Vosniadou, 2002). Moreover, students may not differentiate force and energy and use the two concepts interchangeably (Chabalengula et al., 2012; Diakidoy et al., 2003; Ioannides & Vosniadou, 2002; Kruger et al., 1992); for instance, they think that “force is the energy inside objects” or “energy is a force produced by muscles” (Lijnse, 1990; Megalakaki & Thibaut, 2016). Megalakaki and Thibaut's (2016) research reveals that students initially perceived force and energy as inherent characteristics of inanimate objects but later understood force as a phenomenon involving interaction. In living organisms, force and energy were primarily linked to physical attributes.

Consequently, misconceptions about force and energy are prevalent among students in both elementary and secondary education, posing significant barriers to the scientific comprehension of these concepts. Different instructional strategies have developed to address these misconceptions. One of the most widely used is refutational texts, which directly confront learners' preexisting misconceptions with scientifically accurate explanations. Diakidoy et al. (2003) demonstrated that sixth-grade students who read refutational texts on the topic of energy outperformed those who read standard expository texts. Fang and Liu (2019) found that enhanced hands-on experimentation using interactive kits significantly supported engineering students in grasping complex concepts such as force, acceleration, momentum, and impulse. Similarly, Atasoy et al. (2011) reported that structured group activities using worksheets helped prospective science teachers identify and revise their misconceptions about force and motion through peer discussion and reflection. Nalkıran and Karamustafaoğlu (2020) implemented the Predict-Observe-Explain (POE) strategy in teaching the concepts of work, energy, and power and found that students corrected their misconceptions and developed more scientifically coherent understandings of the interrelationships among these concepts. Recently, Özkan and Umdu Topsakal (2021) showed that integrating science, technology,

engineering, arts, and mathematics (STEAM) in middle school instruction led to significantly higher levels of conceptual understanding in force and energy while also reducing the prevalence of common misconceptions. In our study, cognitive conflict-based activities were implemented to address the students' misconceptions about force and energy.

Cognitive Conflict

Cognitive conflict is a fundamental element of the conceptual change framework (Limón, 2001), which is based on Piaget's theory of disequilibrium and Kuhn's philosophy of paradigm changes and may be described as the process by which an individual's conceptual beliefs are challenged, altered, or rejected in response to an anomalous situation (Madu & Orji, 2015). The conceptual change theory, articulated by Posner et al. (1982), argues that learners must feel dissatisfaction with their current understandings and perceive the new idea as intelligible, plausible, and fruitful for conceptual change to occur. This progression begins with the moment that students confront conflicting material with their existing knowledge. At this moment a cognitive conflict is created. It is defined by Lee and Kwon (2001) as a mental condition in which an individual observes the inconsistency between his/her cognitive framework and the environment. Students are expected not only confess the conflict but also actively resolve it through noteworthy cognitive reorganization (Lee et al., 2003).

Cognitive conflict is an essential key in prompting conceptual change. It makes students aware of the inconsistencies between their existing conceptions and new scientific information. Without recognizing this gap, learners are unlikely to spontaneously revise their prior knowledge to accommodate new ideas (Dignath et al., 2015). Effective instruction, therefore, goes beyond merely activating prior knowledge—it must also help students confront and reflect on contradictions between what they believe and what they observe, thereby enhancing both motivation and engagement (Dignath et al., 2015; Limón, 2001). When students are exposed to situations that challenge their current understandings, cognitive conflict can stimulate metacognitive awareness and foster self-regulated learning, which in turn supports deeper conceptual change (Shahbari & Peled, 2015). Brod (2021) suggests that strategies that stimulate metacognitive awareness also creates space for students to actively articulate and revise their own ideas. To better understand this process, Lee and Kwon (2001) proposed a three-stage cognitive conflict model comprising the preliminary, conflict, and resolution stages. In the preliminary stage, the learner accepts the authenticity of an anomalous situation despite holding a conflicting preconception. If the learner does not trust the anomalous data or lacks confidence in their prior belief, cognitive conflict may not occur. The conflict stage is characterized by recognition of the contradiction, emotional arousal (e.g., curiosity or anxiety), and an effort to resolve the inconsistency through cognitive reappraisal. Finally, in the resolution stage, students reformulate their understanding in light of the new information. Together, these stages illustrate how cognitive conflict can be strategically used to support meaningful learning and promote lasting conceptual change.

Researchers who have studied misconceptions stated that making students confront the misconceptions and changing these preconceptions through cognitive conflict is crucial (Vosniadou et al., 2001). In science education, the effectiveness of cognitive conflict-based instruction over remediation of students' misconceptions has been investigated by several studies. According to Chan et al. (1997), conceptual conflict, including the determination of prior conceptions, creation of inconsistency, and post-instruction evaluation, is a widely implemented instructional strategy. On the other hand, there are varied findings attaining no change of students' understanding (e.g., Dreyfus et al., 1990; Guzzetti et al., 1993; Limón & Carretero, 1997), improvement on students' learning (Başer, 2006; Madu & Orji, 2015; Stavy & Berkovitz, 1980; Toka & Aşkar, 2002) after confronting a conflicting situation. In the concept of heat and temperature, for instance, Başer (2006) revealed that physics instruction with cognitive conflict improved students' conceptual understanding rather than conventional instruction. Similarly, students had significant improvement in thermal concepts through a six-week cognitive conflict-based instruction in Madu and Orji's (2015) investigation. Additionally, the study by Vosniadou et al. (2001) also displayed that cognitive conflict strategies helped fifth and sixth-grade students understand force and energy better when they were aware of their own thinking. Vosniadou et al. showed that a learning environment that created cognitive conflict helped students better comprehend force and energy concepts. Furthermore, the positive effect of cognitive conflict on students' understanding of floating and sinking is displayed by Hadjiachilleos et al. (2013). They found that cognitive conflict is a personal experience whose effect on conceptual change lies in the learner's ability to experience and feel the conflict. Therefore, promoting an environment where students can engage with their misconceptions may improve their learning process. Eventually, addressing cognitive conflicts can lead to deeper conceptual understanding.

Research on instructional activities (Hadjiachilleos et al., 2013; Vosniadou et al., 2001), textual strategies (Aygün & Tan, 2021; Taşlıdere & Yıldırım, 2023), and analogies (Başer, 2006) has been showed the effectiveness of cognitive conflict in making abstract concepts more tangible. Students are expected to confront their misconceptions when they directly engage with materials. They observe situations which have inconsistency with their expectations and are forced to re-evaluate their understanding (Chiu, 2007; Özdemir & Clark, 2007). These activities enhance deeper cognitive engagement. Besides, they stimulate curiosity and motivation, which are essential for learning. A series of instructional activities were designed in this study. They were implemented to make students confront their conceptual understanding and create a consistence between their pre-knowledge and scientific knowledge. The activities, implemented in this study, served as a basis for creating cognitive conflict and enabling conceptual change on force and energy.

Methodology

Research Design

In this quasi-experimental factorial design with pretest–posttest control groups study (Gay & Airasian, 2000; Fraenkel & Wallen, 2019), four intact classrooms participated. Four intact classes were allocated as control and experimental groups from two public schools. The distribution of groups across schools and instructors (classroom teacher vs. researcher) is summarized in Table 1. This factorial design supported the examination of (i) the effectiveness of the cognitive conflict-based activities versus the 2018 Turkish National Science Curriculum–based activities and (ii) the potential interaction between the instructional treatment and the instructor in remediating students' misconceptions.

Table 1: *Distribution of Experimental and Control Groups across Schools*

School	Class Code	Group Type	Instructor	n
School 1	S1-E	Experimental	Teacher	15
	S1-C	Control	Teacher	15
School 2	S2-E	Experimental	Researcher	13
	S2-C	Control	Researcher	15

Participants

The participants of this study consisted of 58 seventh-grade students (27 males and 31 females). The students were from four intact classes from two public elementary schools. The study was implemented during the second semester of the 2018-2019 academic year. As shown in Table 1, each school contributes one experimental class (cognitive conflict-based activities) and one control class (2018 Turkish National Science Curriculum–based activities). The students, aged between 12 and 14, were enrolled in schools located in an urban district of Zonguldak, Turkey. Of the total sample, 30 students were from School 1 and 28 from School 2, within class sizes of 15 and 15 in School 1 (experimental and control, respectively) and 13 and 15 in School 2 (experimental and control, respectively).

The key difference between the groups lay in the instructional approach: the experimental groups received cognitive conflict-based activities, whereas the control groups were taught using curriculum-based activities from the national science textbook. Both groups covered identical content on force and energy, aligned with the objectives of the seventh-grade Turkish National Science Curriculum. Instruction in all groups was delivered over a total of 24 class hours, organized into six weekly sessions of four class hours each. Apart from the cognitive conflict-based activities—implemented exclusively in the experimental groups—all other instructional materials, classroom resources, and homework assignments were equivalent across groups.

To minimize researcher bias and ensure consistency, two instructors implemented the study. The first instructor was the researcher (first author), and the second was the science teacher from the second school. The science teacher received training on the cognitive conflict-based activities prior to the study. Additionally, the researcher and the

teacher collaborated to develop instructional plans before delivering the activities to students.

All class activities for both groups were conducted simultaneously, ensuring consistency in instructional time and schedule. All students fully participated in the study, completing both the pretest and posttest assessments.

Instrument

Force and Energy Misconception Test (FEMT)

This test was adapted by the researchers to evaluate students' misconceptions related to force and energy. It comprises 20 conceptual research-based questions covering various topics, including weight, gravity, gravitational force, work, kinetic energy, potential energy, and conservation of energy, friction, and air resistance. The development process of the test involved some key steps: The learning objectives for force and energy concepts were derived from the 7th grade Turkish National Science Curriculum. A comprehensive review of the relevant literature was conducted to identify common student misconceptions about force and energy. Based on these instructional objectives and documented misconceptions, test items were developed. The classification of misconceptions embedded in the instrument is provided in Table 2, which presents the targeted concepts, the corresponding misconceptions, and the alternative response sets used to identify each misconception. Each misconception was represented by at least two alternative responses in the instrument.

The questions were selected from sources, including the master's thesis of Dostal (2005), the Ph.D. theses of Tural Dinçer (2009), Kınık Topalsan (2015), Yıldız (2008), Yılmaz (2001), and the study by Watts & Zylbersztajn (1981). All items in the FEMT are structured in three tiers: the first tier presents the primary question, the second tier elicits the rationale, and the third tier captures students' confidence levels. The test comprises 20 multiple-choice items focus on conceptual understanding rather than quantitative calculations. Each item includes one correct answer, three or four distractors, and an opportunity for students to provide an alternative response when none of the supplied options reflects their thinking.

Table 2: *Concepts, Misconceptions, and Corresponding Alternative Response Sets in FETM*

Category	Misconceptions	Alternative Sets
Energy	M1. Energy is possessed only by living beings.	1.1b, 1.2b
	M2. Energy is used up or lost.	6.1b, 6.2d
	M3. Energy is associated only with movement.	14.1a, 14.2a
Work	M4. A force acting on an object does work even if the object does not move	3.1c, 3.2c; 4.1c, 4.2c
Friction force	M5. Friction happens only when things move (slipping)	5.1b, 5.2b
	M6. The friction force depends on the surface area; the larger the surface area, the greater the friction force.	7.1a,7.2a

	M7. Only rough surfaces cause friction force, no friction on air.	2.1b, 2.2b; 15.1b, 15.2a; 16.1b, 16.2b
	M8. The direction of the friction force is always opposite to the direction of the object's motion.	17.1a, 17.2a; 18.1b, 18.2a
	M9. Mass and weight are the same	19.1d, 19.2b
	M10. Massive objects exert a greater force on less massive one.	8.1c,8.2c; 9.1a, 9.2a; 11.1c, 11.2b
Gravitational force	M11. Heavier objects fall faster than lighter ones	12.1a, 12.2b
	M12. Weightlessness means there is no gravity.	13.1c, 13.2b
	M13. No gravity on the Moon/ Gravity is caused (or partly caused) by air pressure	10.1c, 10.2b;
	M14. Gravity requires a medium (air) to act through.	20.1a, 20.2a

The initial version of the test consisted of 23 items and was piloted for feedback. Experts, including three science teachers, two physics teachers with over eleven years of experience, and one academic specialist in physics education, reviewed the content validity of the items. The experts assessed the appropriateness of the questions in terms of content, alignment with curriculum objectives, and overall format. Based on their feedback, three items were removed due to ambiguity or inconsistency with the curriculum, and certain answer choices were revised. The finalized version of the test, containing 20 items, was administered individually in the semester of 2018-2019 as a pre-test and post-test to both experimental and control groups. Participants were given 60 minutes to complete the test, but they completed the test between 30 and 45 minutes. Students were informed that the results of the test would not affect their course grades. The reliability of the test was calculated as 0.84 for the first tier, 0.77 for the first two tiers, and 0.68 for the entire test, which is considered reasonable for a misconception test (Maloney et al., 2001).

The FEMT is a diagnostic tool where incorrect answers provide valuable insights into students' misconceptions. The three-tier structure of each item includes: 1. A multiple-choice question that assesses students' content knowledge. 2. A multiple-choice question asking for the reasoning behind the first-tier answer, evaluating the student's understanding. 3. A binary question that gauges students' confidence in their answers to the first and second tiers. Additionally, In the FEMT, correct answers correspond to scientifically accurate conceptions of force and energy, while distractors are based on common alternative conceptions. Misconception scores are calculated based on choices that align with these misconceptions. Students' responses were analyzed by using the Statistical Package for the Social Sciences (SPSS, version 20).

Treatment

Two science teachers (one of whom is the first author of this article) delivered instruction on the concept of force for four class hours a week across six weeks, totaling 24 class hours. The experimental groups were taught using cognitive conflict-based activities as part of a conceptual change approach. In contrast, the control groups received instruction offered by the 2018 Turkish National Science Curriculum, utilizing conceptual activities

from the contemporary science textbook (MEB, 2018) (see Table A1. Curriculum-based activities implemented in control groups in the Appendix 1). Both the experimental and control groups covered topics related to the concept of force as part of the regular seventh-grade science curriculum. The topics included the relationship between mass and weight, the relationship between force, work, and energy, conservation of energy, frictional force and kinetic energy loss, and air and water pressure. Thus, students in both groups had equal opportunities to engage with the same content through activities within same time span. However, the instructional approaches differed: the experimental group's activities emphasized addressing students' misconceptions, while the control group followed a more curriculum approach without specifically targeting misconceptions.

In the control groups, a teaching prescribed by the 2018 Turkish National Science Curriculum was employed. The teachers primarily used lecture-based and discussion methods to teach the force concepts. Students engaged with the contemporary science textbook, performing activities as outlined within the curriculum. The focus remained on executing the textbook activities as they were, with no specific attention given to addressing student misconceptions.

The researchers designed seven cognitive conflict activities (see Table A2. Cognitive conflict-based activities implemented in experimental groups in the Appendix 1) in line with the Cognitive Conflict Process Model (CCPM) (Lee et al., 2003) for the experimental groups. To ensure treatment fidelity, the materials were reviewed by two physics teachers and an academic expert in physics education. According to the CCPM (Lee et al., 2003), the cognitive restructuring is comprised of three stages:

1. Preliminary stage: This initial stage aimed to uncover students' pre-existing ideas about the subject matter. The sessions began by eliciting students' perspectives on various topics, using real-life phenomena related to force and energy. Students were asked to respond to conceptual questions based on these scenarios. The goal of this step was to identify students' preconceptions, which then served as critical reference points throughout the instructional sessions. The approach centered on students, emphasizing their active engagement with learning materials, whether individually or in peer discussions, and fostering a deep involvement in reconstructing their understanding. Teachers encouraged students to share their preconceptions by presenting scenarios and asking them to predict the outcomes.

2. Conflict Stage: During this stage, students worked collaboratively to perform demonstration experiments. While conducting these activities, students were prompted with a series of questions to stimulate group discussions. Following their initial predictions, teachers guided hands-on activities to facilitate observations. These observations were then compared to students' predictions through group discussions, fostering a space for cognitive conflict to arise. The students' engagement in demonstrations, observations, and conceptual questioning was intended to challenge

their pre-existing ideas. If misconceptions were identified, the activities prompted students to confront these through targeted questions. Additionally, a related video was shown, encouraging students to analyze the experimental process depicted, deepening their cognitive conflict experience.

3. Resolution Stage: In the final stage, the teachers provided scientific explanations for the conceptual questions addressed during the activities. The focus was on aligning students' observations with established scientific knowledge. This stage ensured that students recognized the alignment between their experimental observations and scientific principles. A sample of the activity used is included in the Appendix 2.

Data Analysis

Six scores were first produced in this study by the FEMT as described by Peşman and Eryılmaz (2010). Table 3 summarizes the scores and how these scores were calculated.

Table 3: *Types of Scores and Their Calculations*

Type of Scores		Calculation
First Tier		Only the first tier of items was taken into account.
	Score 1	The sum of the correct answers coming from all items when correct answers were coded as 1 and the others were coded as 0.
	Alternative Score 1	The sum of the answers from all items when the misconception answers were coded as 1 and the others were coded as 0.
Second Tier		First two tiers of items were taken into account.
	Score 2	The sum of the answers when a student's responses to the first and second tiers were correct, and coded as 1, otherwise coded as 0.
	Alternative Score 2	The sum of the answers when a student's responses to the first and second tiers were aligned with misconception, and coded as 1, otherwise coded as 0.
Third Tier		All three tiers of items were taken into account.
	Score 3	The sum of the correct answer to all three tiers of items. If a student's response to the first two tier correct and the third tier of a question was "Yes, I am,", then, it was coded as 1. Otherwise, it was coded as 0.
	Alternative Score 3	The sum of the answers when a student's responses to first two tier were aligned with misconception, and the third tier was "Yes, I am,", then, it was coded as 1. Otherwise, it was coded as 0.

There are eight possible categories obtained according to students' responses to all three tiers. Table 4 demonstrates these categories.

Table 4: *Eight Different Categories Obtained by Responses to Three Tiers*

Categories	First Tier	Second Tier	Third Tier
Scientific knowledge	Correct	Correct	Sure
Misconception	Incorrect	Incorrect	Sure
False positive	Correct	Incorrect	Sure
False negative	Incorrect	Correct	Sure
Lack of confidence/lucky guess	Correct	Correct	Not sure
Lack of knowledge type 1	Incorrect	Incorrect	Not sure
Lack of knowledge type 2	Correct	Incorrect	Not sure
Lack of knowledge type 3	Incorrect	Correct	Not sure

Based on the information in Tables 2 and 3 together, "score 3" is designated *scientific knowledge*, while "alternative score 3" is classified as a *misconception*. A higher "score 3"

indicates a high understanding level of force and energy concepts while a higher score of "alternative score 3" points to a high level of misconception students have. Additionally, "score 1" comprises categories of scientific knowledge, false positives, lucky guesses, and lack of knowledge, whereas "score 2" consists of scientific knowledge and lucky guesses. Similarly, "alternative score 1" encompasses the categories of misconception, false negatives, and lack of knowledge, while "alternative score 2" includes only misconceptions and lack of knowledge.

In the data analysis process, student responses were first inserted into an Excel document, where each type of score and its corresponding categories were calculated for each item. The data were then transferred to the SPSS, where they were dichotomized according to the answer key. Quantitative analyses were performed by using SPSS. Six different scores were produced; independent t-tests were run for "*score 1*," "*score 2*," and "*score 3*" and also for "*alternative score 1*," "*alternative score 2*," and "*alternative score 3*." Two-way ANOVA was carried out to determine scientific knowledge and misconception categories and to provide corresponding findings. Moreover, a one-way ANOVA was applied to assess significant differences among schools regarding students' scientific knowledge. The results showed no statistically significant differences in pre- and post-test scores among the schools, indicating that the school variable did not confound the findings. Additional calculations were conducted in Excel to compare the percentages of each misconception assessed by the pre- and post-tests.

Results

To examine the impact of cognitive conflict-based activities on students' misconceptions (dependent variable) and to control for prior knowledge of force and energy concepts before the intervention, the FEMT was administered as a pre-test. Independent samples t-tests were conducted on six different score types (Table 3) to determine whether there were significant differences in the mean scores between the experimental and control groups concerning students' understanding of force and energy concepts. The analysis revealed no statistically significant differences between the two groups for "*score 1*" ($t= 0.70$, $p= 0.94$, $p> 0.05$), "*score 2*" ($t= 0.84$, $p= 0.40$, $p> 0.05$), or "*score 3*", which was classified as scientific knowledge ($t= 0.63$, $p= 0.53$, $p> 0.05$). Descriptive statistics presented in Table 5 show the means of scores for scientific knowledge in both the experimental and control groups. These results indicate that the two groups did not differ significantly in their understanding of force and energy concepts. Therefore, the groups had similar levels of understanding of the force and energy concept before the treatment.

Similarly, no statistically significant difference was observed for "*score 3*", which represented misconception ($t=0.65$, $p=0.52$, $p> 0.05$). However, significant differences were found between the groups in scores for "*alternative score 1*" ($t= 2.45$, $p=0.017$, $p< 0.05$) and "*alternative score 2*" ($t= 2.03$, $p= 0.046$, $p< 0.05$). The results indicate that the experimental group exhibited more misconceptions, false negatives, and lack of knowledge compared to the control group. Consequently, the experimental group, which

demonstrated these deficiencies, was selected to participate in cognitive-conflict activities aimed at enhancing their understanding.

After the treatment, students instructed with cognitive-conflict activities got lower misconceptions scores on FEMT (Xexp=1.63) than students instructed with curriculum-based activities (Xcont =5.18). The findings obtained in the study should be presented in accordance with the research objectives and/or hypotheses. Relevant tables, figures, charts, or diagrams may be used to present the findings.

Table 5: *Descriptive Statistics of Pre-and Post-test Scores of FEMT regarding Treatment*

Score	Group	*n*	Pre-FEMT		Post-FEMT	
			Mean	SD	Mean	SD
Scientific knowledge	Experimental	30	1.97	1.69	12.73	2.52
	Control	28	1.82	1.66	4.57	2.15
Misconception	Experimental	30	5.17	2.38	1.63	1.25
	Control	28	5.18	2.21	5.18	2.21

Table 5 indicates that the mean of scientific knowledge score for experimental groups increased from 1.97 to 12.73, whereas the mean score for control groups increased from 1.82 to 4.57. The mean of misconception score for the experimental group decreased from 5.17 to 1.63, while the control group's mean remained constant at 5.18.

To investigate the effect of treatment and instructor on students' understanding of the force and energy concept, a two-way Analysis of Variance (ANOVA) was run at 0.05 significance. Table 6 shows the results of two-way ANOVA for scientific knowledge.

Table 6: *Two-way ANOVA Summary for Scientific Knowledge*

Source	df	SS	MS	*F*	*p*
Treatment	1	958.78	958.78	198.21	0.00*
Instructor	1	43.83	43.83	9.06	0.04*
Treatment x instructor	1	6.25	6.25	1.29	0.26
Error	52	251.53	4.84		

Note. * Significant at $p<0.05$

It was found that there was a significant mean difference between scores of students taught by cognitive-conflict activities and curriculum-based activities regarding understanding the concept of force and energy ($F=198.21$; $p<0.05$). Similarly, there was a significant mean difference between the scores of students taught by different instructors ($F=9.06$; $p<0.05$). Table 7 represents the descriptive measures of pre-and post-test scores for scientific knowledge and misconception categories of FEMT regarding instructors. However, the interaction between the instructor and treatment had no significant effect on students' understanding of the force and energy concept ($F=1.29$; $p>0.05$).

Table 7: *Descriptive Statistics of Pre-and Post-test Scores of FEMT regarding Instructors*

Score	Group	*n*	Pre-FEMT		Post-FEMT	
			Mean	SD	Mean	SD
Scientific knowledge	Teacher	30	1.63	1.71	7.80	4.41
	Researcher	28	2.18	1.59	9.86	4.90
Misconception	Teacher	30	5.27	2.68	3.63	2.55
	Researcher	28	5.07	1.80	3.04	2.47

To investigate the effect of treatment and instructor on remediating students' misconceptions about force and energy, a two-way Analysis of Variance (ANOVA) was run at a 0.05 significance level. Table 8 displays the results of two-way ANOVA for misconception.

Table 8: *Two-way ANOVA Summary for Misconception*

Source	df	SS	MS	F	p
Treatment	1	182.67	182.67	59.12	0.00*
Instructor	1	2.97	2.97	0.96	0.33
Treatment x instructor	1	2.47	2.47	0.80	0.38
Error	52	160.68	3.09		

Note. * Significant at $p<0.05$

The results revealed a significant mean difference between the scores of students taught using cognitive-conflict activities and those taught through curriculum-based methods in terms of remediating misconceptions about force and energy ($F = 59.12$; $p < 0.05$). However, no significant mean difference was found between the misconception scores of students taught by different instructors ($F = 0.96$; $p > 0.05$). Table 8 further indicates that there was no significant interaction effect between treatment and instructor on the remediation of misconceptions related to force and energy ($F = 0.80$; $p > 0.05$).

The "alternative score 3," which indicates the presence of a misconception, was precisely analyzed for each item in the pre-and post-tests to determine the percentage of misconceptions within both the experimental and control groups. The items were systematically categorized, as shown in Table 3, to facilitate the calculation of misconception percentages. In cases where multiple items corresponded to the same misconception, the average percentage was computed. Table 9 presents the pre-and post-test percentages of misconceptions for both groups, providing insight into the effect of the treatment.

Table 9: *Percentages of Students with Misconceptions: Pre-and Post-Treatment*

	Control Group (n=28)		Experimental Group (n=30)	
Misconceptions	Pre (%)	Post (%)	Pre (%)	Post (%)
M1. Energy is possessed only by living beings.	17.9	21.4	26.7	0.0
M2. Energy is used up or lost.	7.1	53.6	20.0	3.3
M3. Energy is associated only with movement.	21.4	10.7	23.3	0.0
M4. A force acting on an object does work even if the object does not move	29.0	2.0	33.0	0.0
M5. Friction occurs only when objects move (slipping)	32.1	28.6	43.3	6.7
M6. The friction force depends on the surface area; the larger the surface area, the greater the friction force.	28.6	42.9	33.3	13.3
M7. Only rough surfaces cause friction force, no friction on air?	22.0	29.0	13.0	7.0
M8. The direction of the friction force is always opposite to the direction of the object's motion.	23.0	30.0	22.0	10.0
M9. Mass and weight are the same	10.7	3.6	13.3	3.3
M10. Massive objects exert a greater force on less massive one.	18.0	14.0	10.0	3.0

M11. Heavier objects fall faster than lighter ones	50.0	57.1	63.3	6.7
M12. Weightlessness means there is no gravity.	3.6	0.0	6.7	0.0
M13. No gravity on the Moon/Gravity is caused (or partly) by air pressure	21.4	17.9	33.3	13.3
M14. Gravity requires a medium (air) to act through.	21.4	35.7	30.0	0.0

The post-test results revealed that the percentage of misconceptions among students in the experimental groups was generally lower compared to the control groups. However, before the treatment, certain misconceptions were more prevalent in the experimental groups, with notable differences at misconceptions especially M2, M5, M11, and M13. For instance, 63.3% of students in the experimental groups thought that heavier objects fall faster than lighter ones, whereas this belief was held by 50% of students in the control groups. Similarly, 43.3% of experimental group students thought that friction occurs only when object moves, compared to 32.1% in the control groups.

Following the treatment, a significant reduction in the percentage of misconceptions was observed within the experimental groups. The most persistent misconceptions in the experimental groups were: "The friction force depends on the surface area; the larger the surface area, the greater the friction force," (M6) and "There is no gravity on the Moon/Gravity is caused (or partly caused) by air pressure," (M13) both with a prevalence of 13.3%. Additionally, misconception M8, "The direction of the friction force is always opposite to the direction of the object's motion," followed closely with a reduction to 10%. Although there are still misconceptions determined after treatment, most of them stayed under 10%. This situation of experimental groups demonstrates an important overall enhancement in conceptual understanding.

Divergent trends are observed between experimental and control groups through the comparison of pre- and post- test results. In the experimental groups a noteworthy decline was determined. However, in the control groups percentage of some misconceptions increased. The misconception "heavier onjects fall faster than lighter ones" (M11), for instance showed an impotant decline from 63.3% to 6.7% in the experimental groups. On the other hand, in the control group the percentage of this misconception increase from 50 to 57.1. In the same way, the percentages of students who think "friction depends on the surface area" increased from 28.6 to 42.9 in the control groups, where it decreased from 33.3 to 13.3 in the experimental groups.

Table 9 displays varied trends in the prevalence of misconceptions within the groups in detail. Specifically, misconceptions M3, M4, M5, M9, M10, M12, and M13 exhibited a decrease in prevalence, while M1, M2, M6, M7, M8, M11, and M14 showed increases. Notably, M2, "Energy is used up or lost," displayed the most dramatic change, with a 46.5% increase, rising from 7.1% to 53.6%. Misconceptions M6 "The friction force depends on the surface area; the larger the surface area, the greater the friction force" and M14 "Gravity requires a medium (air) to act through" also increased by 14.3%. Conversely, the remaining misconceptions exhibited an increase of less than 10% between the pre-and post-tests.

Discussion

This study examined the effects of contemporary teaching activities in science textbook and cognitive conflict-based activities on conceptual change in students' misconceptions of force and energy. Many studies in physics education reveal that students have difficulty in understanding abstract concepts such as force, motion, mass, energy, gravitation, and acceleration (Bar, 1989; Coelho, 2010; Halloun and Hestenes, 1985; Lijnse, 1990; Minstrell, 1982; Neumann et al., 2013; Sharma et al., 2004; Stylianidou, 2002; Temiz & Yavuz, 2014) and have common misconceptions about these topics (Galili & Lehavi, 2003; Küçük et al., 2005; Megalakaki & Thibaut, 2016; Özkan & Umdu Topsakal, 2021; Siantuba et al., 2023; Yürümezoğlu et al., 2009). However, these conceptual difficulties are not limited to students; preservice teachers (Anggoro et al., 2019; Bayraktar, 2009; Gönen, 2008; Kınık Topalsan & Bayram, 2019; Timur, 2012), teachers (Galili & Lehavi, 2003; Kruger et al., 1992) have alternative understandings of the concepts of force, motion, and energy.

In this context, the pre-test findings of the study showed that students had quite common misconceptions about force and energy. Regarding force, it was observed that students adopted expressions such as "heavier objects fall faster than lighter ones," "friction occurs only when an object moves," "a force acting on an object does work even if the object does not move," and "the friction force depends on the surface area; the larger the surface area, the greater the friction force." These misconceptions are consistent with previous studies such as Özkan and Umdu Topsakal (2021), Streveler et al. (2008), and Vosniadou et al. (2001). Regarding gravity, expressions such as "No gravity on the Moon," or "Gravity is caused (or partly caused) by air pressure," and "Gravity requires a medium (air) to act through" are noteworthy. These findings show that students' tendency to see air as a necessary context (Bar, 1989; Philips, 1991) is still effective. The concept of energy is also abstract and complex for students and is represented by misconceptions such as "energy is possessed only by living beings" and "energy is used up or lost." These results are parallel to the findings of studies such as Megalakaki and Thibaut (2016), Nordine et al. (2011), Özkan and Umdu Topsakal (2021), and Yürümezoğlu et al. (2009). Accordingly, students' view of energy as inherently consuming rather than using conservation and deprivation to explain phenomena (Besson & De Ambrosis, 2014) is quite reasonable.

Misconceptions, especially about the relationship between weight and falling speed, indicate that pre-Galileo intuitive ways of thinking (Gruszczyński, 2022) continue among students today. Similarly, associating energy only with biological processes stems from students' limited and contextual daily life experiences, emphasizing young children's beliefs in accuracy of sensory impressions (Megalakaki & Thibaut, 2016). If such misconceptions are not eliminated at the elementary school level, students have difficulty in making sense of scientific knowledge, and these misconceptions can continue from primary school to university (Gönen, 2008). In this context, cognitive conflict-based teaching activities provide an effective strategy that supports meaningful learning processes by allowing students to question their existing concepts (Madu & Orji, 2015).

The findings of this study also revealed that cognitive conflict-based activities are effective in eliminating misconceptions about force and energy among seventh grade students. In particular, students in the cognitive conflict-based activities group showed a significant decrease in misconceptions compared to the curriculum-based activities group. These results are consistent with previous studies emphasizing the effect of cognitive conflict on conceptual change (Başer, 2006; Madu & Orji, 2015; Hadjiachilleos et al., 2013; Vosniadou et al., 2001). Contrary to the positive effects of cognitive conflict-based teaching, it is remarkable that the percentage of certain misconceptions increases in the curriculum-based teaching environment.

The misconception “energy is used up or lost" showed a striking increase in the control groups. Before instruction, only two students thought that energy is used or lost; however, the number of students having the same misconception increased to fifteen after treatment. This increase in certain misconceptions suggests that the curriculum-based activities may be influencing them rather than remediating. The ambiguity of everyday language regarding the concept of energy may be the reason for the increase in this misconception. The words such as “consumption,” “spending,” and “using up” are commonly used in daily life conversations. Even when used mistakenly in instruction, these expressions about energy may affect students’ conceptual understanding. Linguistic patterns, as research displays, can support non-scientific interpretations of energy; it can be perceived as a substance that lessens during physical practices (Lancor, 2014; Halilovic et al., 2022). Students, then, internalize these expressions when similar terminology is used in textbooks or during instruction. Kohn et al (2018) indicated that educational metaphors portraying energy as a material can raise alternatice conceptions. Similarylyi Guerra-Reyes et al. (2024) revealed that reviews emphasize the role of contextual factors in sustaining misconceptions in physics education. So, the determined raise in misconceptions in the control group may mirror the unintentional influence of everyday language involved in curriculum-based instruction. This misconception, therefore may need more explicit scaffolding about the principle of energy conversation. Also, a greater attention may be required to the role of language used in the classroom in shaping students’ conceptual understanding.

The persistent misconceptions determined in this study align with the broader literature demonstrating that traditional instruction often fails to enhance conceptual change. In this study, some misconceptions increased after the curriculum-based instruction. That means these activities did not effectively challenge pre-existing unscientific comprehension of students, however reinforced them. Prior research also underlined that conventional instructions are generally ineffective in addressing misconceptions (Resbiantoro et al., 2022; Seyed Fadaei & Mora, 2015; Erman, 2017; Widiyatmoko & Shimizu, 2018). Furthermore, these misconceptions may not simply caused by prior knowledge but also they may be construted during instructions not having adequate scaffolding. (Graham et al., 2013).

On the contrary, the misconception "a force acting on an object does work even if the object does not move" had a different pattern. A substantial remediation was determined in this misconception in both control and experimental groups. It is realized that the textbook activity implemented in the control groups, which addresses the concept of physical work implicitly, had key features of cognitive conflict. The activity requires students to compare their pre-knowledge with the scientific one, which creates a latent form of cognitive disequilibrium. This reflective comparison seems to support the conceptual reorganization of students for this particular misconception. Resbiantoro et al. (2022) indicate that traditional teaching methods are ineffective in altering students' existing misconceptions in physics education. Additionally, Seyed Fadaei and Mora (2015) found that misconceptions regarding force and motion persisted despite traditional teaching methods among high school students. Teachers and teaching methods are among the primary factors contributing to students' misconceptions (Erman, 2017; Widiyatmoko & Shimizu, 2018). Moreover, the study by Graham et al. (2013) showed that misconceptions about force and motion may not be structures that existed before instruction and that students' ideas about these concepts may emerge spontaneously during the instructional process, as they attempt to make sense of them. Consequently, augmentation is necessary to address misconceptions. Teachers may enhance their understanding of students' misconceptions and their remediation, while also employing conceptual change teaching methods.

This study's findings indicate no statistically significant interaction between instructors and treatment regarding students' conceptual understanding or the elimination of misconceptions. Although students in the researcher's class exhibited higher conceptual understanding scores, this pattern should be interpreted with caution, as the dual role of the researcher as both instructor and implementer of the cognitive conflict activities may introduce potential internal validity concerns. Specifically, differences in implementation fidelity and the possibility of an experimenter expectancy effect may have contributed to performance differences independent of the treatment itself, functioning as a potential confounding factor. In contrast, students from the control groups taught by two independent instructors showed similar misconception scores post-treatment. Moreover, students in both the teacher and researcher classes exhibited higher misconception scores after being instructed through curriculum-based activities, unlike those taught using cognitive conflict-based activities. Prior research has demonstrated that conventional teaching methods are generally ineffective in addressing misconceptions (Saul & Redish, 1998). The present findings reinforce this pattern, suggesting that curriculum-based activities may not reduce students' misconceptions unless they explicitly incorporate cognitive conflict as a conceptual change mechanism and—in some cases—may inadvertently reinforce existing alternative conceptions.

The findings further indicate that misconceptions are not equally complying to change. Persistent misconceptions, including "the friction force depends on the surface area; the larger the surface area, the greater the friction force," "the direction of the

friction force is always opposite to the direction of the object's motion" and "No gravity on the Moon," or "Gravity is caused (or partly caused) by air pressure" remained evident among students even engaged in cognitive conflict-based activities. The notions of force and energy are among the most challenging for students to comprehend (Chi, 2005; Streveler et al., 2008), and their robustness and persistence in students depend on their accurate ontological categorization (Chi, 2005). Another factor contributing to this persistence may be social, stemming from insufficient negotiation of meanings between students and teachers (Novak, 2002), or personal, related to students' beliefs about intelligence (Dweck, 2000). The extent to which students view their intelligence as either static or not may affect conceptual change; those with a fixed mentality view are less likely to undertake demanding learning tasks or to persist in them (Dweck, 2000). Zohar and Aharon-Kravetsky (2005) critiqued cognitive conflict-based teaching, asserting that high-achieving students derive greater benefits than their low-achieving students. Cognitive conflict-based instruction hinders the advancement of low-achieving students, whereas traditional instruction obstructs the progress of high-achieving students. This underscores the importance of considering ontological shifts, students' beliefs, motivations, and academic levels when preparing the instructional intervention.

Conclusion and Reccomendations

The important role of cognitive conflict-based instruction in remediating misconceptions in physics concepts, especially in force and energy, is underlined by this study. The findings of this study show that students who participated in intentionally designed cognitive conflict activities showed greater conceptual change than those instructed through curriculum-based activities. The efficacy of cognitive conflict that challenges students' pre-conceptions and fosters deeper understanding through active cognitive process is confirmed by this study. The role of hands-on activities is critical in providing achance to make abstract physical phenomena observable and tangible. Students confront and evaluate their misconceptions through direct observations and experiments provided by hands-on acitivities.

A noteworthy finding of this study is the absence of a significant interaction between the instructors and the treatment. This indicates that the cognitive conflict-based activities were implemented with comparable effectiveness by both the researcher and the classroom teacher. However, the fact that the researcher served as the instructor for one of the experimental groups introduces a potential threat to internal validity. Even though no statistically significant instructor × treatment interaction emerged, the dual role of researcher and teacher may have created experimenter expectancy effects or subtle differences in instructional delivery. These factors may have influenced student engagement or the fidelity of implementation in ways not fully captured by quantitative analyses. Acknowledging this methodological limitation is important for interpreting the results, as it suggests that part of the observed learning gains may reflect characteristics of the instructional delivery rather than the intervention itself. Future research could mitigate such potential confounding by employing independent instructors, using

external observers to monitor fidelity, or adopting counterbalanced designs to separate researcher effects from intervention effects.

Moreover, although the participating teachers worked in different schools, an additional ANOVA analysis revealed no statistically significant differences among the schools in students' scientific knowledge scores in either the pre- or post-tests. This finding suggests that school-related factors—such as learning environment or socioeconomic context—did not substantially influence the results. Consequently, the outcomes can be attributed primarily to the cognitive conflict-based intervention rather than to school-level variations. Overall, these results reinforce the idea that well-designed and carefully prepared cognitive conflict activities can be successfully implemented by teachers, yielding outcomes comparable to those achieved in researcher-led implementations.

The persistent existence of specific misconceptions despite targeted interventions indicates that conceptual change may not occur immediately or comprehensively. This limitation underscores the complex nature of the learning process and the necessity for endured instructional support. The study indicated significant improvements in students' conceptual understanding; however, it also demonstrated that responses to cognitive conflict varied among students. This variation may result from individual differences, including cognitive readiness, motivational factors, epistemological beliefs, or affective responses to the learning context. Additionally, the study was conducted at 2018–2019 academic year, using curriculum materials, textbooks, and instructional approaches of that period. Given subsequent updates to national curricula and changes in teachers' instructional practices, caution is warranted when generalizing the findings to contemporary science classrooms. The study had further limitations related to its focus on a particular set of physics concepts, its limited sample, and the relatively short duration of the instructional intervention. The results, therefore, may not generalize to all science topics or educational contexts.

Despite these limitations, the study offers several implications for teaching and future research. First, it suggests that teachers should deliberately design instructional activities that not only convey scientific concepts but also explicitly elicit and confront students' misconceptions. Embedding cognitive conflict in hands-on, inquiry-oriented tasks can stimulate students' metacognitive awareness and promote deeper conceptual restructuring. Second, the findings underscore the importance of professional development for teachers, enabling them to recognize common misconceptions and implement cognitive conflict strategies effectively in diverse classroom settings. Finally, future research should explore how cognitive conflict interacts with other instructional variables, such as scaffolding, emotional engagement, and the use of metacognitive supports, over extended periods and across different science domains. Employing independent instructors, incorporating fidelity-of-implementation monitoring, replicating the intervention under updated curricular conditions, or adopting

counterbalanced designs could strengthen future studies and provide more robust evidence on the mechanisms through which cognitive conflict fosters conceptual change.

Ethical Approval

Ethical approval and written permission were obtained from the Zonguldak Bülent Ecevit University Social and Humanities Sciences Ethics Committee (approval granted at the meeting dated 30 November 2018, Protocol No. 441).

Author Contributions

Özge Gökçe-Erdem: Conceptualisation, Theoretical Background, Methodology, Data Collection, Data Analysis, Data Visualisation, Writing

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Conflict of Interest

The authors declare no conflict of interest.

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The authors used AI-based tools for language polishing and academic writing support to enhance the manuscript's readability. The final version was thoroughly reviewed and approved by the authors.

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