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Effectiveness of conceptual change strategies in science education: A meta-analysis

Cagatay Pacaci[1] | **Ulas Ustun**[2] | **Omer Faruk Ozdemir**[3]

[1]Kastamonu Science and Art Center, Kastamonu, Turkey

[2]Department of Mathematics and Science Education, Faculty of Education, Artvin Çoruh University, Artvin, Turkey

[3]Department of Mathematics and Science Education, Faculty of Education, Middle East Technical University, Ankara, Turkey

Correspondence
Cagatay Pacaci, Kastamonu Science and Art Center, Kamil Demircioğlu Cd. No: 34/B, Kuzeykent Mah., 37150 Kastamonu, Turkey.
Email: pacacicagatay@gmail.com

Abstract

There is extensive literature focusing on students' misconceptions in various subject domains. Several conceptual change approaches have been trying to understand how conceptual change occurs to help learners handle these misconceptions. This meta-analysis aims to integrate studies investigating the effectiveness of three types of conceptual change strategy: cognitive conflict, cognitive bridging, and ontological category shift in science learning. We conducted a random-effects meta-analysis to calculate an overall effect size in Hedges' g with a sample of 218 primary studies, including 18,051 students. Our analyses resulted in a large overall effect size ($g = 1.10$, 95% CI [1.01, 1.19], $k = 218$, $p < 0.001$). We also performed a robust Bayesian meta-analysis to calculate an adjusted effect size, which specified a large effect (adjusted $g = 0.93$, 95% CI [0.68, 1.07], $k = 218$). Results are also consistent across the conceptual change strategies of cognitive conflict ($g = 1.10$, 95% CI [0.99, 1.21], $k = 150$, $p < 0.001$), cognitive bridging ($g = 1.06$, 95% CI [0.84, 1.28], $k = 30$, $p < 0.001$), and ontological category shift ($g = 0.88$, 95% CI [0.50, 1.26], $k = 9$, $p < 0.001$). However, a wide-ranging prediction interval [0.19, 2.38] points out a high level of heterogeneity in the distribution of effect sizes. Thus, we investigated the

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moderating effects of several variables using simple and multiple meta-regression. The final meta-regression model we created explained 35% of overall heterogeneity. This meta-analysis provides robust evidence that conceptual change strategies significantly enhance students' learning in science.

KEYWORDS

cognitive bridging, cognitive conflict, conceptual change, meta-analysis, ontological category shift

1 | INTRODUCTION

Students get diverse experiences and construct many ideas based on these experiences even before starting formal education, some of which may contradict scientific knowledge (Abdullah et al., 2017; Barke et al., 2009; Heng & Karpudewan, 2017; Hewson, 1992; Posner et al., 1982). Therefore, extensive research has focused on understanding students' preinstructional ideas. Different researchers have adopted different terminologies to refer to students' pre-instructional ideas because of different epistemological orientations. Some of the most common terminologies are misconceptions (Griffiths & Preston, 1992; Posner et al., 1982; Vosniadou, 1994), alternative conceptions (Driver & Easley, 1978; Hewson & Hewson, 1989; Mungsing, 1993), naïve conceptions (Baillargeon, 2004; Caramazza et al., 1981; Vosniadou, 1994), intuitive knowledge (diSessa et al., 1998), spontaneous reasoning, and children's science (Karpudewan et al., 2017). In this study, we will use the term, misconception, simply because it is the most common term used in conceptual change literature, especially the ones focusing on instructional practices. While using this term, we do not intend to situate this study into a particular position. As will be seen in the following sections, a broad range of theoretical positions and corresponding instructional strategies were included in this study. While some of these studies have a position to see students' conceptions as unproductive, some others see them as highly productive while learning new concepts.

Misconceptions are generally defined as student conceptions that may produce systematic error patterns (Vosniadou, 2019). These misconceptions may stem from several types of sources such as textbooks, instructional materials, educational analogies, the language of science, teachers' misconceptions, as well as student's interactions with the physical world or social interactions with their peers, friends, or parents (Barke et al., 2009; Karpudewan et al., 2017; Sinatra & Pintrich, 2003). They cause learning difficulties and may hinder comprehension of scientific ideas (Chinn & Brewer, 1993; Smith et al., 1993). This is why overcoming misconceptions has become one of the primary goals of instructional practices. In this sense, the conceptual change instruction was proposed to help students shift from scientifically incorrect pre-instructional knowledge structures to scientifically accepted ones. Since the 1980s, especially after Posner et al. (1982) proposed the conceptual change model, an immense body of literature has focused on understanding how conceptual change occurs, and accordingly, different types of conceptual change approaches have been developed for learning science. These approaches do not mutually exclude each other but attribute different roles to prior knowledge of the conceptual change process. Hence, they propose different types of instructional strategies to achieve conceptual change.

There are numerous studies investigating the effectiveness of these instructional strategies in the literature. However, their results do not show a consistent pattern (Brown, 1995; Tsai, 2003; Slotta & Chi, 2019; 2006; Smith et al., 1993; Zohar & Kravetsky, 2005). Some studies favor these strategies, while others do not (Saigo, 1999; Seyedmonir, 2000; Windschitl & Andre, 1996; Zohar & Kravetsky, 2005). It is not uncommon to find such conflicting findings on the same research topic in any scientific discipline (Rosenthal & DiMatteo, 2001). Indeed, it gets even more complicated in the social sciences, particularly in the educational sciences (Berliner, 2002). That is one of the reasons why researchers are highly encouraged to conduct research syntheses in educational sciences. The research synthesis provides an overall summary of the findings and helps us explain the reasons for conflicting results (Üstün & Eryılmaz, 2014).

Meta-analysis is one of the most common methods of research synthesis. It is a quantitative research methodology that synthesizes the studies conducted on the same research topic to summarize their results and resolve any contradictory findings. Given that there are many studies examining the effect of conceptual change strategies on science achievement and the results of these studies show significant heterogeneity, conducting a meta-analysis on this topic would be helpful for both researchers and policymakers in education.

Some meta-analyses have already been conducted to summarize the studies examining the effectiveness of conceptual change strategies (Guzzetti et al., 1993). None of them, however, compare the different types of conceptual change strategies. They mainly focus on Posner's model of conceptual change. Accordingly, they typically cover the primary studies using cognitive conflict strategy. Although this type of primary study dominates the literature on conceptual change, some studies use different strategies based on different approaches. To the best of our knowledge, this is the first meta-analysis to combine and compare studies using several conceptual change strategies.

In this context, we aim to synthesize the studies that used conceptual change strategies and compare the results across different types of conceptual change strategies. We particularly focus on the effect of these strategies on science achievement in this meta-analysis. We also examine any heterogeneity via potential moderators.

1.1 | Review of literature

Conceptual change is one of the most studied areas of science education, and it is not feasible to give the full breadth of the literature in a brief review. In this literature review, we limited ourselves to the theoretical frameworks and instructional strategies used by the "experimental studies" covered in this meta-analysis. The experimental studies in the literature dominantly use cognitive and knowledge-based interpretations of the conceptual change process. This is probably because it is relatively easier to develop instructional strategies based on these theoretical perspectives. In this study, we are not comparing the conceptual change theories but rather the instructional practices that employ conceptual change strategies emerging from different theories. In this section, we provided a general framework covering most of the experimental studies available in the literature on conceptual change.

The conceptual change process was deeply rooted in Piaget's (1964) theoretical constructs of assimilation, accommodation, and equilibration processes, proposed in the context of the evolution of knowledge in children's cognitive development. Thomas Kuhn's (1970) historical account of change in the history of science also enhanced the understanding of the conceptual change process. He stressed the revolutionary changes in scientific conceptions throughout the history of science, such as the transitions from the Aristotelian view to Galilean, from Galilean to Newtonian, or from Newtonian to quantum physics (Özdemir, 2004). Based on both Piaget's and Kuhn's arguments, Posner et al. (1982) introduced the conceptual change model (CCM) into science education literature. This model successfully integrated the historical and cognitive aspects of how we know about scientific knowledge and provided a general framework for the conditions of a successful conceptual change. Dissatisfaction with the existing conception was described as the first condition of conceptual change, and the following conditions were defined as intelligibility, plausibility, and fruitfulness of the new conception.

In the following years, different theoretical perspectives about the nature of misconceptions and possible ways of conceptual change emerged. The original CCM proposed by Posner et al. (1982) assumed that misconceptions are theory-like conceptions because of the parallelism between students' misconceptions and early scientific conceptions, such as Aristotelian and Newtonian views in mechanics, which consist of coherent knowledge structures. The theory-like knowledge perspective was further elaborated by several researchers, such as Vosniadou et al. (2008) and Carey (1985, 2008), under the heading of a coherent view of students' knowledge. Vosniadou (1994) rationalized this perspective based on ontological and epistemological presuppositions shaping students' misconceptions, such as continuity, solidity, gravity, and inertia, which begin to form in infancy. The primary instructional implication of the original CCM is creating a cognitive conflict to initiate learning new scientific knowledge.

Contrary to the coherent or theory-like view of students' misconceptions, some researchers argue that students' misconceptions are neither theory-like nor coherent but fragmented in nature (diSessa, 1993a; Hammer, 1996; Smith, 1993). According to diSessa (1998), misconceptions are large amounts of fragmented knowledge pieces abstracted from everyday experiences, allowing more abstract and higher-level reasoning about physical processes. diSessa (2017, 2018) defines abstractions from primitive experiences as phenomenological primitives (p-prims). He interprets the organization of students' misconceptions as a weakly coherent structure of p-prims. He argues that new knowledge is gradually developed by adding new knowledge to previous but productive ones. Smith et al. (1993) and diSessa and Levin (2021) state that a particular p-prim can be productive or unproductive depending on the context. From this perspective, the conceptual change mechanism is explained in terms of using productive p-prims to explain the new phenomena.

On the other hand, Chi and her colleagues (1993; 2002) brought out a completely different interpretation of the nature of students' misconceptions. Chi and Slotta (1993) based their interpretation of students' misconceptions on the ontological nature of entities in the world and the nature of scientific conceptions. Chi and Slotta propose several ontological categories and subcategories for the entities in the world, such as matter, process, and mental states. They argue that some of the students' misconceptions are due to the mismatch or incompatibility between students' ontological categorization of concepts and the true ontological category to which the concepts actually belong. This is why, when students' misconceptions conflict with correct ideas that are at different category levels, the experienced conflict does not necessarily lead to conceptual change. According to Chi and her colleagues, if students' misconceptions are due to miscategorization, a successful conceptual change can be achieved only if students experience an ontological category shift.

The different theoretical approaches briefly discussed above suggest different mechanisms of conceptual change. The literature on conceptual change with an emphasis on instructional interventions has also evolved around them. When we analyze the experimental studies of conceptual change in the literature on science education, we find that conceptual change strategies fall into three distinct categories: cognitive conflict, cognitive bridging, and ontological category shift. The verification process of these categories will be explained in the methodology section. The following sections will provide an overview of the conceptual change strategies. Before moving onto the strategies, it is worth noting that in recent years, there have been some efforts exploring possible complementarity or consensus in different approaches to conceptual change (Amin & Levrini, 2018). These efforts show that some consensus can be achieved on several factors related to conceptual change processes, such as the role of identity, metacognition, motivation, or discourse. However, finding a consensus on the core theoretical arguments behind these approaches seems difficult. According to Sherin (2021), the major impediments to consensus are lack of clarity on the notion of "concept." He also believes that progress toward more consensus can be achieved if the researchers:

- "Recognize that our main problems are theoretical, not empirical.
- Recognize that we are, in some cases, working on quite different problems.
- Adopt some minimal consensus language (e.g., elements and ensembles, dynamic mental constructs).
- Assume that conceptual change will be difficult for a variety of reasons" (p. 223).

1.1.1 | Cognitive conflict strategy

Cognitive conflict as an instructional strategy has roots in the traditional CCM proposed by Posner et al. (1982). Cognitive conflict is considered one of the most effective instructional strategies that emerged from the CCM (Duit et al., 2008). To initiate conceptual change, the CCM claims that students must become aware of the inconsistencies between their prior knowledge and scientific knowledge. This model has broad support within the science education community (Chinn & Brewer, 1993; Duit et al., 2008; Limon, 2001; Vosniadou, 1994; Vosniadou et al., 2008). Regarding instructional implications of CCM, it is expected that the learner will become dissatisfied with prior conceptions when faced with anomalous data or knowledge conflicting with prior knowledge (Posner et al., 1982). He described the radical form of conceptual change as accommodation. The following four conditions were proposed to achieve successful accommodation. The first condition of the conceptual change process is dissatisfaction with existing knowledge. The second condition is that new knowledge should be intelligible (the learner should grasp the true meaning of the new knowledge). Posner et al. (1982) also stated that intelligibility requires understanding concepts, terms, symbols, or representations defining the meaning of new knowledge. Thirdly, new knowledge should be plausible so that the new knowledge should be consistent with current scientific knowledge and have the capacity to solve problems. Fourthly, new knowledge should be fruitful, which can suggest new insights and discoveries when encountering new situations. When new knowledge is both intelligible and plausible, students may interpret new experiences to resolve problems. Therefore, the fruitfulness of new knowledge enables the accommodation process to be more persuasive and permanent for students.

Several researchers have also criticized the role of cognitive conflict in conceptual change. These critiques can be summarized regarding epistemological and motivational arguments. Epistemological arguments related to the nature of students' misconceptions initiated an alternative mechanism of conceptual change, which is detailed in the following section. Besides, the motivational arguments prompted revisions in the cognitive conflict perspective. The major argument against the initial conceptual change mechanism is the overemphasis on rationality and negligence of noncognitive factors, such as interest in science, self-efficacy beliefs, and emotions (Pintrich et al., 1993; West & Pines, 1983). In recent years, more inquiry has been conducted to understand students' specific responses to conflicting evidence, such as the backfire effect, which occurs when a student's misconception becomes more ingrained with conflicting evidence (Nyhan & Reifler, 2010). The research revealed that students' responses to conflicting data are related to not only specific motivational constructs, such as self-efficacy or interest, but also some general constructs, such as worldview, ideology, or identity. Especially when targeted concepts like global warming, evolution, or gender-related issues are entangled with one's identity or worldview, responses to conflicting evidence could be contrary to expectations (Lewandowsky et al., 2017). Some of the major instructional implications emerging from the current research on the motivational aspect of conceptual change are to motivate students to set accuracy-oriented goals (Darner, 2019; Kunda, 1990) and help them to become more self-regulated (Sinatra & Taasoobshirazi, 2017) and self-determined learners (Darner, 2019; Taasoobshirazi et al., 2016). Although we believe that motivationally enriched conceptual change strategy, generally referred to as "hot conceptual change" or "intentional conceptual change," deserves to be treated as another conceptual change strategy, we failed to do that in this meta-analysis. This is because of the limited experimental studies explicitly integrating motivational strategies into the instruction of conceptual change. The majority of the studies are either theoretical or correlational research inquiring about the possible roles of motivational factors on the effect of cognitive conflict strategy.

Another issue with the conceptual change strategies is the use of text as an instructional tool. Although texts have been used for different purposes during instruction, there are quite number of experimental studies testing the effect of cognitive conflict strategy by the use of text, frequently referred to as conceptual change text (Pabuccu & Geban, 2006; Wang & Andre, 1991) or refutation text (Sinatra & Broughton, 2011; Tippett, 2010). Nevertheless, texts are not the only tool used for conceptual change. Other tools, such as hands-on materials or computer tools like simulations, were also used in experimental studies to test the effectiveness of instruction. Therefore, "instructional material" was used as a moderator variable to understand the role of each material type on the effectiveness of conceptual change strategies.

1.1.2 | Cognitive bridging strategy

According to diSessa (2002, 2008, 2018), it is not fruitful to take dissatisfaction as the main focus of instruction for the conceptual change; instead, productive knowledge elements should be in the foreground. Furthermore, Smith et al. (1993) argue that the constructivist view of learning requires prior knowledge to make sense of the new knowledge. This is why an instruction focusing on creating dissatisfaction with prior knowledge contradicts the basic premise of constructivism. diSessa (2008) proposes that the richness of students' conceptual resources should be used productively rather than creating dissatisfaction with them. In this study, we used the term "cognitive bridging strategy" inspired by Yaman (2013) and Vidak et al. (2019) to refer to instructional practices using students' productive knowledge elements to overcome students' misconceptions. This term was chosen because it implies a link between existing and new knowledge to achieve conceptual change and reveal its position against cognitive conflict strategy. Analogies, particularly anchoring and bridging analogies, are common instructional tools used for cognitive bridging strategy, as proposed by Clement (1993).

Nevertheless, the roots of analogical reasoning as a fundamental aspect of human thinking go back to the works of Aristotle (Goswami, 2013). In the simplest form, analogical reasoning is a way of thinking that involves finding similarities between two or more things. Analogical reasoning is highly related to the transfer of knowledge, which has been considered an essential aspect of the learning process because students are expected to extend acquired knowledge and skills beyond the conditions of initial learning (Bransford & Schwartz, 1999). Therefore, analogies seem to be perfect tools for making sense of new ideas. Quite a number of research has already shown that analogies to what students already know can help them acquire new knowledge (Bassok & Holyoak, 1989; Forbus et al., 1995; Gentner et al., 1993; Gick & Holyoak, 1983; Holyoak & Thagard, 1989; Novick & Tversky, 1987). Because of the parallel arguments of cognitive bridging and analogical reasoning about how to make sense of new knowledge, the use of analogies became one of the best tools of instructional practices aiming for conceptual change, which refers to cognitive bridging strategies in this meta-analysis.

Although some studies have demonstrated the effectiveness of cognitive bridging strategy (Clement, 1993; Gokhale, 1996; Li, 2008; Stavy, 1991; Yaman, 2013), several researchers, particularly those who hold a theory perspective on students' conceptions, argue that naïve physics is not fragmented but rather a whole. This is why focusing solely on the pieces makes it difficult to achieve a conceptual change. In this sense, Vosniadou et al. (2008) state that "The change of the framework theory is difficult because it forms a coherent explanatory system, it is based on everyday experience, and it is constantly reconfirmed by our everyday experiences in the context of lay culture" (p. 4).

1.1.3 | Ontological category shift strategy

The central argument behind the theory of ontological categories is that all concepts fall into different ontological categories, such as "matter," "processes," or "mental states," and individuals learn about these concepts by implicitly or explicitly situating them into a specific category (Chi & Slotta, 1993). There are also several subcategories, such as direct, sequential, and emergent processes, under the category of processes. The theory also claims that these categories are stable and constraining. This is why creating a cognitive conflict may not necessarily provide conceptual change. Chi and Roscoe (2002) have defined conceptual change as a shift of miscategorized knowledge from one ontological category (mis-category) to another (true) one. According to Chi and her colleagues, conceptual change can be facilitated by helping students be aware of different ontological categories and the actual ontological category of a scientific conception. As Slotta and Chi (2006) described, the critical aspect of instructional practices aiming for an ontological category shift is ontological training, especially when the ontological category of a targeted concept does not exist in students' cognitive structure.

A typical instruction of ontological category shift begins with understanding students' attributions to the targeted concepts and the ontological nature of their conceptions. If there is an ontological difference between students' conceptualization and scientific one, there is a need for an ontological category shift. The second step is to understand whether students already have an available ontological category for the targeted concept. If students have one, then the instruction focuses on replacing the students' conceptions with the appropriate category. However, if they do not have the appropriate category, then instruction should focus on creating a new category called ontological training.

Although numerous studies have shown that ontological category shift is an effective strategy for conceptual change (Chiu & Lin, 2005; Erdmann, 2001; Slotta & Chi, 2006), some researchers have provided several arguments against it. For example, diSessa (1993b) argued that making direct ontological distinctions between some physics concepts, such as entropy, quantum field, and relativity, is implausible by providing examples of how experts use them. In recent years, major arguments have been provided against context-independent conceptualizations of ontological categories. For example, Teichert et al. (2008) and Gupta et al. (2010) demonstrated students' context-dependent conceptualizations of several concepts in physics and chemistry.

1.2 | Moderating factors in conceptual change instruction

When we look at the literature, we see that most conceptual change studies focus on cognitive conflict as an instructional strategy. However, there are also a significant number of studies that propose different strategies. The previous meta-analysis studies either focused on a specific instructional strategy of conceptual change (Armağan, 2011; Gelen, 2015; Mufit et al., 2020) or treated conceptual change as a unique strategy by ignoring the variations (Guzzetti et al., 1993). In this sense, a comprehensive review should include a representative sample of conceptual change literature by focusing on the variations of instructional strategies. Thus, the main goal of this meta-analysis is to compare the effectiveness of different conceptual change strategies on students' science achievement.

Nevertheless, the variations in experimental studies focusing on conceptual change are not limited to conceptual change strategies. Other factors, such as instructional materials, the length of instruction, sample size, or research design, vary across the studies as well. Therefore, these variables were also included as moderator variables in the current study. These moderator variables were grouped into five general categories and reviewed in the following sections. Figure 1 shows the various elements of prominent characteristics used in the analyses.

1.3 | Publication characteristics

Publication-related characteristics, such as type of publication (i.e., journal article, theses, or dissertation) or publication year, have emerged as important moderator variables in several studies (Armağan, 2011; Bayraktar, 2000; Gelen, 2015; Kaçar et al., 2021). That might be related to the quality of the publications (Valentine, 2019) and the publication bias in the literature (Rosenthal, 1979). Dissertations, for example, are more comprehensive and maybe better controlled than other types of publication. In addition, the published studies might have a larger mean effect size due to publication bias. These tendencies may affect the overall effect estimated in meta-analyses.

1.4 | Design characteristics

The design of studies has a strong influence on their quality. For example, the type of experimental designs (i.e., true, quasi, or weak experiments) is primarily determined by the process of assigning students to the treatment groups, and "random assignment is intended to eliminate

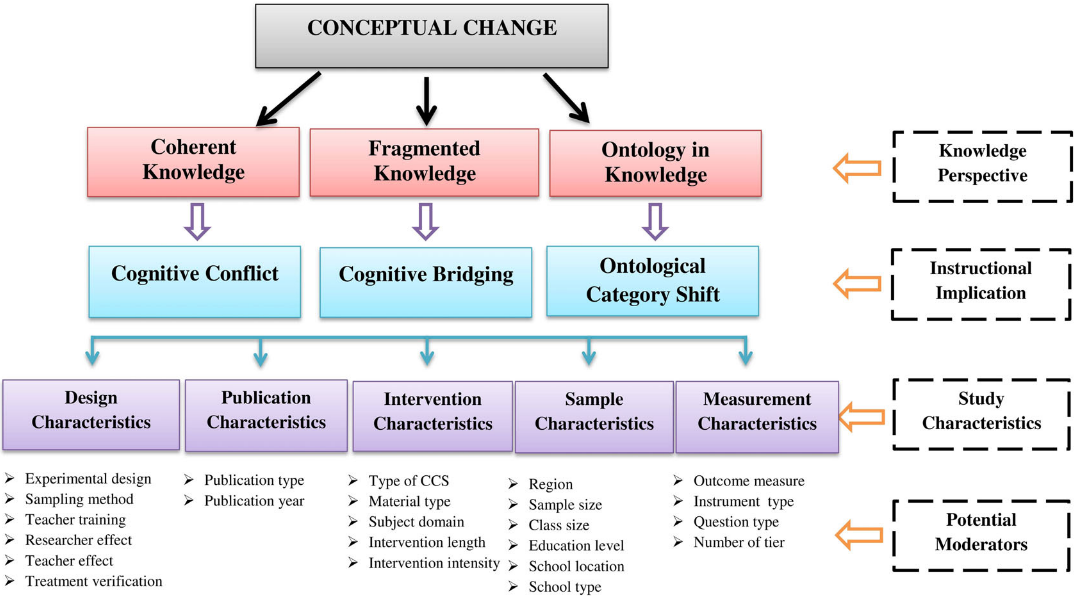

FIGURE 1 Conceptual change strategies and potential moderators.

the threat of extraneous, or additional variables—not only those of which researchers are aware, but also those of which they are not aware—that might affect the outcome of the study" (Fraenkel et al., 2012, p. 267). That is why the type of experimental design was considered one of the moderator variables for the effectiveness of conceptual change strategies. Besides, some other threats to internal validity, such as the researcher/teacher effect and treatment verification, were also included in the analysis to determine their potential roles in the results of conceptual change strategies. The sampling method appears to be an essential factor in terms of the external validity of the results. This is why the sampling method was included as a moderating variable in this category as well.

1.5 | Intervention characteristics

The main intervention characteristics we focused on in this meta-analysis were conceptual change strategies, namely, cognitive conflict, cognitive bridging, and ontological category shift, which yield divergent results in science education (Slotta & Chi, 2006; Smith et al., 1993; Tsai, 2003; Zohar & Kravetsky, 2005). Besides, the subject domain (e.g., physics, chemistry, or biology) in which the study was conducted, as well as the type of materials (e.g., hands-on, text, or computer materials) used during interventions, were considered potential moderators.

Additionally, the effect of intervention length is also frequently addressed in the literature (Chadwick, 1997; Clark, 1983; White, 1988). One of the hypotheses regarding this variable is that increasing intervention length might boost the effectiveness of the instruction (White, 1988). However, the intensity of the intervention (i.e., how many hours the intervention was in a week) is just as important as the length of the intervention. Accordingly, both intervention length and intervention intensity were assigned as possible moderator variables to examine their potential roles in the effectiveness of the conceptual change strategies.

1.6 | Sample characteristics

Similar to any research, the studies on conceptual change have various sample characteristics such as region, school type, school location, education level, sample size, or class size. The literature has already provided strong evidence that sample characteristics play an important role in experimental research. For example, some meta-analyses show that some instructional strategies work better in lower-level grades (Arık & Yılmaz, 2020; Kim et al., 2021). Additionally, class size (Chadwick, 1997) or region (Yu, 2021) can be explanatory moderators for the overall effect of instruction.

1.7 | Measurement characteristics

One of the most critical aspects of experimental studies is the measurement of outcome variables. In this meta-analysis, we focused on science achievement as the outcome variable. However, the primary studies on conceptual change use various tools to measure science achievement. Some use general achievement tests, while others use specifically designed misconception tests to measure the outcome. Since measuring the outcome might affect the overall effect size estimation in the meta-analysis, we assigned this variable as another moderator.

Other moderators included in this category are the instrument type (adapted test, pre-existing test, or researcher-developed test) and question type (open-ended, objective-type, or mix). It is evident in the literature that validated standardized tests are more robust against random errors and researcher bias (Bayraktar, 2000). Similarly, open-ended questions can measure higher-level learning outcomes compared to objective-type questions. Therefore, we decided to examine the potential moderating effects of these variables in the current meta-analysis.

1.7.1 | Previous meta-analyses on the effectiveness of conceptual change strategies

Some meta-analyses have previously been conducted on the effectiveness of conceptual change strategies. This section compares and contrasts five previous meta-analyses with the current research. One of these studies, arguably the most well-known, is the meta-analysis by Guzzetti et al. (1993) on the effectiveness of refutation texts, augmented activation activities, and discussion webs. These instructional strategies aim to handle students' misconceptions by creating dissatisfaction with existing knowledge and introducing scientific knowledge to replace it. Although this is a well-conducted study, it has some limitations. First, it is not current because it covers only studies published between 1986 and 1990. As the bridging and ontology perspectives emerged after this time interval, this meta-analysis used only the cognitive conflict perspective. Second, this study included only 23 studies during this period. This is not surprising given that instructional strategies based on conceptual change emerged following Posner's conceptual change theory (1982). Third, the vast majority of primary studies (96%) included in this meta-analysis were conducted in the United States, with only a few from Canada. Finally, the small sample size prevented the authors from conducting moderator analyses using some critical characteristics of the primary studies, focusing on estimating the overall effect size.

The second meta-analysis was conducted by Armağan (2011). This dissertation investigates the effectiveness of conceptual change texts by using 42 primary studies conducted between

1998 and 2010. All of these primary studies, except one, were conducted in Turkey. The first limitation of this meta-analysis is that it focused only on the cognitive conflict perspective. Additionally, the sample of this meta-analysis was limited to studies conducted in Turkey before 2010. From a methodological standpoint, the meta-analysis performed moderator analyses but only used subgroup analyses without multiple meta-regressions.

Another meta-analysis of conceptual change is Gelen's (2015) master's thesis. This study investigated the effectiveness of some instructional tools based on conceptual change, such as analogies, concept networks, conceptual change texts, and concept maps. The theoretical framework of this meta-analysis was built solely from the perspective of Posner's cognitive conflicts. In addition, the meta-analysis sample included 64 primary studies, the majority (94%) of which were conducted in Turkey between 2002 and 2014. Although the author performed moderator analyses, multiple meta-regression was not used to examine the simultaneous effects of the moderator variables.

Another meta-analysis on the effectiveness of conceptual change strategies was conducted by Mufit et al. (2020). Although it is a more recent study, it has some limitations. First, the sample size of this meta-analysis was small (25 studies), including primary studies, mainly from Indonesia, between 2012 and 2020. Primary studies were classified as either national or international. However, neither the list of primary studies nor the countries in which they were conducted were reported in this article. The limited sample size and short time span restricted the generalizability of the study. Furthermore, as with previous meta-analyses, this study relied solely on the cognitive conflict perspective of conceptual change.

Schroeder and Kucera (2021) performed the most recent meta-analysis. Compared to Mufit et al. (2020), this well-conducted study had a slightly larger sample size (33 studies) and covered a more extended period (1991–2020). It did, however, include only studies that examined the effectiveness of refutation texts. Thus, its generalizability is limited to the universe of studies using a specific instructional tool, i.e., refutation text, which is based on the cognitive conflict perspective.

To the best of our knowledge, the current meta-analysis is the most recent and comprehensive in terms of sample size and time span. Furthermore, it synthesizes studies using various conceptual change perspectives, whereas previous meta-analyses have focused solely on the cognitive conflict perspective. This meta-analysis is also the most inclusive in terms of language restrictions. Previous meta-analyses have restricted primary studies to either English or Turkish. The current meta-analysis was also unique in categorizing instructional strategies using a comprehensive framework of conceptual change approaches. This classification system was also validated by most authors of the primary studies included in this meta-analysis (Cohen's kappa for inter-rater reliability = 0.84). We believe this meta-analysis uniquely contributes to the literature because of its novel aspects. Table 1 summarizes the main features of previous meta-analyses and the current meta-analysis of conceptual change strategies to facilitate comparison.

1.8 | Research questions

The main research questions examined in this meta-analysis are as follows:

1. How effective are CCS on science achievement?
2. How effective is cognitive conflict strategy on science achievement?
3. How effective is cognitive bridging strategy on science achievement?

TABLE 1 Comparison of previous meta-analyses on the conceptual change strategies with the current meta-analysis.

Meta-analysis	Instructional approach	Region	*k*	ES	TI	Limitations	k_s (%)
Guzzetti et al. (1993)	Refutation texts, augmented activation activities, and discussion web	Canada and the United States	23	0.22, 0.85, 0.51	1986–1990	It focuses only on the conflict perspective It is outdated It was conducted before the emergence of bridging and ontology perspectives It covers a short time interval It has a small sample size It has a limited regional scope	0 (0)
Armağan (2011)	Conceptual change texts	Turkey (with one study from Jordan)	42	1.18	1998–2010	It focuses only on the conflict perspective It only includes text-based tools It is not current (up to 2010) Almost all studies were conducted in Turkey	38 (17)
Gelen (2015)	Conceptual change tools	Turkey (with two from Jordan and one from Germany)	64	1.13	2002–2014	It focuses only on the conflict perspective It is not current (up to 2014) It has a limited regional scope	42 (19)

TABLE 1 (Continued)

Meta-analysis	Instructional approach	Region	k	ES	TI	Limitations	k_s (%)
Mufit et al. (2020)	Cognitive conflict	Mostly Indonesia	25	1.41	2012–2020	It focuses only on the conflict perspective It covers a short time interval Most of the studies were conducted in Indonesia There are some issues with reporting	Not listed
Schroeder and Kucera (2021)	Refutation text	Europe and North America	33	0.41	1991–2020	It focuses only on the conflict perspective It only includes refutation texts	11 (5)
The current meta-analysis	Conflict, bridging, and ontology perspectives	Africa, America, Europe, Asia, and Turkey	218	1.10	1989–2021	The results are generalizable to the universe of studies in English and Turkish	-

Note: k, number of primary studies included in the meta-analysis; ES, overall effect size; TI, time interval covered by the meta-analysis; k_s (%), number (and percentage) of primary studies shared by that meta-analysis and the current meta-analysis.

4. How effective is ontological category shift strategy on science achievement?
5. What are the roles of publication, sample, design, intervention, and measurement characteristics on the effectiveness of CCS on science achievement?

2 | METHOD

We followed the guidelines provided by Meta-Analysis Reporting Standards (MARS; Appelbaum et al., 2018) for this meta-analysis. We also used Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA; Page et al., 2021) guidelines to create the flow diagram for the process of study selection. The details of the meta-analytic procedure are presented in the following sections.

2.1 | Inclusion and exclusion criteria

We selected primary studies to be included in this meta-analysis only if they met all five of the following criteria:

1. The study's research design should be experimental, focusing on a between-subjects comparison of CCS and traditional instruction.
2. The dependent variable of the study should be science achievement.
3. The study should be published/reported after 1983 since the theoretical framework for instructional implications of conceptual change was constructed by Posner et al. (1982).
4. The study should be reported in English or Turkish.
5. The study should provide enough data to calculate an effect size measure.

We aimed to maximize the generalizability of the meta-analysis results. In this sense, in addition to the primary studies published in English, we expanded our corpus to include studies published in Turkish, a non-English language. We did not include other non-English languages because we limited the languages to those in which at least one of the authors was proficient. Our coding sheet was too detailed to code articles using an online tool's translated version. We required a thorough understanding of the primary studies that would be coded. However, we did not restrict the language in which the intervention was carried out in primary studies as long as the findings were published in English or Turkish.

Furthermore, we did not impose any restrictions on study locations to increase the generalizability of the meta-analysis. This approach also allowed us to compare findings from various locations worldwide. We also included all publication types to reduce the possibility of publication bias. We controlled for this variable's effect while running multiple meta-regressions to examine potential moderator variables.

2.2 | Literature search and study selection

We conducted a comprehensive literature search to identify the eligible primary studies to be included in this meta-analysis. First, we defined an initial set of keywords and conducted a pilot literature search in Web of Science, Scopus, ERIC, ProQuest, Academic Search Ultimate, and

Taylor and Francis Online Journals using the following keywords: "conceptual change" OR "misconception in science" OR "cognitive conflict" OR "refutation texts" OR "refutation map" OR "conceptual change texts" OR "bridging analogy."

We revised the initial keywords based on the pilot search to create two clusters of keywords. The first cluster was "conceptual change" OR "cognitive conflict" OR "conflict map" OR "refutation text" OR "refutation map" OR "bridging analogy" OR "anchoring analogy" OR "ontological category" OR "ontological shift" OR "conceptual shift" OR "cognitive shift." The second one was "refutation AND conflict" OR "dissatisfaction AND misconception" OR "conflict AND misconception" OR "ontology AND misconception" OR "analogy AND misconception."

In the second round of literature searches, we used a comprehensive search engine provided by the University Library. This search engine covers the Web of Science, EBSCOhost, Scopus, ERIC, Academic Search Ultimate, Science Direct, Taylor and Francis Online Journals, Wiley Online Library, African Journals Online, Teacher Reference Center, ULAKBIM, and DergiPark. Therefore, it let us conduct a literature search in all of these databases simultaneously using two clusters of keywords identified before. In addition, we conducted a literature search using ProQuest, Turkish National Thesis Center, Turkish Education Index, and Google Scholar, which the University Library Search Engine did not cover.

Following this systematic literature search, we used a snowball approach (Greenhalgh & Peacock, 2005). We screened out approximately 14,000 references cited in the reference lists of 345 primary studies. Then, we identified 278 researchers conducting research on conceptual change strategies and tracked down their research studies. We screened out 5300 studies and contacted more than 200 researchers all around the world during this process. The entire literature search is summarized in the PRISMA flow diagram presented in Figure 2.

We identified 17,474 and 20,665 studies using the databases and other sources, respectively. Before screening the full text, we excluded 22,815 of these records due to duplications, language limitations, and unfitting document types, such as e-books, books, chapters, magazines, or subject domains. We contacted the corresponding authors for the studies for which full text was unavailable. We assessed the eligibility of 11,697 studies using the inclusion and exclusion criteria. Eventually, we collected 218 studies to be included in this meta-analysis. Figure 2 presents the details of the study selection procedure.

2.3 | Coding of studies

We created a codebook and a coding manual for this meta-analysis in an iterative process. First, we scanned many primary studies in conceptual change literature and previous meta-analyses to construct the first version of the codebook. The potential moderator variables were identified based on the corresponding theories and the empirical findings in the literature. Two researchers in science education, other than the authors, provided substantial feedback in developing the codebook. After creating the codebook and the coding manual explaining how to use the codebook, six independent coders used them to code a sample of primary studies. They also provided additional feedback on how comprehensive and user-friendly the codebook was. During this iterative process, the codebook underwent numerous revisions. The final version of the codebook was an excel sheet including 35 items related to publication, sample, design, intervention, and measurement characteristics, as well as the information needed to calculate effect sizes Table 2 shows some of the items coded in this meta-analysis as potential moderators (Tables A1 and B1).

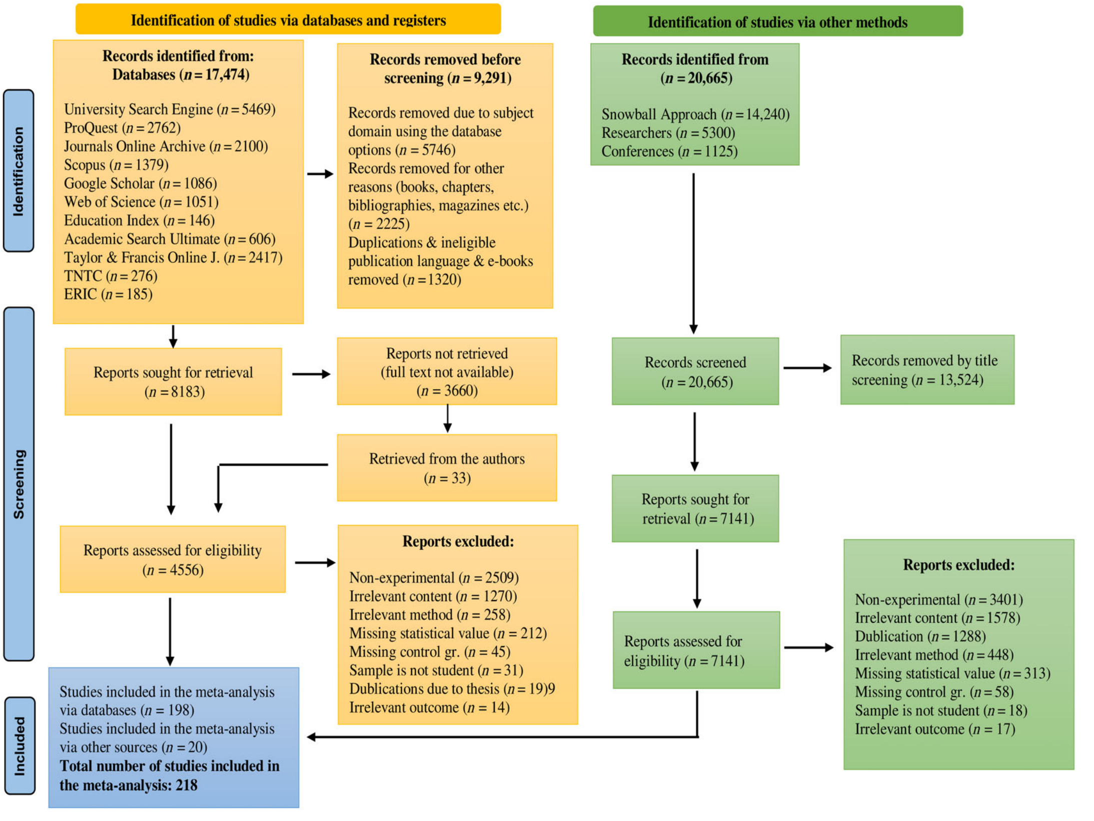

FIGURE 2 PRISMA flow diagram.

One of the authors coded all primary studies, and other researchers coded some randomly selected studies to establish inter-rater coder reliability. We then calculated Cohen's kappa (κ) (Cohen, 1960) for inter- and intra-rater reliabilities. We followed Cohen's suggestion to interpret the kappa value as follows: below 0.20, none to slight; 0.21–0.40 fair; 0.41–0.60 moderate; 0.61–0.80 substantial; and higher than 0.80, almost perfect agreement.

The classification of conceptual change strategies used in the primary studies is one of the most critical aspects of this meta-analysis. Therefore, the first Cohen's κ values were calculated to establish the inter-rater reliability for this coding. Three coders with a solid background in conceptual change classified the CCS for 22 randomly selected studies after we explained the CCS categories and coding procedures to these coders. The arithmetic mean of κ was 0.81, indicating perfect agreement for the final coding round. To collect further evidence for reliability, we contacted the authors of 128 studies and asked them to classify the conceptual change strategy used in their studies. We explained the three categories created for CCS and informed them of the category in which their studies were placed. Sixty-five authors of eighty-four primary studies responded to clarify their grouping. The calculated κ value was 0.84, indicating very high consistency between the authors' classifications and ours. Then, six researchers, three of whom had a Ph.D., and the others were Ph.D. candidates in educational science, coded 40 randomly selected primary studies. The final κ value was 0.82. Moreover, we calculated a high value of κ (0.85) for intra-rater reliability.

TABLE 2 Overview of the potentially moderating variables related to study characteristics.

Study characteristics	Variables	Categories
Publication characteristics	Publication type	Journal articles, doctoral dissertations, master theses, and conference proceedings
	Publication year	1989–2000, 2001–2005, 2006–2010, 2011–2015, 2016–2020
Sample characteristics	Region	Africa, America, Europe, Asia, Turkey
	Sample size	16–46, 47–56, 57–72, 73–100, 102–396
	Class size interval	8–22, 23–26, 27–30, 30–38, 38–87
	Sampling method	Random sampling, nonrandom sampling
	Education level	Elementary, middle school, high school, university
	School location	Urban, suburban, rural
	School type	Public, private
Design characteristics	Experimental design	Poor experiments, quasi-experiments, true experiments
	Researcher effect	Not teacher, one of the teacher, only teacher
	Teacher effect	Same teacher, different teachers
	Treatment verification	Stated, unstated
	Teacher training	Stated, unstated
Intervention characteristics	Type of CCS	Cognitive conflict, cognitive bridging, ontological category shift
	Material	Computer-based, text-based, hands-on
	Subject domain	Biology, chemistry, physics
	Intervention length	1–48 course hours (continuous)
	Intervention intensity	1–8 course hours per week (continuous)
Measurement characteristics	Type of outcome measure	Conceptual change, general achievement, mixed
	Type of assessment instrument	Preexisting test, adapted test, researcher-developed test
	Type of questions	Open-ended, objective, mixed

2.4 | Data analysis

We used Comprehensive Meta-Analysis (CMA v3) (Borenstein et al., 2013) to conduct the meta-analysis, heterogeneity analysis, moderator analysis, sensitivity analysis, and several tests for publication bias. We also performed a PET-PEESE analysis, selection models, and robust Bayesian Meta-Analysis using the JASP (v0.16.1) (JASP Team, 2022) Meta-Analysis module. Furthermore, we used the CMA Prediction Intervals Program to estimate the prediction intervals.

2.4.1 | Calculation of effect sizes

We calculated Hedges' g as the common measure of effect size in this meta-analysis. Hedges' g is an unbiased estimate of the standardized mean difference. Cohen's d tends to give a slightly biased estimate of population effect size in small samples, whereas Hedges' g employs a correction factor to overcome this issue (Borenstein et al., 2009, p. 27; Borenstein & Hedges, 2019, p. 212). If available, we calculated the effect sizes using the control and experimental groups' means, standard deviations, and sample sizes. If these values were not given in the primary study, we used the statistics reported by null hypothesis significance tests, such as t, F, or nonparametric values along with sample sizes, to calculate the corresponding effect sizes using CMA v3. If none of them were available, we used the effect size presented in the article, if available, and transformed it into Hedges' g as needed.

The unit of analysis is each primary study in this meta-analysis. That is, only one effect size was yielded from each study. When there was more than one effect size representing independent subgroups within a study, we calculated a weighted average of these effect sizes using the variance of these subgroups (Borenstein et al., 2009). When a particular study reported multiple outcomes for different CCS types, we included only one of those outcomes.

2.4.2 | Main analysis

Because of the nature of our research questions, we used a random-effects meta-analysis rather than a fixed-effect analysis. Borenstein et al. (2009, pp. 83–84) suggest using a random-effects model when all studies in the meta-analysis cannot be assumed identical since these studies are conducted independently by different researchers. They also propose that the random-effects model should be used when the purpose of the meta-analysis is to generalize the results to different scenarios. To estimate the between-study variance, CMA employs the DerSimonian and Laird method (method of moments), which is a simple method that makes no assumptions about the distribution of random effects (Borenstein et al., 2009, p. 115).

2.4.3 | Heterogeneity analysis

We estimated several measures to identify and quantify the heterogeneity across the effect sizes. First, we calculated Cochran's Q statistic and ran the corresponding χ^2 test to determine if the heterogeneity was significantly different from zero. Then, we calculated the I^2 value to estimate what proportion of the total variance reflected the between-study variance, that is, heterogeneity, in the distribution of effect sizes (Higgins et al., 2003). Furthermore, we computed T^2 and T, which are the estimates of τ^2 and τ, respectively. τ^2 is the parameter representing the variance of true effects, while τ serves as the standard deviation of true effects. Thus, they are the direct measures of dispersion in the distribution of the true effects. Finally, we calculated the prediction intervals using the T values. Prediction intervals illustrate the actual dispersion of effect sizes (Borenstein et al., 2009, p. 131).

2.4.4 | Publication bias

Publication bias is arguably the most severe threat to the validity of meta-analyses (Rothstein et al., 2005, p. 2). Therefore, we employed numerous visual and statistical approaches to detect and adjust the publication bias. To begin, we calculated Orwin's fail-safe N (Orwin, 1983) to examine how robust the overall effect is to publication bias. We set the criterion for trivial effect size as 0.10 and the mean effect size in missing studies as 0.00 while calculating Orwin's fail-safe N. Next, we used the funnel plot to display the small-study effect, and we performed Egger's Linear Regression Method (Egger et al., 1997) to examine if there was a statistically significant asymmetry in the funnel plot. Then, we conducted the Trim and Fill method (Duval & Tweedie, 2000) to estimate and adjust the potential publication bias based on the asymmetry in the funnel plot. We performed both fixed-random and random-random trim and filled methods to interpret the results for sensitivity analysis as suggested in the literature (Duval, 2005, p. 134). Since the distribution of the effect sizes turned out to be highly heterogeneous in this meta-analysis, we used the method of selection models instead of PET-PEESE estimates, as suggested by several researchers (Carter et al., 2019; Hedges & Vevea, 2005). Therefore, we also calculated an adjusted effect size using the selection model. In addition to these frequentist approaches, we also conducted a Robust Bayesian Meta-Analysis, which employed Bayesian model-averaging rather than focusing on a single model. JASP Meta-Analysis Module enabled us to conduct Robust Bayesian Meta-Analysis using 36 different models to calculate a weighted mean estimate (Bartoš et al., 2022; Maier et al., 2020).

2.4.5 | Moderator analysis

We first conducted a simple meta-regression for each potential moderator variable. Then, a multiple meta-regression analysis was performed to create a parsimonious model explaining significant heterogeneity in true effects. We used a hierarchical approach to create this model using prominent variables revealed by simple meta-regression.

3 | RESULTS

3.1 | Description of study characteristics

A total of 218 primary studies were included in this meta-analysis. This sample of primary studies includes 18,051 students. Table 5 presents a descriptive summary of the following study characteristics.

3.1.1 | Publication characteristics

The majority of these studies ($k = 133$) are published articles, while 85 of them consist of dissertations ($k = 40$), master theses ($k = 35$), and conference proceedings ($k = 10$). The publication date ranges from 1989 to 2020, while most studies (65%) have a publication date between 2006 and 2015.

3.1.2 | Sample characteristics

This meta-analysis covers a sample of 18,051 students in total. The sample size of the studies changes from 16 to 396, but most sample sizes are below 100 (81%). The sample typically comes from public schools (76%) and high schools (46%) and mainly represents the students in urban areas (72%). Given that we expanded our language restriction to include Turkish in addition to English, it seems reasonable that Turkey has the most primary studies. Most primary studies (157 of 218 studies) were still published in English. Yet, the highest number of primary studies comes from Turkey, with 61 in Turkish and 86 in English.

3.1.3 | Design characteristics

The primary studies are generally quasi-experimental (74%), selecting their samples using a nonrandom sampling method (90%). The researcher and teacher effects appear not to be a threat to internal validity for most of the studies. About half of the studies reported using treatment verification and training the teachers for the intervention.

3.1.4 | Intervention characteristics

Most of the studies implemented cognitive conflict (69%), while only nine studies (4%) used ontological category change, and 30 studies (14%) used cognitive bridging as the CCS. We could not classify 29 studies (13%) into one of the three CCS types. The number of studies in Physics (42%) and Chemistry (39%) is greater than that in Biology (19%). The intervention length reported for 144 studies ranges from 8 to 48, with a mean of 11-course hours.

3.1.5 | Measurement characteristics

The primary studies typically measure the outcome using researcher-developed instruments (71%) and assessing misconceptions (88%). These instruments mainly consist of one-tier (75%) and objective-type questions (52%).

3.2 | The effect of CCS on science achievement

The random-effects analysis of 218 independent primary studies investigating the effect of CCS on science achievement yielded a large overall effect size (Hedges' $g = 1.10$, $p < 0.001$, 95% CI [1.01, 1.19], $k = 218$). The same analysis for the studies using only cognitive conflict resulted in the same effect size with a similar confidence interval (Hedges' $g = 1.10$, $p < 0.001$, 95% CI [1.00, 1.21], $k = 150$). The overall effect size calculated for cognitive bridging was also large, with a wider confidence interval due to the smaller sample size (Hedges' $g = 1.06$, $p < 0.001$, 95% CI [0.84, 1.28], $k = 30$). Finally, the overall effect size of nine studies using ontological category shift was slightly smaller than the others but still corresponds to a large effect size (Hedges' $g = 0.88$, $p < 0.001$, 95% CI [0.50, 1.26], $k = 9$).

TABLE 3 The overall effectiveness of CCSs on science achievement.

Strategy	k	Overall effect size	Standard error	z-value	p-value	%95 CI Lower limit	%95 CI Upper limit
Overall conceptual change	218	1.10	0.04	24.78	<0.001	1.01	1.19
Cognitive conflict	150	1.10	0.05	20.48	<0.001	1.00	1.21
Cognitive bridging	30	1.06	0.11	9.48	<0.001	0.84	1.28
Ontological category shift	9	0.88	0.19	4.55	<0.001	0.50	1.26

Note: *k*, number of studies; CI, confidence interval.

TABLE 4 The heterogeneity analyses results for CCSs.

Strategy	k	Overall effect size	p	95% CI	Heterogeneity T^2	I^2	Q_T	95% PI
Overall conceptual change	218	1.10	<0.001	[1.01, 1.19]	0.35	84.80	1428.10	[0.19, 2.38]
Cognitive conflict	150	1.10	<0.001	[1.00, 1.21]	0.36	85.35	1017.18	[0.18,2.03]
Cognitive bridging	30	1.06	<0.001	[0.84, 1.28]	0.30	81.39	155.83	[0.20,1.92]
Ontological category shift	9	0.88	<0.001	[0.50, 1.26]	0.22	72.62	29.21	[0.07,1.69]

Note: *k*, number of studies; Q_T, total heterogeneity; CI, confidence interval; PI, prediction interval; T^2, between study variance; I^2, the ratio of true variance to total variance.

Table 3 summarizes the results of the random-effects analysis used to estimate the overall effect of CCS on science achievement.

3.3 | Heterogeneity analysis

The heterogeneity analyses yielded statistically significant results for not only the effect size distribution of all 218 studies ($Q[217] = 1428.10$, $p < 0.001$), but also that of cognitive conflict ($Q[149] = 1017.18$, $p < 0.001$), cognitive bridging ($Q[29] = 155.83$, $p < 0.001$), and ontological category shift ($Q[8] = 29.21$, $p < 0.001$). As shown in Table 4, all I^2 values are above 80% except for the ontological category shift (73%), which means that most of the total variance corresponds to the between-study variance for all distributions. In addition, large tau-squared values provide evidence of a high amount of heterogeneity within the distributions, which results in a wide prediction interval for each distribution, as presented in Table 5. In other words, each distribution has a significant and large amount of true heterogeneity.

3.4 | Publication bias and sensitivity analyses

As we explained before, we ran several analyses to examine the degree to which publication bias was a threat to the validity of this meta-analysis. First, Orwin's fail-safe N

TABLE 5 Descriptive summary for each moderator variables.

Study characteristics	Variables	k	%	g	95% CI
Publication characteristics	Publication type				
	Journal Articles	133	61	1.06	[0.95, 1.17]
	Doctoral Dissertations	40	18	1.35	[1.12, 1.58]
	Master Theses	35	16	1.01	[0.82, 1.19]
	Proceedings	10	5	0.98	[0.68, 1.29]
	Publication year[a]				
	1989–2000	14	6	0.56	[0.35, 0.78]
	2001–2005	48	22	1.08	[0.88, 1.28]
	2006–2010	73	33	1.30	[1.15, 1.45]
	2011–2015	69	32	1.09	[0.95, 1.24]
	2016–2020	14	6	0.75	[0.49, 1.00]
Sample characteristics	Region[a]				
	Africa	8	4	0.88	[0.48, 1.28]
	America	28	13	0.68	[0.50, 0.86]
	Asia	23	11	0.79	[0.56, 1.02]
	Europe	12	6	0.66	[0.31, 1.01]
	Turkey	147	67	1.28	[1.18, 1.38]
	Sample size				
	16–46	45	21	1.09	[0.92, 1,26]
	47–56	45	21	1.07	[0.90, 1,24]
	57–72	45	21	1.23	[1.04, 1,42]
	73–100	41	19	1.18	[0.97, 1,38]
	102–396	42	19	0.93	[0.73, 1,12]
	Class size				
	8–22	50	23	0.95	[0.76, 1.14]
	23–26	45	21	1.05	[0.88, 1.21]
	27–30	41	19	1.26	[1.08, 1.45]
	31–38	40	18	1.14	[0.97, 1.31]
	39–87	42	19	1.13	[0.91, 1.35]
	Education level[a]				
	Elementary	13	6	0.96	[0.64, 1.29]
	Middle	50	23	1.03	[0.90, 1.16]
	High school	101	46	1.24	[1.10, 1.39]
	Undergraduate	54	25	0.93	[0.76, 1.12]
	School location				
	Rural	22	10	0.96	[0.72, 1.20]
	Urban	157	72	1.13	[1.03, 1.24]
	Unspecified[b]	39	18	1.08	[0.90, 1.36]

TABLE 5 (Continued)

Study characteristics	Variables	k	%	g	95% CI
	School type				
	Private	11	5	1.03	[0.73, 1.33]
	Public	165	76	1.11	[1.01, 1.21]
	Unspecified[b]	42	19	1.10	[0.89, 1.31]
Design characteristics	Experimental design[a]				
	Poor	23	11	0.84	[0.63, 1.06]
	Quasi	162	74	1.23	[1.12, 1.33]
	True	33	15	0.64	[0.49, 0.79]
	Sampling method				
	Nonrandom sampling	196	90	1.09	[1.00, 1.18]
	Random sampling	22	10	1.24	[0.95, 1.52]
	Researcher effect				
	Not teacher	108	50	1.20	[1.07, 1.33]
	One of teachers	12	6	0.99	[0.65, 1.32]
	Only teacher	48	22	1.14	[0.97, 1.30]
	Unspecified[b]	50	23	0.88	[0.72, 1.05]
	Teacher effect				
	Different teachers	44	20	1.12	[0.94, 1.30]
	Same teacher	134	61	1.18	[1.07, 1.30]
	Unspecified[b]	40	18	0.81	[0.64, 0.97]
	Treatment verification				
	Unstated	107	49	1.06	[0.96, 1.21]
	Stated	111	51	1.13	[1.00, 1.25]
	Teacher training[a]				
	Unstated	111	51	0.92	[0.81, 1.03]
	Stated	107	49	1.29	[1.16, 1.42]
Intervention characteristics	Type of CCS				
	Cognitive bridging	30	14	1.06	[0.84, 1.28]
	Cognitive conflict	150	69	1.10	[1.10, 1.21]
	Ontological change shift	9	4	0.88	[0.50, 1.26]
	Unspecified[b]	29	13	1.21	[0.95, 1.47]
	Material[a]				
	Computer-based	32	15	0.87	[0.70, 1.12]
	Hands-on	69	32	1.23	[1.07, 1.39]
	Text-based	117	54	1.09	[0.97, 1.21]

(Continues)

TABLE 5 (Continued)

Study characteristics	Variables	*k*	%	*g*	95% CI
	Subject domain[a]				
	Biology	42	19	0.82	[0.64, 0.99]
	Chemistry	85	39	1.37	[1.23, 1.51]
	Physics	91	42	0.98	[0.86, 1.10]
	Intervention length[a]	144	66	-	[0.01, 0.03]
	Intervention intensity	142	65	-	[−0.06, 0.11]
Measurement characteristics	Instrument type[a]				
	Adapted test	23	11	1.01	[0.76,1.26]
	Preexisting test	40	18	0.88	[0.68, 1.09]
	Researcher developed test	155	71	1.17	[1.07, 1.28]
	Question type[a]				
	Mix[b]	73	33	1.09	[0.94, 1.23]
	Objective	113	52	1.21	[1.09, 1.33]
	Open ended	32	15	0.75	[0.55, 0.94]
	Number of tier				
	1	164	75	1.13	[1.03, 1.23]
	2	31	14	0.91	[0.69, 1.12]
	3	15	7	1.13	[0.84, 1.42]
	Mix[b]	8	4	1.18	[0.58, 1.78]
	Outcome measuring type				
	Conceptual change	192	88	1.12	[1.03, 1.22]
	General achievement	16	7	0.87	[0.60, 1.14]
	Mix[b]	10	5	1.04	[0.70, 1.37]
	Overall	218	100	1.10	[1.01, 1.19]

Note: *k*, number of studies; *g*, Hedges' g value; CI, confidence interval.
[a]The moderators explaining a significant amount of heterogeneity.
[b]These subgroups were not included in heterogeneity analyses.

was 1853, much larger than the total number of studies (218) included in this meta-analysis. Therefore, the results of the meta-analysis seem robust to publication bias. Then, we examined the funnel plot for small study bias. Figure 3 shows the funnel plot, which appears asymmetrical: as the standard error increases, the effect sizes tend to have larger effect sizes. Egger's regression test also points out an asymmetry ($t(216) = 8.21$, two-tailed $p < 0.001$). The Trim and Fill method imputes 70 studies to the left of the mean to eliminate this asymmetry, resulting in an adjusted effect size of 0.71 when using a fixed-fixed model. On the other hand, the random-random model yields an adjusted effect size of 1.23, imputing 24 studies to the right of the mean. The asymmetry in the funnel plot and the trim and fill method indicates a small study bias, which may or may not result from a publication bias. Therefore, we also performed selection models to calculate an adjusted effect size. The selection model gives us an adjusted $g = 0.93$, 95% CI [0.75, 1.11] for random effects estimate. Finally, we conducted a Robust Bayesian Meta-Analysis using 36 models to calculate a robust mean effect size. This analysis gives us a robust mean effect size of $g = 0.93$.

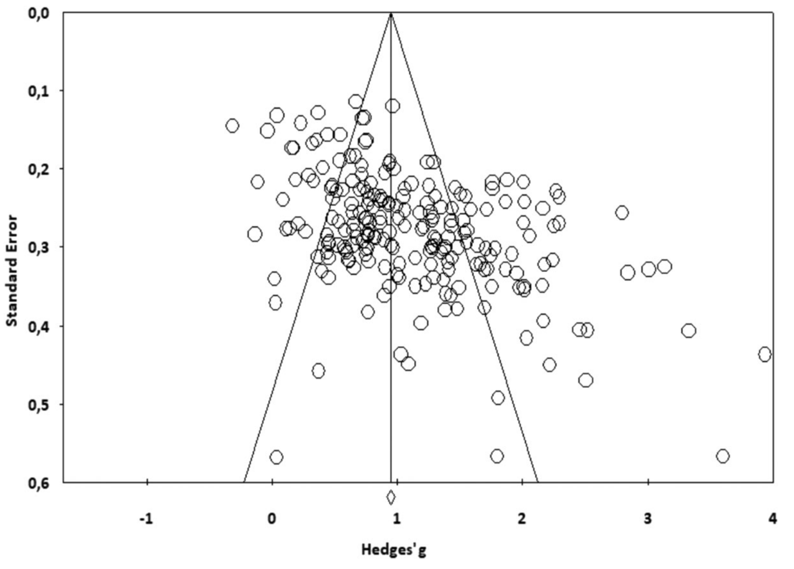

FIGURE 3 The funnel plot of the studies.

The adjusted effect sizes estimated by the selection method and Robust Bayesian Meta-Analysis are close to each other and are still considered large effects. Accordingly, we conclude that publication bias does not change our interpretation of the mean effect size. Table 6 presents the results of the analyses we conducted to examine publication bias.

Besides the publication bias analyses, we also performed a sensitivity analysis to examine if any primary study substantially affected the mean effect size. We used a random-effects model to perform a one-study-removed analysis using CMA v3. When we leave one study out, the mean effect sizes change from 1.09 to 1.11. This analysis shows that no single study influences the overall effect size substantively.

3.5 | The roles of study characteristics on the effectiveness of CCS

We conducted moderator analyses to investigate the roles of study characteristics on the effectiveness of CCS. We first performed a simple meta-regression analysis for each potential moderator. Table 7 summarizes the results of simple meta-regression analyses for 23 potential moderator variables. Then, we ran multiple meta-regression to create a parsimonious model that explains the reasons for the heterogeneity in the distribution of effect sizes.

3.5.1 | Publication characteristics

The simple meta-regression analyses yielded a significant result for publication year ($Q[4] = 22.59$, $p = 0.001$) but not for publication type ($Q[3] = 6.73$, $p = 0.089$). 73 studies published between 2006 and 2010 have the largest mean effect size of $g = 1.30$, while those published between 1989 and 2000 ($k = 14$) have the smallest mean effect size, $g = 0.56$. The publication year alone explains 12% of the between-study variance.

TABLE 6 The overall effect sizes were adjusted for publication bias.

			Adjusted overall effect sizes			
Strategy	***k***	**Unadjusted overall effect sizes [%95 CI]**	**RoBMA**	**Selection model (random model) [%95 CI]**	**Trim and fill (fixed-random) [%95 CI]**	**Trim and fill (random–random) [%95 CI]**
Overall conceptual change	218	1.10, [1.01,1.19]	0.93	0.92, [0.75,1.11]	0.71, [0.75, 1.11]	1.23, [1.13, 1.33]
Cognitive conflict	150	1.10, [1.00,1.21]	0.94	0.93, [0.71,1.15]	0.69, [0.58, 0.81]	1.21, [1.09, 1.33]
Cognitive bridging	30	1.06, [0.84,1.28]	0.87	0.91, [0.48,1.35]	1.06, [0.90, 1.34]	1.12, [0.99, 1.44]
Ontological category shift	9	0.88, [0.50,1.26]	0.69	0.85, [0.75,1.05]	0.58, [0.20, 0.96]	0.88, [0.50, 1.25]

Note: *k*, number of study; CI, confidence interval; RoBMA, robust Bayesian meta-analysis.

TABLE 7 Summary of the results yielded by simple meta-regression analyses.

Study characteristics	Variables	Heterogeneity Q	p	T^2	I^2	R^2
Publication characteristics	Publication type	6.73	0.089	0.34	84.57	0.02
	Publication year[a]	22.59	0.001	0.32	83.30	0.12
Sample characteristics	Region[a]	48.33	<0.001	0.27	81.12	0.24
	Sample size	5.98	0.200	0.33	84.80	0.05
	Class size	5.74	0.219	0.34	84.31	0.03
	Education level[a]	9.27	0.026	0.34	84.43	0.02
	School location	1.27	0.296	0.36	85.34	<0.01
	School type	0.07	0.790	0.35	85.22	<0.01
Design characteristics	Experimental design[a]	23.72	<0.001	0.33	83.77	0.08
	Sampling method	0.99	0.319	0.35	84.71	0.01
	Researcher effect	8.39	0.573	0.36	84.64	<0.01
	Teacher effect	9.68	0.601	0.37	85.12	<0.01
	Treatment verification	0.32	0.570	0.35	84.84	<0.01
	Teacher training[a]	16.68	<0.001	0.32	83.52	0.10
Intervention characteristics	Type of CCS	0.95	0.622	0.35	84.53	<0.01
	Material[a]	6.16	0.046	0.34	84.50	0.02
	Subject domain[a]	28.27	<0.001	0.30	82.73	0.14
	Intervention length[a]	15.81	<0.001	0.31	83.46	0.11
	Intervention intensity	0.33	0.564	0.37	85.58	<0.01
Measurement characteristics	Instrument type[a]	3.76	0.035	0.35	84.42	0.02
	Question type[a]	2.95	<0.001	0.32	82.24	0.14
	Number of tiers	3.12	0.215	0.34	84.50	<0.01
	Type of outcome measure	2.04	0.165	0.36	85.07	<0.01

Note: Q, total heterogeneity; T^2, between study variance; I^2, ratio of the true variance to the total variance; R^2, ratio of the explained variance to the total variance.

[a]The moderators explaining a significant amount of heterogeneity.

3.5.2 | Sample characteristics

We performed regression analyses for five potential moderators related to sample characteristics. Only the region variable yielded a statistically significant result ($Q[4] = 48.33$, $p < 0.001$). The studies conducted in Turkey ($g = 1.28$) considerably differ from those in other regions/countries. This one explains the highest between-study variance (23.5%) among all the moderator variables.

3.5.3 | Design characteristics

Among six variables related to design characteristics, teacher training ($Q[1] = 16.68$, $p < 0.001$), and experimental design ($Q[3] = 23.72$, $p < 0.001$) are the only variables explaining a significant amount of variance (9.5% and 8.1%, respectively). Compared to others, the studies reporting that the teacher(s) were trained about the intervention and the quasi-experimental studies tend to have larger mean effect sizes ($g = 1.29$ and 1.23, respectively).

3.5.4 | Intervention characteristics

Although ontological change studies appear to have a smaller mean effect size than cognitive bridging and cognitive conflict studies, the simple regression analysis for the different types of CCS did not yield a statistically insignificant result ($Q[2] = 0.95$, $p < 0.622$). The subject domain, on the other hand, is a significant moderator variable ($Q[3] = 28.27$, $p < 0.001$) that explains 14.1% of the heterogeneity. The studies in Chemistry reveal a larger mean effect size than those in Physics and Biology. Furthermore, the moderating effect of the material used during the intervention is marginally significant ($Q[2] = 6.16$, $p = 0.046$). Hands-on materials are more effective than text-based and computer-based materials. Finally, intervention length is another influential moderator ($Q[1] = 15.81$, $p < 0.001$), which is responsible for 11.2% of the heterogeneity alone. As the intervention length increases, so does the effect of CCS on science achievement.

3.5.5 | Measurement characteristics

We examined the moderating effects of four variables related to measurement characteristics. The type of assessment instrument ($Q[2] = 3.76$, $p < 0.035$) and questions ($Q[2] = 2.95$, $p < 0.001$) are the variables that significantly moderate the effect of CCS on science achievement. Question type explains 13.5% of the variance, while the type of assessment instrument is only responsible for 2.3% of the heterogeneity. Regarding question type, the studies using objective-type questions to measure the outcome report a larger mean effect size than those using open-ended questions.

3.6 | Simultaneous model

The simple meta-regression analyses we conducted pointed out the important moderator variables that explained a significant amount of variance alone. Yet, simple meta-regression does not allow us to control the effect of other variables while examining the moderating effect of a particular variable. Therefore, we performed a multiple meta-regression to determine the unique variance explained by some prominent moderators identified by simple meta-regression. We conducted a hierarchical meta-regression to create a parsimonious model. First, we ran the regression with two significant moderators related to design characteristics: experimental design and teacher training. Then, because there was empirical evidence that they were influential moderators, we added two more variables related to publication characteristics: publication type and year. Finally, we included the subject domain and region based on the results of the simple meta-regression analyses. Table 8 shows the results of the hierarchical meta-regression conducted in these four steps.

The final model includes six variables that explain 35.1% of the heterogeneity. All the variables are statistically significant, as shown in Table 8. In other words, each of these

TABLE 8 Summary of the results yielded by the multiple meta-regression analysis.

Moderators	Characteristics	k	p	Multiple R^2
Experimental design	Design	218	0.010	0.35
Teacher training	Design	218	0.008	
Publication type	Publication	218	0.025	
Publication year	Publication	218	0.046	
Subject domain	Intervention	218	0.005	
Region	Sample	218	0.029	

Note: k, number of studies; R^2, ratio of the explained variance to the total variance.

variables explains statistically significant variance above and beyond the other variables in the model. However, the remaining heterogeneity is still significant, with a prediction interval of [0.19, 2.38].

4 | DISCUSSION

In this meta-analysis, we aim to synthesize the studies investigating the effect of CCS on science achievement in more than 30 years. By doing so, we sought not only to estimate the degree to which overall CCS affects science achievement, but also to examine if there is any difference in the effectiveness of different types of CCS. In this sense, we compare three main types of CCS extensively studied in the literature: cognitive conflict, cognitive bridging, and ontological category shift. Furthermore, we conduct moderator analyses to explain the heterogeneity in the distribution of true effect sizes.

In this context, we combine the results of 218 studies involving 18,051 students. This broad sample of studies consists of both published and unpublished studies conducted in a wide range of time-interval, from 1989 to 2020. It also includes a variety of publications, designs, samples, interventions, and measurement characteristics. Given that we collected these studies through a systematic and comprehensive literature search, we believe the sample of this meta-analysis is highly representative of CCS studies in the science education literature.

4.1 | The effect of CCS on science achievement

Our findings show that CCS has a large overall effect on science achievement. This result is consistent across all CCS types. Although the mean effect size for studies using ontological category shift is slightly smaller than for others, the difference is neither statistically significant nor explains a considerable heterogeneity of true effect sizes. In other words, each type of CCS consistently has a large effect on science achievement. However, the distributions of effect sizes are highly heterogeneous, resulting in a wide prediction interval for the mean effect size for each type of CCS. Therefore, we conducted moderator analyses using some variables related to study characteristics.

The overall effect size indicating the effectiveness of CCS is consistent with previous meta-analyses in the literature (Armağan, 2011; Gelen, 2015; Guzzetti et al., 1993; Schroeder & Kucera, 2021). In other words, our findings, similar to previous meta-analyses, confirm that CCS significantly affects science achievement regardless of publication, sample, design, intervention, or measurement characteristics. Although the scope and sample of the prior meta-analyses are not the same as ours, the consistent findings revealed in all these meta-analyses provide strong evidence for the effectiveness of conceptual change strategies.

As we underlined before, what is unique about this meta-analysis is that we compare the relative effectiveness of each conceptual change strategy. Thus, one of the key findings in this meta-analysis is that each conceptual change strategy consistently has a large effect on science achievement. The meta-analyses of Armağan (2011) and Gelen (2015), focusing mainly on cognitive conflict, estimate the overall effect size to be 1.18 and 1.13, respectively. These values are very close to the one estimated for the cognitive conflict in this meta-analysis ($g = 1.10$). However, in their recent meta-analysis, Schroeder and Kucera (2021) synthesize the studies on the refutational text and give us an overall effect size of 0.45 for science, which is smaller than the one in this meta-analysis ($g = 1.09$ for text-based CCS). There could be several reasons for this discrepancy, one of which is the sample characteristics of the meta-analyses. Schroeder and Kucera reviewed 33 studies published in English, whereas we synthesized 218 studies, 150 of which used the cognitive conflict as the conceptual change strategy.

We also performed several analyses to examine the effect of the publication bias on our results. The high value of Orwin's Fail-safe N shows that the results are robust to publication bias. Furthermore, both selection models and Robust Bayesian Meta-Analysis estimate large adjusted effect sizes close to the unadjusted one. Thus, we conclude that publication bias does not considerably affect our interpretation of the results in this meta-analysis.

4.2 | The role of study characteristics on the effectiveness of CCS

We examined several moderator variables to explain the high level of heterogeneity in true effect sizes. We categorized these variables into five broad groups: publication, sample, design, intervention, and measurement characteristics. Then, simple meta-regression analyses revealed that only publication year was a significant moderator related to the publication characteristics. The mean effect size of the studies conducted between 2006 and 2010 is larger than the others. Previous meta-analyses appear to show a similar pattern. For example, Guzzetti et al. (1993), one of the earliest meta-analyses on conceptual change, covers the studies between 1981 and 1991, but most of them were conducted in the second half of this time interval. The findings of this meta-analysis indicate an overall effect size of 0.85. In addition, Armağan (2011) classifies the primary studies into three groups separated by 5 years. The mean effect sizes are 0.98, 1.08, and 1.25 for the studies conducted between 1995–1999, 2000–2005, and 2006–2010, respectively. There could be several reasons for this trend, such as the developments in the conceptual change theory or improved experimental conditions in more recent studies. Yet, we do not have any empirical evidence to support these explanations in this meta-analysis.

Publication type is not a significant moderator when included in the analysis alone. However, it turns out to be significant when it is analyzed with some other variables using multiple meta-regression. Doctoral dissertations have a larger mean effect size than other types of studies. We need to note that if a dissertation or thesis was also published in a journal, we included the dissertation or thesis since it generally provided us with much more detailed information about the study than journal articles. That is to say, the results revealed from some of these dissertations were also published in journals, but we still labeled them as dissertations. Thus, this classification does not directly represent a comparison of published and unpublished studies.

Regarding sample characteristics, region is the only variable that explains a significant amount of heterogeneity. We believe that the sample of primary studies in this meta-analysis fairly represents the universe of studies in Turkish and English because we conducted a thorough literature search, as previously explained. Study selection yielded 61 studies in Turkish and 157 in English. Including a non-English language expanded the generalizability of this meta-analysis, allowing us to compare the regions with a greater number of primary studies. The studies conducted in Turkey have a significantly larger mean effect size than those in other studies. Previous meta-analyses on the conceptual change also support this finding. For example, most of the primary studies synthesized in Armağan (2011) and Gelen (2015) were conducted in Turkey. The overall effect sizes estimated in these meta-analyses are large and close to the one in this meta-analysis. Schroeder and Kucera (2021), on the other hand, cover mostly the studies conducted in Europe and North America and estimate an overall effect size of 0.45 for science. As noted previously, this could be one of the reasons for the discrepancy between their findings and ours. It is important to note that this variable remains significant in the final model created using multiple meta-regression analyses. In other words, it is a significant moderator above and beyond the other variables in the model, which includes some other important moderators. It would seem reasonable that this finding arises from another moderator we could not include in this meta-analysis. Experimental design and teacher training are important variables related to design characteristics. The quasi-experimental studies have a much larger mean effect size than the true-experimental studies. Unlike quasi-experimental design, true-experimental design requires the random assignment of the subjects to treatment groups, which is an influential way to control threats to internal validity due to subject characteristics (Fraenkel et al., 2012, p. 266). Therefore, any difference between the mean effect sizes of true and quasi-experimental studies may result from the degree to which they control the threats to internal validity. And if this is so, then we might be overestimating the overall effect size because of the weakness of the quasi-experimental design because the mean effect size for the studies using the true-experimental design is nearly half of the one estimated by the quasi-experimental studies in this meta-analysis.

Furthermore, the studies stating that teachers have been trained reveal a larger mean effect size than those that have not. Teacher training is essential to boost implementation fidelity. Carroll et al. (2007) claim that the variations in the degree to which implementation fidelity is achieved in primary studies might explain the heterogeneity in their results. From this perspective, our findings show that the conceptual change strategies work more effectively when the implementation fidelity is elevated through teacher training.

Subject domain and intervention length are the most important moderating variables regarding the intervention characteristics. The type of material also yields a marginally significant result, but it only explains a slight variance in the true effect size distribution. The studies in Chemistry have a considerably larger mean effect size than those in Physics and Biology, while the studies in Biology have the smallest mean effect size among these three subject domains. Intervention length also moderates the effect of CCS on science achievement. The effect size increases as the intervention length increases, indicating that it takes time to see the actual impact of conceptual change strategies. This finding is reasonable because both students and teachers may require some time to get used to a new method, which is considerably different from what they usually experience in their classes.

Finally, question type is a significant moderator representing measurement characteristics. The studies using objective-type questions in the assessment instrument produce a larger overall effect size than those using open-ended questions. Open-ended questions fit better to assess conceptual understanding and student misconceptions. Consequently, assessments with objective-type questions might be overestimating the effectiveness of conceptual change strategies. The type of assessment instrument also appears to be significant, but it does not explain a considerable variance.

The hierarchical multiple meta-regression analysis yielded a parsimonious model including six moderators, explaining 35.1% of the heterogeneity. This model allows us to estimate the effect of a particular moderator variable above and beyond the other variables in the model. In other words, quasi-experimental studies have a larger mean effect size than other studies even when we control for the type and year of the publication, the subject domain and the region where the studies were conducted, and whether the teachers were trained before the intervention.

To sum up, we identified some moderator variables affecting the effectiveness of conceptual change strategies on science achievement in terms of publication, sample, design, intervention, and measurement characteristics. Furthermore, we created a parsimonious model using multiple meta-regression to examine the unique moderating effect of some important variables. On the other hand, what is evident based on our meta-analysis is that the conceptual change strategies significantly improve science achievement regardless of any study characteristics.

4.3 | Implications for theory and practice

In earlier sections, we limited ourselves to discussions of the results of quantitative analyses. In this section, we will question our findings from a theoretical perspective and discuss some issues from a practical point of view. One of our frustrations in this meta-analysis is that we used only science achievement as an outcome variable because most of the studies focused on this variable. However, the theoretical framework of each strategy gives different messages about how to learn science. Cognitive bridging, for example, appreciates what is already known, while cognitive conflict does the opposite. This may cause a difference in students' epistemologies about how to learn science. Similarly, several motivational factors, especially self-efficacy beliefs, can be affected by consistent falsification of what students already know during the implementation of cognitive conflict strategy (Smith et al., 1993). However, only a few studies focus on motivational or epistemological factors as outcome variables. Although the three conceptual change strategies do not significantly differ in the degree to which they affect students' science achievement, they may still diverge, considering their effects on other outcome variables.

Treatment fidelity emerges as another issue for the available primary studies in the literature on conceptual change, as argued by different researchers in other domains (Moncher & Prinz, 1991; Swanson et al., 2013). Unfortunately, the primary studies hardly provide evidence about the fidelity of the treatments. All of the conceptual strategies require carefully designed procedures for implementation. In the case of cognitive conflict strategy, anomalous data or discrepant events have been used to trigger cognitive conflict. Nevertheless, several researchers reported that the intended conflict might not be achieved (Chinn & Brewer, 1993). According to these researchers, students' responses to anomalous data can range from unadopted to comply with anomalous data. Even though carefully selected anomalous data cannot guarantee a meaningful conflict, it is the best available tool to initiate a conflict. Some researchers have included data about how students' responses to anomalous data contribute to their gains from the cognitive conflict strategy (Lee & Byun, 2012). We need more of this kind of study to perform analyses examining the heterogeneity of the effects of cognitive conflict strategies.

Similarly, the cognitive bridging strategy highly relies on analogies, especially anchoring/bridging analogies. Anchoring analogies have some unique qualities. Furthermore, calling them analogies can be misleading because they are not analogies but the concept itself. For example, the analogy of "a hand pressing on a spring" is used to eliminate students' misconception that "inanimate objects do not exert force." This analogy was used in the preliminary study by Clement et al. (1989) to overcome students' misconceptions about the reaction force acting on a book resting on a table. Without going into details, both analog (the force acting on a hand pushing the spring) and target concepts (the force acting on a book resting on the table) are related to the same concept, the reaction force. The difference is that the force on the hand exerted by the spring is more noticeable for students compared to the force on the book by the table. However, in traditional analogies, the analog and the target concepts are different from each other. This is why, when using these analogies, it is critical to discuss the dissimilarities as well as the similarities between the analog and the target concepts. It is always possible for students to pick up new misconceptions out of the traditional analogies if the necessary precautions are not taken (Spiro et al., 1988). However, this is not the case for anchoring "analogies" because they are not analogies. In primary studies, we encounter traditional analogies as well as anchoring ones. More detailed discussions about the similarities and differences between the analog and the target concept in these studies are needed.

On the other hand, ontological category shift seems to be the most novel approach among the conceptual change strategies. This is probably why the number of studies testing ontological category shifts' effectiveness is far smaller than the ones for the other strategies. Furthermore, most of the studies on ontological categories focus on the concepts already categorized by Chi and her colleagues (1992; 1993; 2002). Identifying the ontological categories of different concepts seems to be one of the challenging tasks of this strategy. Several researchers engaging in such a task, especially for physics concepts, have been arguing about the difficulties of locating them into distinct categories (Chiu & Lin, 2005; Çoruhlu & Çepni, 2015; Yang et al., 2012). All these discussions are very fruitful for creating awareness about the ontological nature of concepts and providing feedback for the theory of ontological categories.

4.4 | Limitations and future directions

The first limitation of this meta-analysis is the language of the primary studies we included. We can only generalize the findings of this meta-analysis to the studies published in either English or Turkish. Furthermore, this limitation resulted in more studies conducted in Turkey than in other countries in the sample of this meta-analysis. Given that the region appears to moderate the effectiveness of conceptual change strategies, we should keep in mind that the overall effect size for primary studies in all languages may differ to some extent from that estimated in this study. In addition, any meta-analysis is limited by the scope of the primary studies synthesized in that meta-analysis. We could only examine the effect of conceptual change strategies on science achievement since most primary studies focus on the cognitive dimension rather than the affective one. Conceptual change strategies may affect the motivational constructs as well. Cognitive conflict, for example, may affect the students' self-efficacy due to the dissatisfaction it aims to create. Furthermore, it may also affect students' epistemology since it focuses on unproductive preconceptions rather than productive ones. Yet, the outcomes of these conceptual change strategies in the affective domain are often neglected in the literature. Another limitation of any meta-analysis is the potential effect of publication bias on the findings. However, several analyses we ran show that our results seem to be robust to publication bias. Therefore, it would not change our interpretation of the overall effect size in this meta-analysis. Finally, the findings revealed by the moderator analyses should be interpreted cautiously. Because of the associational nature of these analyses, we cannot claim a cause-effect relationship directly.

Each type of conceptual change strategy appears to be effective when used in an appropriate context. Yet, there is a need for studies comparing the effectiveness of these strategies on the same misconception. Since each conceptual change strategy is based on a different approach, its effectiveness might change according to the nature of the misconception. In addition, the effectiveness of conceptual change strategies may differ as measured by the retention test. Further studies can be conducted to examine the delayed effects of these strategies.

Lastly, this is not the first nor will it be the last meta-analysis on conceptual change. Even if we accept the assumption that this study is limited to the knowledge-based interpretation of conceptual change, it covers a significant portion of the literature and puts some light on the relative effectiveness of conceptual change strategies emerging from very powerful theories by considering a significant number of moderator variables.

5 | CONCLUSION

We synthesized 218 studies investigating the effect of conceptual change strategies on science achievement in this comprehensive meta-analysis. Our findings clearly show that conceptual change strategies have a large effect on science achievement regardless of the study characteristics. This finding is also consistent across the different types of conceptual change strategies. That is to say, cognitive conflict, cognitive bridging, and ontological category shift all appear to be highly effective. Although the overall effect size is consistently large across different study characteristics, there exist some moderator variables affecting the effectiveness of conceptual change strategies. In this sense, the final model we created using the most critical study characteristics explains a significant heterogeneity in the study results. To sum up, this meta-analysis provides strong evidence for the effect of conceptual change strategies on science achievement. Therefore, we suggest teachers use the conceptual change strategy in the appropriate contexts to overcome the misconceptions in science education. We also encourage researchers to examine the effects of these strategies in the affective domain and make in-depth comparisons of different types of conceptual change strategies to overcome the same misconception.

ORCID

Cagatay Pacaci https://orcid.org/0000-0002-5093-3568
Ulas Ustun https://orcid.org/0000-0001-9974-6897
Omer Faruk Ozdemir https://orcid.org/0000-0003-4715-195X

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APPENDIX A

TABLE A1 List of researchers that provide feedback for conceptual change strategy type

No	Name of researcher	Study name	Country	Feedback
1	Okşan Çelikten	The effect of the conceptual change oriented instruction through cooperative learning on 4th grade students' understanding of earth and sky concepts	Turkey	Agree
2	Hatice Belge Can	Structuring cooperative learning for motivation and conceptual change in the concepts of mixtures	Turkey	Agree
3	Ayhan Çinici	Effect of cooperative and individual learning activities on students' understanding diffusion and osmosis	Turkey	Agree
4	Harika Özge Arslan	Learning cycle model to foster conceptual understanding in cell division and reproduction concepts	Turkey	Agree
5	Gülcan Çetin	Effects of conceptuaş change texts based instruction on ecology, attitudes toward biology and environment	Turkey	Agree
6	Özgecan Taştan	Cooperative learning instruction for conceptual change in the concepts of chemical kinetics	Turkey	Agree
7	Özgecan Taştan	Effectiveness of conceptual change text-oriented instruction on students' understanding of energy in chemical reactions	Turkey	Agree
8	Gökhan Demircioğlu	Comparison of the effects of conceptual change texts implemented after and before instruction on secondary school students' understanding of acid–base concepts	Turkey	Agree
9	Gökhan Demircioğlu	Asitler ve Bazlar Konusundaki Öğrenci Yanlış Anlamalarının Değerlendirilmesinde Kavramsal Değişim Metinlerinin Etkisi	Turkey	Agree
10	Gökhan Demircioğlu	Conceptual change was achieved through a new teaching program on acids and bases	Turkey	Agree
11	Ceren Tekkaya	Facilitating conceptual change in students' understanding of ecological concept	Turkey	Agree
12	Ceren Tekkaya	Remediating high school students' misconceptions concerning diffusion	Turkey	Agree

(Continues)

TABLE A1 (Continued)

No	Name of researcher	Study name	Country	Feedback
		and osmosis through concept mapping and conceptual change text		
13	Zeynel Abidin Yılmaz	Kavramsal değişim metinlerinin üniversite öğrencilerinin geometrik optik konusundaki kavram yanılgılarının düzeltilmesi ve fizik dersine karşı tutumlarına etkisinin incelenmesi	Turkey	Agree
14	Ebru Kaya	Reaksiyon Hızı Konusunda Kavramsal Değişime Dayalı Öğretim Metodu ile Kavramsal Değişimin Oluşturulması	Turkey	Agree
15	Muammer Çalık	A comparison of different conceptual change pedagogies employed within the topic of sound propagation	Turkey	Agree
16	Muammer Çalık	Analogical reasoning for understanding solution rates: Students conceptual change and chemical explanations	Turkey	Agree
17	Muammer Çalık	Effect of enriched 5Es model on grade 7 students' conceptual change levels: A case of 'electric current' subject	Turkey	Agree
18	Gamze Arık Dolu	Identification and elimination of several misconceptions of university level students regarding the misconceptions in science course	Turkey	Agree
19	Haluk Özmen	Effect of animation enhanced conceptual change texts on 6th-grade students' understanding of the particulate nature of matter and transformation during phase changes	Turkey	Agree
20	Haluk Özmen	The effectiveness of conceptual change texts in remediating high school students' alternative conceptions concerning chemical equilibrium	Turkey	Agree
21	Haluk Özmen	The effects of conceptual change texts accompanied with animations on overcoming 11th grade students alternative conceptions of chemical bonding	Turkey	Agree
22	Nilüfer Cerit Berber	Kavramsal değişim metinlerinin iş, güç, enerji konusunu anlamaya etkisi	Turkey	Agree
23	Nurşen Azizoğlu	Conceptual change orıented ınstructıon and students' mısconceptıons ın gases	Turkey	Agree
24	Eylem Yıldız Feyzioğlu	The effect of 5E learning model instruction on seventh grade students'	Turkey	Disagree

TABLE A1 (Continued)

No	Name of researcher	Study name	Country	Feedback
		conceptual understanding of force and motion		
25	Aybüke Pabuçcu	Kimyasal bağlarla ilgili kavram yanılgılarının kavramsal degişim metinleri kullanılarak düzeltilmesi	Turkey	Agree
26	Sevgi Kıngır	Using the science writing heuristic approach to enhance student understanding in chemical change and mixture	Turkey	Agree
27	Gülüzar Eymur	The collaboration of cooperative learning and conceptual change: Enhancing the students' understanding of chemical bonding concepts	Turkey	Agree
28	Ali Eryılmaz	Effects of conceptual assignments and conceptual change discussions on students' misconceptions and achievement regarding force and motion	Turkey	Agree
29	Ali Eryılmaz	Integrating gender and group differences into bridging strategy	Turkey	Agree
30	Ali Eryılmaz	Assessing the impact of bridging analogies in mechanics	Turkey	Agree
31	Yunus Karakuyu	Elektrik Konusunda Kavram Yanılgıları ve Kavramsal Değişim Yaklaşımı	Turkey	Agree
32	Gülten Şendur	The role of conceptual change texts to improve students' understanding of alkene	Turkey	Agree
33	Gülten Şendur	Buharlaşma ve Kaynama Konularındaki Kavram Yanılgılarının Önlenmesinde Analoji Yönteminin Etkisi	Turkey	Agree
34	Ayşe Yenilmez Türk	Enhancing students' understanding of photosynthesis and respiration in plant through conceptual change approach	Turkey	Agree
35	Gonca Kasap	To determine the effect of the actıvıtıes based on conceptual change approach on students 'conceptual understanding of floatıng-sınkıng objects	Turkey	Agree
36	Tacettin Pınarbaşı	The conceptual change approach to teaching chemical equilibrium	Turkey	Agree

(Continues)

TABLE A1 (Continued)

No	Name of researcher	Study name	Country	Feedback
37	İsmail Önder	The effect of conceptual change approach on students' understandıng of solubılıty equılıbrıum concept	Turkey	Agree
38	İsmail Önder	The effect of conceptual change texts supplemented instruction on students' achievement in electrochemistry	Turkey	Agree
39	Murat Demirel	Kavramsal değişim yaklaşımına yönelik çalışma: gazlar konusu	Turkey	Agree
40	Tülay Şenel Çoruhlu	Evaluation of the effects of the 5E model enriched with conceptual change pedagogy on students' conceptual change: "comet", "star drift" and "meteor"	Turkey	Agree
41	Gökhan Uyanık	The effect of the conceptual change texts on removing misconceptions in primary 4th grade science course	Turkey	Agree
42	Ahmet Gürses	Kavramsal değişim yaklaşımının öğrencilerin gazlar konusunu anlamalarına etkisi	Turkey	Agree
43	Refik Dilber	Effect of conceptual change instruction on students' understanding of electricity concepts	Turkey	Agree
44	Refik Dilber	High school students' understanding of projectile motion concepts	Turkey	Agree
45	Refik Dilber	Effectiveness of analogy on students' success and elimination of misconceptions	Turkey	Agree
46	Refik Dilber	Teaching of the water waves: Effectiveness of computer simulations on student success and elimination of misconceptions	Turkey	Agree
47	Mutlu Pınar Demirci Güler	Sınıf öğretmeni adaylarının ısı ve sıcaklık konusundaki kavram yanılgıları ve yanılgıların giderilmesinde yapısalcı kuramın etkisi	Turkey	Agree
48	Aygül Aslan	The effect of video-assisted conceptual change texts on 12th grade students' alternative conceptions: The gas concept	Turkey	Agree
49	Barış Çaycı	The impacts of conceptual change text-based concept teaching on various variables	Turkey	Agree

TABLE A1 (Continued)

No	Name of researcher	Study name	Country	Feedback
50	Barış Çaycı	Kavram Değiştirme Metinlerinin Kavram Öğrenimi Üzerindeki Etkisinin İncelenmesi	Turkey	Agree
51	Nejla Yürük	Effectiveness of conceptual change text-oriented instruction on students' understanding of cellular respiration concepts	Turkey	Agree
52	Nejla Yürük	The effect of supplementing instruction with conceptual change texts on students' conceptions of electrochemical cells	Turkey	Agree
53	Nejla Yürük	The effect of conceptual change texts enriched with metaconceptual processes on preservice science teachers' conceptual understanding of heat and temperature	Turkey	Neutral
54	Abuzer Akgün	TGA etkinliklerinin fen bilgisi öğretmen adaylarının çiçekli bitkilerin büyüme ve gelişmesi ile ilgili sahip olduğu kavram yanılgılarının giderilmesine etkisi	Turkey	Agree
55	Alipaşa Ayaş	Farklı Kavramsal Değişim Yöntemleri ile Alternatif Kavramları Gidermek ve Bilimsel Süreç Becerilerini Geliştirmek Mümkün müdür? Elektrokimyasal Piller Örneği	Turkey	Agree
56	Çiğdem Şahin Çakır	Effect of using different teaching methods and techniques embedded within the 5e instructional model on removing students' alternative conceptions: Fluid pressure	Turkey	Agree
57	Nurtaç Canpolat	The conceptual change approach to teaching chemical equilibrium	Turkey	Agree
58	Hüseyin Akkuş	The effect of a conceptual change approach on understanding of students' chemical equilibrium concept	Turkey	Agree
59	Eylem Bayır	Sorgulayıcı-araştırmaya dayalı analitik kimya laboratuvarlarının kimya öğretmen adaylarının kavramsal değişimlerine, bilimi ve bilim öğrenme yollarını algılamalarına etkileri	Turkey	Agree

(Continues)

TABLE A1 (Continued)

No	Name of researcher	Study name	Country	Feedback
60	Eylem Yalçınkaya Önder	The effect of case-based instruction on 10th grade students' understanding of gas concepts	Turkey	Agree
61	Feyzi Osman Pekel	Dynamising conceptual change approach to teach some genetics concepts	Turkey	Agree
62	Norrie Gayeta	Measuring conceptual change on stoichiometry using mental models and ill-structured problems in a flipped classroom environment	Philippines	Agree
63	Patrice Potvin	Experimental evidence of the superiority of the prevalence model of conceptual change over the classical models and repetition	Canada	Agree
64	Lucia Mason	Textual and graphical refutations: Effects on conceptual change learning	Italy	Neutral
65	Michelene Chi	Repairing student misconceptions using ontology training: A study with junior and senior undergraduate engineering students	USA	Agree
66	Michelene Chi	Helping students understand challenging topics in science through ontology training	USA	Agree
67	Mariëtte van Loon	Refutations in science texts lead to hypercorrection of misconceptions held with high confidence	Holland	Agree
68	Mary G. Nwankwo	Effect of analogy teaching approach on students' conceptual change in physics	Nigeria	Agree
69	Ruth Stavy	Using analogy to overcome misconceptions about conservation of matter	Israel	Agree
70	Trevors Gregory	Learner, text, and context factors on conceptual change in biology	Canada	Agree
71	Christine Howe	Peer collaboration and conceptual growth in physics: Task influences on children's understanding of heating and cooling	Scotland	Agree
72	Ilona Södervik	Promoting the understanding of photosynthesis among elementary school student teachers through text design	Finland	Agree
73	Yue Yin	Using formal embedded formative assessments aligned with a shortterm	USA	Agree

TABLE A1 (Continued)

No	Name of researcher	Study name	Country	Feedback
		learning progression to promote conceptual change and achievement in science		
74	Marcuss Lee Johnson	Use of task value instructional induction for facilitating engagement and conceptual change	USA	Agree
75	Ali Bawaneh	Radıcal conceptual change through teaching method based on constructıvısm theory for eıght grade Jordanian student	Jordan	Agree
76	Hsiao Ching She	SCCR digital learning system for scientific conceptual change and scientific reasoning	Taiwan	Agree
77	Kuo-En Chang	Correcting misconceptions on electronics: effects of a simulation-based learning environment backed by a conceptual change model	Taiwan	Agree
78	Mark Windschitl	Using computer simulations to enhance conceptual change: The roles of constructivist instruction and student epistemological beliefs	USA	Agree
79	Tomas Andree	Using computer simulations to enhance conceptual change: The roles of constructivist instruction and student epistemological beliefs	USA	Agree
80	Murray S. Jensen	A computer-assisted instruction unit on diffusion and osmosis with a conceptual change design	USA	Agree
81	Zaınol Badli Budiman	The effects of cognıtıve conflıct management on cognıtıve development and scıence achıevement	Malaysia	Agree
82	Mei-Hung Chiu	Promoting fourth graders' conceptual change of their understanding of electric current via multiple analogies	China	Disagree
83	C. B. Njelita	Effect of constructivist—Based instructional model on students' conceptual change and retention on some difficult concepts in chemistry	Nigeria	Agree

APPENDIX B

TABLE B1 List of effect sizes revealed from primary studies

No	Surname, Year	Effect size (Hedges' g)	Standard deviation	Publication type
1	Stavy, 1991	1.214	0.274	Journal article
2	Woloshyn et al., 1994	0.756	0.264	Journal article
3	Küçük & Çalik, 2015	0.646	0.298	Journal article
4	Yang et al., 2012	0.373	0.458	Journal article
5	Slotta & Chi, 2006	0.899	0.362	Journal article
6	Launey, 1995	1.278	0.301	Doctoral dissertation
7	Chang & Baruffaldi, 1999	0.755	0.164	Journal article
8	Jensen et al., 1996	0.546	0.157	Journal article
9	Gokhale, 1996	0.459	0.294	Journal article
10	Windschitl & Andre, 1996	0.042	0.132	Journal article
11	Saigo, 1999	0.190	0.214	Doctoral dissertation
12	Seyedmonir, 2000	0.030	0.371	Doctoral dissertation
13	Sanger & Greenbowe, 2000	0.934	0.246	Journal article
14	Diakidoy & Kendeou, 2001	1.383	0.300	Journal article
15	Mikkilä-Erdmann, 2001	0.233	0.142	Journal article
16	Sungur et al., 2001	0.953	0.298	Journal article
17	Çakir et al., 2002	0.734	0.224	Journal article
18	Eryilmaz, 2002	0.169	0.174	Journal article
19	Uzuntiryaki, 2003	2.457	0.405	Doctoral dissertation
20	Tekkaya, 2003	0.586	0.304	Journal article
21	Alparslan et al., 2003	0.807	0.250	Journal article
22	Niaz & Chacón, 2003	1.090	0.449	Journal article
23	Çetin, 2003	0.700	0.227	Doctoral dissertation
24	Tsai, 2003	−0.317	0.145	Journal article
25	Charles, 2003	0.036	0.569	Doctoral dissertation
26	Bozkoyun, 2004	1.310	0.291	Doctoral dissertation
27	Ayhan, 2004	1.384	0.380	Doctoral dissertation
28	Özkan et al., 2004	0.780	0.269	Journal article
29	Azizoğlu, 2004	1.462	0.224	Doctoral dissertation
30	Çelebi, 2004	0.599	0.307	Master thesis
31	Ceylan, 2004	3.939	0.437	Doctoral dissertation
32	Uzuntiryaki & Geban, 2005	1.013	0.263	Journal article
33	Cetingul & Geban, 2005	2.016	0.354	Journal article
34	Gulcicek, 2004	1.144	0.314	Master thesis
35	Cetingul & Geban, 2011	1.267	0.306	Journal article

TABLE B1 (Continued)

No	Surname, Year	Effect size (Hedges' g)	Standard deviation	Publication type
36	Yavuz, 2005	0.885	0.240	Doctoral dissertation
37	Zohar & Kravetsky, 2005	−0.115	0.217	Journal article
38	Günay, 2005	1.411	0.329	Doctoral dissertation
39	Demircioğlu et al., 2005	1.060	0.226	Journal article
40	Savinainen et al., 2005	0.527	0.298	Journal article
41	Chiu & Lin, 2005	1.358	0.937	Journal article
42	Bilgin & Geban, 2006	2.250	0.273	Journal article
43	Bilgin & Geban, 2001	1.020	0.339	Journal article
44	Yilmaz et al., 2007	2.297	0.236	Journal article
45	Yilmaz & Eryılmaz, 2010	0.965	0.121	Journal article
46	Başer, 2006a	0.795	0.219	Journal article
47	Başer, 2006b	2.012	0.269	Journal article
48	Baser & Geban, 2007a	1.781	0.302	Journal article
49	Baser & Cataloglu, 2005	0.775	0.239	Journal article
50	Başer & Geban, 2007b	1.267	0.256	Journal article
51	Pabuccu, 2004	0.772	0.318	Doctoral dissertation
52	Canpolat et al., 2006	1.718	0.252	Journal article
53	Önder, 2006	2.269	0.229	Doctoral dissertation
54	Onder, 2017	0.580	0.300	Journal article
55	Balci, 2006	0.441	0.307	Master thesis
56	Vatansever, 2006	1.430	0.362	Master thesis
57	Yenilmez & Tekkaya, 2006	0.737	0.135	Journal article
58	Pinarbasi et al., 2006	1.303	0.235	Journal article
59	Erdemir, 2006	0.406	0.199	Doctoral dissertation
60	Yilmaz, 2007	0.141	0.276	Master thesis
61	Alkhawaldeh, 2007	0.935	0.244	Journal article
62	Yürük, 2007	2.245	0.317	Journal article
63	Taştan et al., 2008a	0.267	0.280	Journal article
64	Sevim, 2007	1.696	0.377	Doctoral dissertation
65	Cibik et al., 2008	0.516	0.228	Journal article
66	Liu, 2008	0.562	0.227	Master thesis
67	Taştan et al., 2008b	1.917	0.309	Journal article
68	Dilber, 2008	1.705	0.302	Journal article
69	Li, 2008	0.904	0.326	Journal article
70	Acar & Tarhan, 2008	3.330	0.407	Journal article
71	She & Lee, 2008	0.864	0.269	Journal article
72	Anyanwu, 2009	1.645	0.298	Doctoral dissertation

(Continues)

TABLE B1 (Continued)

No	Surname, Year	Effect size (Hedges' g)	Standard deviation	Publication type
73	Demircioglu, 2009	1.030	0.437	Journal article
74	Atasoy et al., 2009	1.760	0.351	Journal article
75	Ozmen et al., 2009	0.484	0.263	Journal article
76	Berber & Sari, 2009	0.769	0.286	Journal article
77	Ceylan & Geban, 2009	2.800	0.257	Journal article
78	Uce, 2009	2.017	0.242	Journal article
79	Çetin, 2009	1.281	0.266	Doctoral dissertation
80	Cetin et al., 2009	2.060	0.286	Journal article
81	Dilber et al., 2009	1.588	0.252	Journal article
82	Liao & She, 2009	0.637	0.245	Journal article
83	Yuruk et al., 2009	0.751	0.303	Journal article
84	Bawaneh et al., 2010	1.437	0.251	Journal article
85	Çalik et al., 2010	1.527	0.266	Journal article
86	Turgut & Gürbüz, 2011	1.390	0.360	Journal article
87	Pekmez, 2010	1.438	0.314	Journal article
88	Broughton et al., 2010	0.369	0.313	Journal article
89	Udogu & Njelita, 2010	2.521	0.406	Journal article
90	Akgul, 2010	1.146	0.350	Master thesis
91	Dilber, 2010	1.183	0.257	Journal article
92	Aykutlu & Şen, 2011	0.724	0.293	Journal article
93	Barthlow, 2011	0.672	0.115	Doctoral dissertation
94	Yilmaz et al., 2011	0.817	0.287	Journal article
95	Cetingul, 2006	1.268	0.300	Doctoral dissertation
96	Özmen, 2011	2.163	0.349	Journal article
97	Taşdelen, 2011	1.559	0.279	Doctoral dissertation
98	Karslı & Ayaş, 2013	1.696	0.329	Journal article
99	Cinici et al., 2011	0.769	0.383	Journal article
100	Hirca et al., 2011	1.016	0.322	Journal article
101	Karakuyu & Tüysüz, 2011	1.433	0.273	Journal article
102	Lin et al., 2011	0.444	0.157	Journal article
103	Akbas, 2008	2.294	0.270	Journal article
104	Akbulut et al., 2011	0.970	0.301	Journal article
105	Nwankwo & Madu, 2014	0.718	0.196	Journal article
106	Wozniak, 2012	3.601	0.567	Doctoral dissertation
107	Kaya, 2011	1.286	0.262	Doctoral dissertation
108	Seker, 2012	1.725	0.328	Doctoral dissertation
109	Sota, 2012	0.021	0.341	Doctoral dissertation

TABLE B1 (Continued)

No	Surname, Year	Effect size (Hedges' g)	Standard deviation	Publication type
110	Çelikten et al., 2012	0.648	0.271	Journal article
111	Feyzioglu et al., 2012	0.762	0.283	Journal article
112	Kıngır et al., 2013	0.627	0.184	Journal article
113	Köseoğlu & Bayır, 2012	1226	0.347	Journal article
114	Allen & Coole, 2012	0.94	0.351	Journal article
115	Chen & She, 2012	0.358	0.164	Journal article
116	Yaman, 2013	2.010	0.217	Doctoral dissertation
117	Kasap & Ültay, 2014	1.665	0.322	Journal article
118	Özkan, 2013	1.195	0.277	Master thesis
119	Belge Can & Boz, 2016	1.761	0.218	Journal article
120	Chen et al., 2013	0.452	0.339	Journal article
121	Demirezen & Yağbasan, 2013	1.240	0.244	Journal article
122	Sendur & Toprak, 2013	0.698	0.257	Journal article
123	Johnson & Sinatra, 2013	1.507	0.233	Journal article
124	Wood et al., 2013	1.001	0.336	Journal article
125	Sodervik et al., 2014	0.294	0.209	Journal article
126	Tlala, 2014	0.870	0.235	Journal article
127	Aslan & Demircioglu, 2014	1.372	0.342	Conference paper
128	Ünlü, 2012	1.762	0.226	Doctoral dissertation
129	Budiman et al., 2014	1.547	0.235	Journal article
130	Yin et al., 2014	0.826	0.288	Journal article
131	Arslan et al., 2015	0.722	0.136	Journal article
132	Sarı Ay, 2011	2.169	0.394	Journal article
133	Loyens et al., 2015	0.584	0.279	Journal article
134	Cetin et al., 2015	0.645	0.226	Journal article
135	Karamustafaoglu & Naaman, 2015	1.493	0.352	Journal article
136	Yumusak et al., 2015	2.508	0.470	Journal article
137	Hacimustafaoglu, 2015	0.613	0.317	Master thesis
138	Pekel & Hasenekoğlu, 2015	1.955	0.334	Journal article
139	Çoruhlu & Çepni, 2015	0.993	0.248	Journal article
140	Södervik et al., 2015	−0.033	0.152	Journal article
141	Yalcınkaya & Boz, 2015	1.240	0.192	Journal article
142	Loon et al., 2015	0.545	0.190	Journal article
143	Diakidoy et al., 2016	0.089	0.240	Journal article
144	Eymur, 2014	2.844	0.333	Doctoral dissertation
145	Mason et al., 2017	0.677	0.288	Journal article
146	Özmen & Naseriaza, 2017	1.878	0.214	Journal article

(Continues)

TABLE B1 (Continued)

No	Surname, Year	Effect size (Hedges' g)	Standard deviation	Publication type
147	Fan et al., 2018	0.934	0.194	Journal article
148	Mason et al., 2017	0.329	0.216	Journal article
149	Muisa et al., 2018	0.941	0.191	Journal article
150	Adesope et al., 2017	0.748	0.310	Journal article
151	Gayeta & Caballes, 2017	−0.135	0.284	Journal article
152	Sahhyar & Nts, 2017	0.867	0.263	Journal article
153	Alkhawaldeh, 2012	0.864	0.241	Journal article
154	Dilber & Duzgun, 2008	3.013	0.329	Journal article
155	Sendur et al., 2008	1.404	0.319	Journal article
156	Karakethudaoglu, 2010	0.655	0.327	Master thesis
157	Demirci & Sarikaya, 2004	1.063	0.273	Conference paper
158	Gedik et al., 2002	0.767	0.301	Conference paper
159	Tokur et al., 2014	0.479	0.225	Journal article
160	Demircioglu et al., 2013	1.480	0.379	Journal article
161	Demirel & Anıl, 2018	3.137	0.325	Journal article
162	Kırık & Boz, 2012	1.375	0.303	Journal article
163	Seker & Geban, 2014	0.766	0.245	Journal article
164	Köse, 2004	2.165	0.251	Doctoral dissertation
165	Yilmaz, 2010	0.668	0.184	Doctoral dissertation
166	Damli, 2011	2.037	0.416	Master thesis
167	Uyanik & Dindar, 2016	1.632	0.323	Conference paper
168	Alkhawaldeh & Olaimat, 2010	1.433	0.266	Journal article
169	Cobanoglu & Bektas, 2012	1.976	0.352	Conference paper
170	Diakidoy et al., 2003	0.746	0.166	Journal article
171	Gürses et al., 2002	0.642	0.256	Conference paper
172	Alkhawaldeh, 2012	1.296	0.299	Journal article
173	Durmus, 2009	1.865	0.242	Master thesis
174	Tokatlı, 2010	1.747	0.311	Master thesis
175	Özmen, 2007	0.817	0.234	Journal article
176	Özmen & Demircioğlu, 2003	2.175	0.323	Journal article
177	Polat, 2007	1.558	0.294	Master thesis
178	Keleş, 2009	1.484	0.301	Doctoral dissertation
179	Gürbüz, 2008	1.352	0.307	Master thesis
180	Lee & She, 2010	1.297	0.287	Journal article
181	İpek, 2007	0.940	0.281	Master thesis
182	Zohar & Kravetsky, 2003	0.115	0.277	Conference paper
183	Trevors, 2011	0.774	0.279	Master thesis

TABLE B1 (Continued)

No	Surname, Year	Effect size (Hedges' g)	Standard deviation	Publication type
184	Clement, 1993	1.271	0.323	Journal article
185	Çakmak, 2016	1.062	0.253	Doctoral dissertation
186	Harman, 2016	0.716	0.207	Doctoral dissertation
187	Aydın, 2011	1.253	0.222	Doctoral dissertation
188	Alemisoğlu, 2014	0.452	0.314	Master thesis
189	Demirer, 2015	1.800	0.567	Master thesis
190	Duman, 2015	2.218	0.450	Master thesis
191	Atılğanlar, 2014	0.401	0.331	Master thesis
192	Aksu, 2010	1.192	0.397	Doctoral dissertation
193	Kılıç, 2016	1.541	0.282	Master thesis
194	Coetzee & Imenda, 2012	0.158	0.174	Journal article
195	Karamustafaoglu et al., 2002	1.048	0.236	Conference paper
196	Can et al., 2006	1.349	0.249	Journal article
197	Tezcan & Salmaz, 2005	0.654	0.279	Journal article
198	Kör, 2006	0.744	0.264	Master thesis
199	Aydın, 2007	0.532	0.268	Master thesis
200	İnal, 2003	1.865	0.329	Master thesis
201	Çaycı, 2007	0.441	0.285	Journal article
202	Toros, 2015	0.902	0.205	Master thesis
203	Çelik, 2013	1.410	0.288	Master thesis
204	Carlsen, 1989	0.480	0.222	Doctoral dissertation
205	Amponsah & Ochongor, 2016	0.891	0.291	Conference paper
206	Pabuçcu & Geban, 2015	1.292	0.192	Journal article
207	Çaycı, 2018	0.972	0.200	Journal article
208	Asana, 2020	0.769	0.285	Master thesis
209	Hanson & Seheri-Jele, 2019	0.485	0.238	Journal article
210	İşcan, 2020	1.291	0.339	Master thesis
211	Gürkan, 2021	0.324	0.249	Master thesis
212	Perdana et al., 2018	0.646	0.216	Conference paper
213	Çıbık, 2011	0.758	0.229	Doctoral dissertation
214	Kılıç, 2007	0.453	0.296	Master thesis
215	Okur, 2009	0.614	0.317	Master thesis
216	Uzun, 2010	2.014	0.351	Doctoral dissertation
217	Dilber, 2006	1.116	0.219	Doctoral dissertation
218	Bayar, 2009	0.209	0.271	Master thesis