

## The Duo Conceptual Change Model (CCM) Multimodal Learning: A Pedagogical Innovation for Conceptual Change and Misconception Reduction

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Elementary students often hold persistent misconceptions about plant structure, photosynthesis, and reproduction, which hinder the development of scientific literacy. Traditional teaching methods rarely address these misconceptions effectively. The Duo CCM Science Learning Model, which integrates the Conceptual Change Model and the Cognitive Conflict Model, provides a structured framework for overcoming these challenges. This study investigates the effectiveness of the Duo CCM, supported by multimodal resources (two-tier diagnostic tests, flipbooks, flashcards, and mind maps), in reducing misconceptions and enhancing student engagement in elementary science learning. Six research questions guided the study, focusing on the comparative effectiveness of each modality (RQ1–RQ5) and the role of engagement (RQ6). A quasi-experimental design was implemented with 188 fourth-grade students across four schools in Yogyakarta. Students were assigned to experimental groups, each using a different multimodal tool, and to a control group. Data were collected through validated two-tier diagnostic instruments and analyzed using descriptive statistics, independent-samples t-tests, and the Kruskal–Wallis test. Experimental groups outperformed controls ( $M = 92.59$  vs.  $87.09$ ). Flipbooks showed significant improvement ( $p = 0.03 < 0.05$ ), flashcards produced the strongest overall gains, while mind maps yielded weaker outcomes due to cognitive load. Across groups, True–True (T–T) responses increased, and engagement improved across behavioral, cognitive, emotional, and metacognitive dimensions. Integrating conceptual change pedagogy with multimodal supports enhances conceptual understanding, reduces misconceptions, and fosters multidimensional engagement. This study contributes theoretically to conceptual change pedagogy and practically to participatory elementary science instruction.

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## **Introduction**

Elementary science education plays a strategic role in fostering early scientific literacy, particularly on plant-related topics such as plant structure, reproduction, and photosynthesis. Mastery of these fundamental concepts is essential, as plants constitute the foundation of life on Earth by supplying oxygen, food, and medicine, while maintaining ecological balance (California Foundation for Agriculture in the Classroom, 2013). Plant material is also directly relevant to daily life and the environment, for example, in horticulture, such as fruits and vegetables (Kwon, 2021). Despite this close connection to students' real-world experiences, numerous studies indicate that misconceptions remain widespread among elementary students. For instance, many believe that roots function only to anchor plants, overlooking their role in absorbing water and nutrients (Science and Plants for Schools, 2004).

Recent research shows that students' mental representations of plants are often simplistic, focusing primarily on flowers, leading to an incomplete understanding of reproduction and photosynthesis (Oesterlin, 2022). Photosynthesis, however, is a fundamental biological process through which plants convert light energy into chemical energy, supporting both plant growth and the survival of humans and animals (Muhammad, 2024). A limited understanding of this process leads students to fail to appreciate plants' critical role in addressing global challenges such as food security and climate change (Compan et al., 2025).

Strengthening elementary science education on plants is therefore crucial, both to meet curriculum standards and to reduce misconceptions from an early stage. Such efforts provide a foundation for scientific literacy, ecological awareness, and sustainable environmental attitudes. Addressing misconceptions requires innovative pedagogical approaches grounded in active engagement and conceptual reconstruction, enabling students to revise prior beliefs and build scientifically accurate understanding. Empirical evidence confirms that misconceptions about plant structure, photosynthesis, and reproduction remain high among elementary learners.

For example, Anderson et al. (2017) reported that younger children often hold overly simplistic views of plant structure, with many unaware of the absorptive function of roots or the transport role of stems. Misconceptions about plant growth include the assumption that plants require only water or that plant parts lack distinct functional roles. A study in Slovenia found that students aged 11–14 still struggled to understand where photosynthesis occurs, how light energy transforms into chemical energy, and the role of chlorophyll, despite prior instruction (Dimec & Strgar, 2017). Another revealed that about 25% of students held misconceptions about plant structure and 40.63% about photosynthesis, including its timing, organs involved, and relationship to growth (Nurbaety et al., 2016).

Lampert et al. (2019) also found that many students failed to differentiate between vegetative and generative reproduction and did not fully understand processes from pollination to seed formation. Research in Yogyakarta further confirmed high levels of misconceptions: plant parts (59%), photosynthesis (56.19%), and reproduction (57.46%) (Ariffia & Kurniawati, 2025; Hutami & Kurniawati, 2025; Prastyani & Kurniawati, 2025; Putri & Kurniawati, 2025). These findings demonstrate that misconceptions about plant material are not only a local issue but also a global phenomenon requiring innovative pedagogical solutions.

Traditional teaching, often dominated by lectures and rote memorization, has proven ineffective in addressing deeply rooted misconceptions (Wynn et al., 2017). While such methods may improve factual recall, they rarely offer students opportunities to confront and revise their misconceptions. Contributing factors also include inadequate learning resources, such as



worksheets, media, and teaching materials, that are not aligned with students' needs (Ariffia & Kurniawati, 2025; Hutami & Kurniawati, 2025; Prastyani & Kurniawati, 2025; Putri & Kurniawati, 2025). These gaps highlight the urgent need for pedagogical innovations that can actively engage students in conceptual change.

The Duo CCM Science Learning Model offers such an innovation. It integrates the Conceptual Change Model, which emphasizes restructuring students' conceptual frameworks, with the Cognitive Conflict Model, which creates cognitive dissonance to challenge prior ideas. This synergistic model, called Duo CCM, systematically reduces misconceptions through six stages: (1) detection, (2) experimentation, (3) formulation, (4) discussion, (5) reconstruction, and (6) evaluation. When implemented with two-tier diagnostic tests, Duo CCM can uncover students' misconceptions in depth. Meanwhile, flipbooks support active exploration of scientific processes, flashcards enhance memory and visual understanding, and mind maps facilitate structured and comprehensive knowledge representation.

The novelty of this study lies in the systematic integration of a conceptual change-based learning model with multimodal supports, including diagnostic instruments and interactive visual media. Previous studies have rarely combined these elements at the elementary level. This study demonstrates how such integration can simultaneously diagnose, confront, and reconstruct students' misconceptions, thereby contributing theoretically to conceptual change pedagogy and practically to early science education. Methodologically, the study bridges a gap in current practice, which remains dominated by memorisation, by offering an evidence-based approach that can detect and systematically reduce misconceptions. These findings are expected to advance participatory, innovative, and transformative science pedagogy.

### ***Purpose and significance of the study***

The primary purpose of this study is to examine the effectiveness of the Duo CCM Science Learning Model, supported by multimodal resources, in reducing elementary students' misconceptions and strengthening their conceptual understanding of plant-related topics. In line with this aim, the study addressed the following research questions:

RQ1: Is there a difference in misconception reduction between students who participated in the Duo CCM Science Learning Model with a two-tier diagnostic test and those in the control group?

RQ2: Is there a difference in misconception reduction between students who participated in the Duo CCM Science Learning Model supported by a flipbook and those in the control group?

RQ3: Is there a difference in misconception reduction between students who participated in the Duo CCM Science Learning Model supported by flashcards and those in the control group?

RQ4: Is there a difference in misconception reduction between students who participated in the Duo CCM Science Learning Model supported by mind maps and those in the control group?

RQ5: Are there differences in effectiveness among the four multimodal supports—two-tier diagnostic test, flipbook, flashcards, and mind maps—when integrated with the Duo CCM Science Learning Model in reducing misconceptions?

RQ6: How does the implementation of the Duo CCM Science Learning Model foster elementary students' engagement in science learning?

Accordingly, the study seeks to determine whether significant differences exist in misconception reduction between students taught using the Duo CCM combined with (a) two-tier diagnostic tests, (b) flipbooks, (c) flashcards, and (d) mind maps, compared to control classes (RQ1–RQ4). It also investigates the relative effectiveness of these four multimodal supports in promoting conceptual change (RQ5). This study adopts the multidimensional student engagement framework proposed by Sinatra et al. (2015), who conceptualize engagement in science learning as an interplay of behavioral, emotional, cognitive, and metacognitive processes. In this framework, students' involvement in learning extends beyond observable participation to include affective responses, strategic thinking, and metacognitive regulation (RQ6).

This research builds on a prior study conducted by Wahyu Kurniawati, the developer of the Duo CCM model, which focused on reducing elementary students' misconceptions in 2023. The earlier study recommended further innovation in science teaching practices by integrating Duo CCM with varied multimodal supports and applying the model to other scientific topics with characteristics similar to those of plant-related concepts.

## **Literature Review**

### ***Misconceptions in Science Education: Plant Material***

Misconceptions are erroneous conceptions that students regard as true and that often persist despite formal instruction (Duit, R., & Treagust, 2003; Treagust, 1988). They may arise from limited conceptual understanding (Andini & Kurniawati, 2024) or from changes in interpretation that deviate from scientific explanations (Rahmawati & Kurniawati, 2024). Common misconceptions in plant science include the belief that roots function solely to anchor plants, that photosynthesis occurs continuously in the absence of light, or that plants are represented exclusively by their flowers (Mahdiyah et al., 2021; Oesterlin, 2022).

Empirical studies indicate that such misconceptions are widespread. Research in Indonesia found that 40.63% of elementary students held misconceptions about photosynthesis, while approximately 25% held misconceptions about plant structure (Nurbaety et al., 2016). Comparable findings were reported in Europe, where students aged 11–14 struggled to understand the location of photosynthesis and the role of chlorophyll, despite formal instruction (Dimec & Strgar, 2017). These studies underscore that misconceptions in plant-related concepts are not limited to local contexts but constitute a global challenge. Addressing them requires targeted strategies and innovative pedagogical approaches that actively engage students in conceptual change.

### ***Conceptual Change Model (CCM) Theory***

The Conceptual Change Model (CCM) emphasizes the importance of students recognizing inconsistencies between their prior conceptions and scientifically accepted ideas, and subsequently reconstructing their knowledge. Conceptual change is triggered when students encounter anomalies that their existing mental models cannot explain. The CCM is effective in addressing misconceptions when combined with active learning strategies, such as experimentation, discussion, and visual media (Lensmire, 1993). Fundamentally, CCM is a pedagogical approach designed to restructure students' pre-existing concepts (Posner et al., 1982).

However, the model does not explicitly describe the mechanisms underlying the emergence of



conceptual conflicts or intellectual inconsistencies. Such conflicts arise when students' prior knowledge is incompatible with new experiences, often resulting in persistent misconceptions. To address this issue, the Cognitive Conflict Model (CCM) provides a framework for explaining how learners confront and resolve these discrepancies. This model highlights the role of cognitive conflict in driving conceptual change, helping students reconcile external experiences with their prior understanding. By engaging learners in stages of cognitive disequilibrium, the Cognitive Conflict Model enables them to adapt and construct more scientifically accurate knowledge structures.

### ***Conflict Cognitive Model Theory***

The Cognitive Conflict Model induces intellectual disequilibrium when students encounter facts or phenomena that challenge their existing beliefs. Such conflict compels students to re-evaluate their initial conceptions, thereby creating opportunities for conceptual change (Pratiwi et al., 2019). In elementary science education, simple experiments are particularly effective in triggering cognitive conflict, as they enable students to directly confront discrepancies between their prior conceptions and observable evidence through demonstrations or probing questions that challenge their predictions.

Cognitive conflict arises during information processing when new information cannot be readily integrated into short-term memory in alignment with students' existing long-term knowledge, prompting them to reconsider their understanding. Two typical patterns of cognitive conflict can be identified:

- Error → cognitive conflict → equilibrium → solve the problem
- Error → cognitive conflict → equilibrium → can't solve the problem

Thus, cognitive conflict should not be viewed merely as an obstacle but as a critical learning strategy. It plays a significant role in enhancing conceptual understanding, fostering conceptual change, and cultivating students' critical thinking and reasoning skills (Limón, 2001).

### ***Integration of the Duo CCM Science Learning Model***

The integration of the Conceptual Change Model (CCM) and the Cognitive Conflict Model (CCM) has led to the development of Duo CCM, a synergistic approach designed to reduce student misconceptions systematically. While the CCM provides a structured framework for knowledge reconstruction, the Cognitive Conflict Model stimulates students' internal motivation to modify their prior conceptions. A recent study by Prasad et al. (2025) demonstrated that combining cognitive conflict with conceptual reconstruction effectively reduces misconceptions about plant growth among elementary students.



**Figure 1.** Duo CCM Syntax

The Duo CCM framework consists of six stages (see Figure 1): Detection, Experimentation, Formulation, Discussion, Reconstruction, and Evaluation. By integrating cognitive conflict with conceptual reconstruction, this model enables students to confront contradictions between their prior beliefs and scientifically accepted explanations. Through guided discussions, hands-on experiments, and reflective activities, supported by multimodal learning tools such as flipbooks, worksheets, flashcards, and mind maps, Duo CCM facilitates the development of accurate scientific understanding (Kurniawati et al., 2023).

## **Method**

### ***Research design***

This study employed a quasi-experimental, non-equivalent control group pretest–posttest design, selected for its relevance to the research objectives and the practical constraints of randomization in educational settings. Nevertheless, the intervention's impact was systematically assessed using pretest–posttest measures to evaluate its effectiveness as an instructional intervention (Creswell & Creswell, 2018).

The independent variable was the Duo CCM Science Learning Model, integrated with multimodal learning supports, including two-tier diagnostic tests, flipbooks, flashcards, and mind maps, to reduce students' misconceptions. The study was conducted with elementary students in Yogyakarta during the 2024/2025 academic year, focusing on science lessons covering plant structure, photosynthesis, and reproduction.

### ***Research population and sample***

The study population comprised all fourth-grade students at public and private elementary schools. The selection of research sites was conducted through purposive sampling, guided by methodological considerations to ensure theoretical and practical relevance to the research objectives (Palinkas et al., 2015). Schools were purposively chosen to represent both

public and private institutions, encompass diverse socioeconomic contexts and facilities, maintain curriculum comparability, and secure institutional and teacher collaboration.

This sampling strategy aligns with best practices in educational intervention research, allowing the testing of pedagogical models in authentic contexts and supporting the generalization of findings to comparable settings (Olsen et al., 2013; Palinkas et al., 2015; Shadish et al., 2002). To reduce potential bias stemming from non-random site selection, the study examined and compared the initial equivalence of the experimental and control groups.

The study involved 188 students, 93 in the experimental group and 95 in the control group, selected through cluster sampling. This non-random approach aligns with the study design and ensures contextual realism in the results (Creswell, 2014). Details of the samples used in this study are shown in Table 1.

**Table 1.** Research Sample

Elementary School	n		Pedagogical Innovation
	Experiment	Control	
School 1	25	25	Duo CCM + Two-tier
School 2	22	22	Duo CCM + Flipbook
School 3	19	21	Duo CCM + flashcard
School 4	27	27	Duo CCM + Mind Map

### **Data collection tools**

Data were collected using a 20-item, two-tier diagnostic test designed to assess students' conceptual understanding and misconceptions regarding plant parts, reproduction, and photosynthesis. To capture students' engagement during the implementation of the Duo CCM multimodal learning model, a structured classroom observation instrument was employed. The observation sheet was designed based on the engagement framework proposed by Sinatra et al. (2015) and encompassed four dimensions of student engagement: behavioral, cognitive, emotional, and metacognitive engagement. The instrument consisted of 16 observable indicators, with each engagement dimension represented by four indicators. The indicators were operationalized to reflect students' observable behaviors, reasoning processes, emotional responses, and reflective activities occurring across the six instructional stages of Duo CCM (Detection, Experimentation, Formulation, Discussion, Reconstruction, and Evaluation).

Each indicator was assessed using a 4-point Likert-type rating scale, ranging from 1 (not observed), 2 (rarely observed), 3 (frequently observed), to 4 (consistently observed), allowing for systematic quantification of students' engagement levels during classroom activities. Classroom observations were conducted independently by two trained raters. To ensure the Reliability of the observational data, inter-rater Reliability was examined using Cohen's kappa coefficient. The analysis yielded a kappa value of 0.71, indicating acceptable agreement between raters. Before data collection, the raters participated in calibration sessions to establish a shared understanding of the observation criteria and scoring procedures.

The diagnostic test consisted of two tiers: The first contained multiple-choice items assessing conceptual knowledge, while the second required students to justify their responses, enabling evaluation of both answer accuracy and reasoning patterns. The initial 60-item instrument underwent expert review and subsequent empirical validation with 91 fifth-grade students from two public elementary schools. Item validity was determined using Pearson's correlation

( $r_{count} > r_{table}$ ,  $\alpha = 0.05$ ,  $df = 89$ ), while reliability was measured with Cronbach's alpha in SPSS. Expert feedback was incorporated to refine the instrument prior to empirical testing (see Table 2).

**Table 2.** Validation test results using Pearson correlation

Sub-material	Misconception Indicators	Reduction Item	$r_{table}$	$r_{count}$	Sig	Decision
Parts of a plant	Examining plant parts	Item 1	.202	.459**	.000	Valid
		Item 2	.202	.412**	.000	Valid
		Item 3	.202	.420**	.000	Valid
	Types of roots	Item 4	.202	.506**	.000	Valid
		Item 5	.202	.389**	.000	Valid
		Item 6	.202	.234*	.023	Valid
	Functions/uses of roots	Item 7	.202	.451**	.000	Valid
		Item 8	.202	.554**	.000	Valid
		Item 9	.202	.536**	.000	Valid
	Types of stems	Item 10	.202	.421**	.000	Valid
		Item 11	.202	.482**	.000	Valid
		Item 12	.202	.169	.102	Invalid
	Functions of stems	Item 13	.202	.205*	.046	Valid
		Item 14	.202	.542**	.000	Valid
		Item 15	.202	.420**	.000	Valid
	Types of leaves according to their shape	Item 16	.202	.369**	.000	Valid
		Item 17	.202	.239**	.020	Valid
		Item 18	.202	.370**	.000	Valid
	Functions of leaves	Item 19	.202	.561**	.000	Valid
		Item 20	.202	.571**	.000	Valid
		Item 21	.202	.620**	.000	Valid
	Functions of flower parts	Item 22	.202	.590**	.000	Valid
		Item 23	.202	.646**	.000	Valid
		Item 24	.202	.218**	.034	Valid
	Identifying flower parts	Item 25	.202	.520**	.000	Valid
		Item 26	.202	.117	.258	Invalid
		Item 27	.202	.652**	.000	Valid
	Photosynthesis is the most important process on Earth	Item 28	.202	.471**	.000	Valid
		Item 29	.202	.481**	.000	Valid
		Item 30	.202	.524**	.000	Valid
The result of photosynthesis	Item 31	.202	.597**	.000	Valid	
	Item 32	.202	.793**	.000	Valid	
	Item 33	.202	.663*	.000	Valid	
Factors in the photosynthesis process	Item 34	.202	.200	.052	Invalid	
	Item 35	.202	.483**	.000	Valid	
	Item 36	.202	.220*	.032	Valid	
The process of photosynthesis	Item 37	.202	.700**	.000	Valid	
	Item 38	.202	.553**	.000	Valid	
	Item 39	.202	.654**	.000	Valid	
		Item 40	.202	.644**	.000	Valid
		Item 41	.202	.677**	.000	Valid

Sub-material	Misconception Indicators	Reduction	Item	r <sub>table</sub>	r <sub>count</sub>	Sig	Decision	
Plant reproduction	The benefits of plants for living things		Item 42	.202	.726**	.000	Valid	
			Item 43	.202	.440**	.000	Valid	
			Item 44	.202	.722**	.000	Valid	
								Valid
	The process of plant reproduction		Item 45	.202	.552**	.000		
			Item 46	.202	.270**	.008	Valid	
			Item 47	.202	.145	.160	Invalid	
		Perfect and imperfect flowers		Item 48	.202	.658**	.000	Valid
				Item 49	.202	.691**	.000	Valid
			Item 50	.202	.554**	.000	Valid	
			Item 51	.202	.665**	.000	Valid	
			Item 52	.202	.379**	.000	Valid	
	Various methods of seed dispersal		Item 53	.202	.528**	.000	Valid	
			Item 54	.202	.597**	.000	Valid	
			Item 55	.202	.224*	.029	Valid	
			Item 56	.202	.490**	.000	Valid	
	Relating living things to their components		Item 57	.202	.438**	.000	Valid	
			Item 58	.202	.396**	.000	Valid	
			Item 59	.202	.417**	.000	Valid	
		Item 60	.203	.454**	.000	Valid		

Table 2 shows that 56 items were valid and four were invalid. The test demonstrated high reliability (Cronbach's alpha = 0.988). Based on these results, 28 representative items were selected to measure students' misconception reduction, with consideration given to balancing test duration with elementary students' attention span to ensure fairness and accurate responses (Chan et al., 2023; Rençber & Genç, 2024). The selected items were representative in principle, ensuring that all subtopics and indicators were covered proportionally while avoiding redundancy within any single indicator (Ryoo et al., 2022).

### Test Structure

Examples of test items that were not selected in the measurement instrument because they were already represented in other items are:

- Test number : 35
- Sub-topic : Photosynthesis
- Misconception reduction indicator : The result of photosynthesis
- Test statement Tier 1 : The main site of photosynthesis in plants is ....
  - a. Roots
  - b. Stems
  - c. Leaves
  - d. Flowers
- Test statement Tier 2 : Reason:
  - a. Because leaves have chlorophyll that can capture energy from sunlight
  - b. Because roots absorb water, photosynthesis occurs in the roots
  - c. Because stems transport water, photosynthesis occurs in the stems

- d. Because flowers produce nectar, photosynthesis occurs in the flowers

### ***Data analysis***

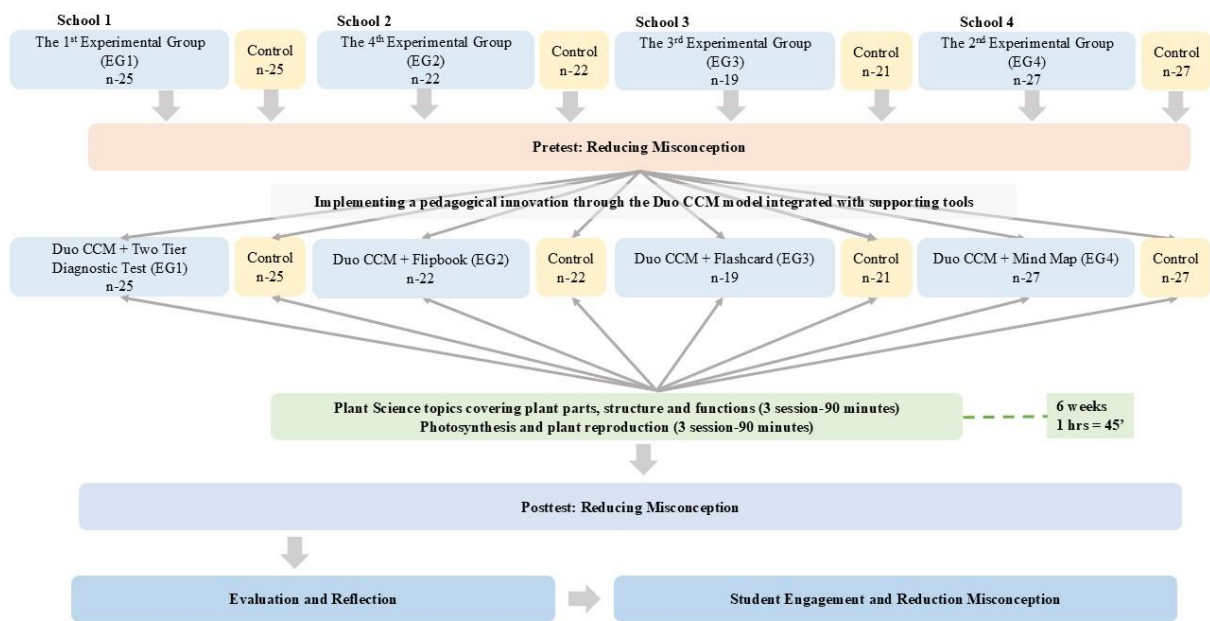
Data were analyzed using both descriptive and inferential statistics. The descriptive analysis calculated the percentage of misconceptions before and after Duo CCM implementation, categorized misconceptions by level (high, medium, low), and evaluated student engagement. Inferential analysis compared the experimental and control groups using independent-samples t-tests. Differences in effectiveness among the Duo CCM, two-tier diagnostic test, flipbook, flashcard, and mind map conditions were assessed using one-way ANOVA; when assumptions for parametric tests were not met, the Kruskal–Wallis test was employed (Field, 2017). This approach also controlled for the inflated error rate associated with repeated t-tests (Creswell & Creswell, 2018). Prior to hypothesis testing, assumption checks were conducted to ensure the appropriateness of parametric analyses.

### ***Experimental process***

The intervention consisted of six 90-minute sessions delivered over the first semester. Each session followed the three stages of the Duo CCM model: (1) Clarifying Concepts, where students activated prior knowledge and identified initial misconceptions; (2) Constructing Meaning, involving guided inquiry activities, collaborative problem solving, and concept explanation; and (3) Monitoring Understanding, where students reflected on their learning and revised their conceptual representations.

Each experimental group completed the same instructional sequence, but with different learning tools supporting the Duo CCM stages: two-tier diagnostic items (EG1), flipbook (EG2), flashcards (EG3), and mind map (EG4). A direct instruction model was used for the control groups.

The implementation of Duo CCM, supported by diverse tools, represents a pedagogical innovation in elementary science education. This approach emphasizes conceptual restructuring and cognitive conflict as the core processes of Duo CCM, while strengthening the learning experience through validated diagnostic instruments and varied, interactive learning media. As illustrated in Figure 2, the implementation of the Duo CCM model enhanced students' engagement across all four dimensions

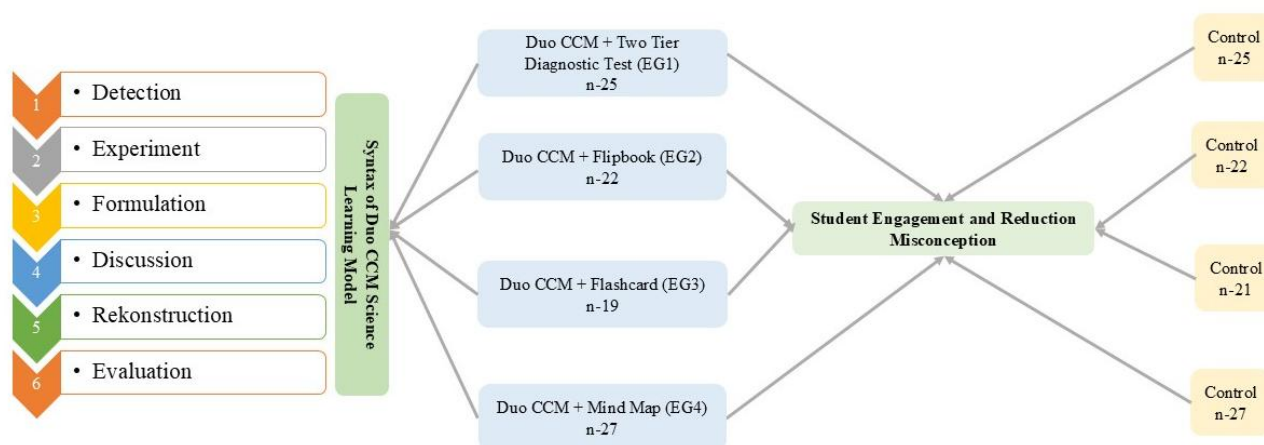


**Figure 2.** Experimental Process

### *Teaching environment to engage students*

The application of the Duo CCM Science Learning Model syntax fosters an effective learning environment that enhances student engagement while reducing misconceptions. The model consists of six core stages: detection, experimentation, formulation, discussion, reconstruction, and evaluation. In the detection stage, teachers create learning situations that encourage students to articulate their initial conceptions. This stage is critical, as engagement increases when students perceive that their prior ideas are acknowledged and utilized as a foundation for learning (Kosel et al., 2021). The experiment stage introduces cognitive conflicts that stimulate curiosity, followed by formulation and discussion activities that promote collaborative interaction as students compare and refine their ideas.

This learning environment is further enhanced by supporting tools such as two-tier diagnostic tests (to identify misconceptions), mind maps (to reinforce conceptual connections), flashcards (to facilitate visual repetition), and flipbooks (to provide multimodal learning experiences). Recent studies indicate that flashcards are particularly effective instructional aids in elementary schools, as they increase enthusiasm, strengthen retention of science concepts, and improve science learning outcomes (Wati & Mahendra, 2025). An environment that incorporates experimentation, discussion, and reflection has also been shown to foster both cognitive and social engagement. These include associative and cooperative interactions, high-level challenge instruction, and teachers' responsiveness to student ideas, all of which are strongly associated with greater student engagement (Christopher & Newman, 2022). In the final stages, reconstruction and evaluation reinforce scientifically accurate concepts and provide opportunities for reflection, enabling students to reconstruct their understanding and evaluate the transition from misconceptions to accurate conceptions. The learning environment created through the characteristics and syntax of Duo CCM is illustrated in Figure 3.



**Figure 3.** Teaching environment to engage students

The learning environment created by Duo CCM, implemented through multimodal approaches such as media, teaching materials, mind maps, and other relevant supports, has the potential to enhance student engagement at the social, emotional, and cognitive levels. Moreover, the characteristics and syntax of the Duo CCM model can accelerate the reduction of misconceptions, as students are actively involved in receiving information, testing their ideas, and revising their understanding.

## Result

Recent meta-analyses and systematic reviews show that interventions targeting conceptual change through cognitive conflict consistently outperform conventional expository methods in correcting misconceptions. Strategies such as refutational texts, anomaly-based demonstrations, and guided discussions have proven effective, supporting the rationale for applying the Duo CCM approach in this study to enhance elementary students' understanding of plant growth. The meta-analyses and recent experimental studies by Aleknavičiūtė et al. (2023) show that conceptual change strategies have positive, significant effects on misconceptions compared to traditional learning.

Recent studies on multimodal learning demonstrate that integrating interactive and organized visual media—such as mind maps, worksheets, flipbooks, and flashcards—enhances students' cognitive and affective engagement and strengthens concept retention (Çeken & Taşkın, 2022). Systematic reviews from 2023–2024 indicate that combining these multimodal resources with active instructional strategies supports effective knowledge reconstruction, providing a strong rationale for implementing the Duo CCM approach in this study (Naimah, 2022).

### ***Descriptive analysis of pre- and post-test data (n participants=188)***

Based on the results of the descriptive analysis of the implementation of the Duo CCM science learning model with Two-Tier Diagnostic Test as the 1<sup>st</sup> experimental group (EG1 n=25) and Control Group (CG n=25) at School 1, Flipbook as the 2<sup>nd</sup> experimental group (EG2 n=22) dan Control Group (CG n=22) at School 2, Flashcard as the 3<sup>rd</sup> experimental group (EG3 n=19), and Control Group (CG n=21) at School 3, mind map as the 4<sup>th</sup> experimental group (EG4 n=27) Control Group (CG n=27) at School 4.

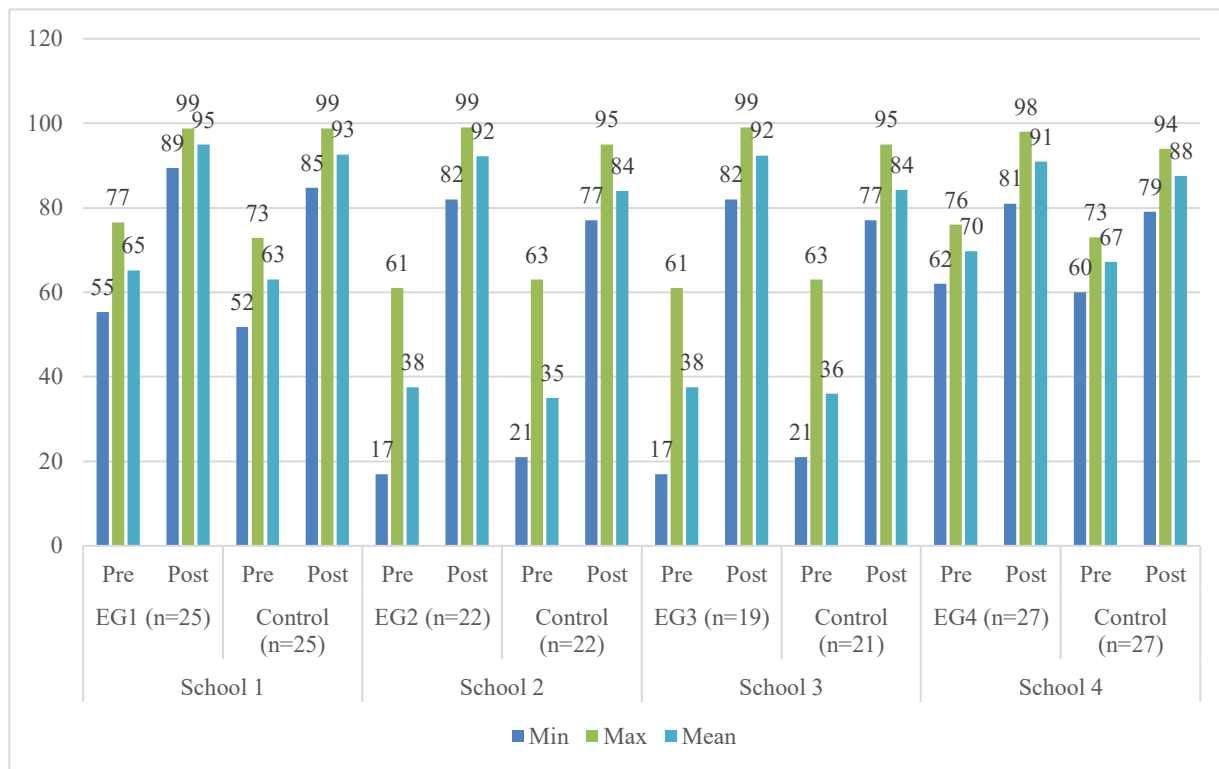


Figure 4. Descriptive Analysis Results

Based on the descriptive analysis results in Figure 4, the average implementation of Duo CCM across various supporting devices is a pretest average of 52.49 and a posttest average of 92.59. At the same time, the control group has a pretest average of 50.29 and a posttest average of 87.09. A visualization of the descriptive analysis results is shown in Figure 4, which compares pretest and posttest scores for the Duo CCM science learning model implementation.

**Effectiveness of Duo CCM Across Multimodal Conditions (RQ1–RQ4)**

The inclusion of qualitative effect-size estimates allows for a more meaningful comparison of the relative strength of each modality in reducing misconceptions. These findings directly address Research Questions 1–4, which examine whether each multimodal integration within the Duo CCM model leads to significantly better outcomes than traditional instruction. Table 3 summarizes the results of normality testing, homogeneity testing, and independent-samples t-tests conducted to compare each experimental group (EG1–EG4) with the control group.

**Table 3.** Summary of normality, homogeneity, t-test results, and effect size interpretation

Comparison	Shapiro–Wilk Normality (EG)	Shapiro–Wilk Normality (CG)	Levene's Homogeneity	p-value (t-test)	Effect Size Category	Interpretation
EG1 (Two-Tier) vs CG	0.24	0.29	0.52	0.94	Negligible	No meaningful difference; the two-tier tool did not outperform the control.

EG2 (Flipbook) vs CG	0.48	0.06	0.32	0.03	Small–Moderate	Flipbook integration produced a statistically significant improvement over the control.
EG3 (Flashcards) vs CG	0.40	0.72	0.50	0.06	Moderate	Flashcards show practically meaningful gains, though marginal in significance.
EG4 (Mind Map) vs CG	0.62	0.17	0.20	0.65	Negligible	The mind-map condition did not differ significantly; high cognitive load likely reduced its impact.

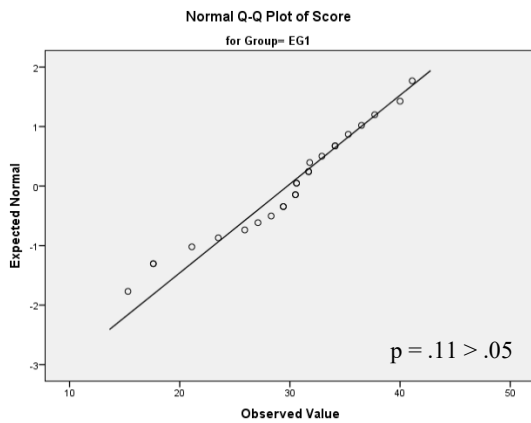
**Testing the Duo CCM science learning model with a two-tier diagnostic test, flipbook, flashcards, and mind maps (RQ5)**

Based on the descriptive analysis of the Duo CCM science learning model implementation with its various supporting materials, the results are presented in Table 4.

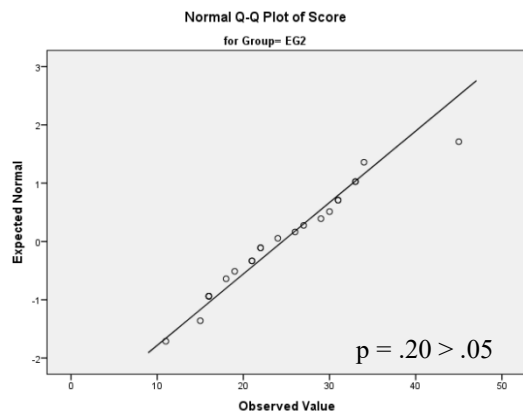
**Table 4.** Descriptive Analysis Results

	n	Mean	STD	Confidence Interval (95)	Min	Max
EG1	25	29,77	6,70	27,00 – 32,54	15,30	41,10
EG2	22	24,54	8,16	20,93 – 28,16	11,00	45,00
EG3	19	54,84	10,91	49,58 – 60,10	32,00	69,00
EG4	27	21,15	6,95	18,40 – 23,90	5,00	34,00

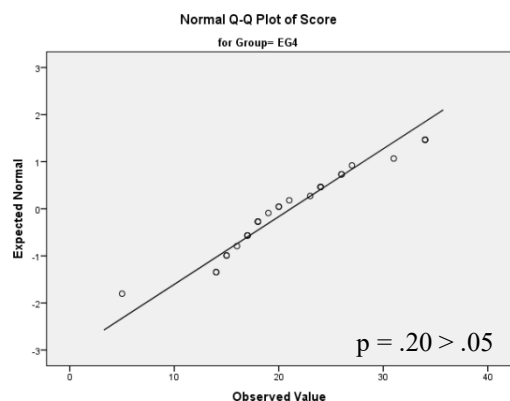
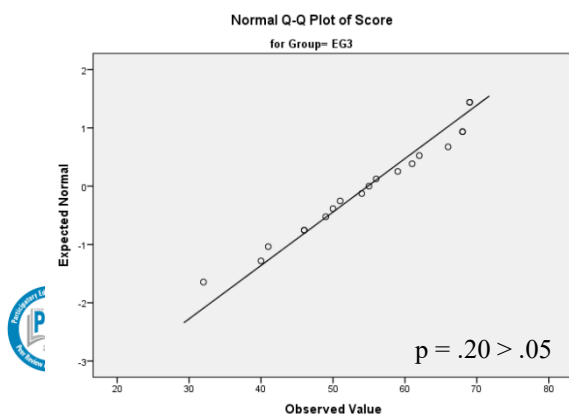
Table 3 shows that EG3 outperformed the other groups, with the highest mean score (54.84) and the widest range, while EG4 scored lowest (21.15, minimum 5.00). EG1 and EG2 performed moderately but below EG3. Confidence intervals confirm significant differences, and a total SD of 14.83 indicates high variability. Kolmogorov-Smirnov tests and Q-Q plots confirm that the normal distribution across the groups is evident in Figure 5.



(a)



(b)



**Figure 5.** Output Normalization Probability Plots of the (a) 1st Experiment-EG 1 (Duo CCM+two tier), (b) 2nd Experiment-EG2 (Duo CCM+flipbook), (c) 3rd Experiment-EG3 (Duo CCM+flashcard), and (d) 4th Experiment-EG4 (Duo CCM+Mind Map)

Figure 5 indicates that data from the four classes are normally distributed ( $p > 0.05$ ). Levene's test showed unequal variances ( $p = 0.04$ ). Given these results, parametric assumptions were not met, and group differences were analyzed using the nonparametric Kruskal-Wallis test, as shown in Table 5.

**Table 5.** Result of Kruskal-Wallis Test

	Score
Chi-Square	52.157
df	3
Asymp. Sig.	.000

Based on the results of the Kruskal-Wallis test, it is known that implementing the Duo CCM science learning model with a two-tier diagnostic test, flipbook, flashcards, and mind maps has a significance value of  $0.00 < 0.05$ . There is a significant difference between implementing the Duo CCM science learning model with a two-tier diagnostic test, flipbook, flashcards, and mind maps.

**Implementation of the Duo CCM Science Learning Model on Student Engagement**

Implementing the Duo CCM Science Learning Model provides a structured pathway for students to actively engage in scientific inquiry while simultaneously addressing and reducing misconceptions related to plant concepts. Each stage of the Duo CCM syntax—Detection, Experimentation, Formulation, Discussion, Reconstruction, and Evaluation—encourages multidimensional engagement (behavioral, cognitive, emotional, social, and metacognitive) that is crucial for transforming inaccurate conceptions into accurate scientific understanding. The results of the analysis of the implementation of Duo CCM on student engagement are shown in Table 6.

**Table 6.** Duo CCM on Student Engagement

Syntax	Process	Student Engagement	Misconception Reduction
Detection	Students are guided to observe and identify scientific phenomena or problems.	Stimulates behavioral engagement (active participation in observation) and emotional engagement (curiosity and interest)	Early misconceptions (e.g., "plants obtain food directly from the soil") are surfaced and made explicit.
Experiment	Students design and carry out experiments to test hypotheses	Enhances cognitive engagement (critical thinking, problem-solving) and behavioral engagement (hands-on activity)	Direct evidence challenges naive conceptions (e.g., plants "breathe like humans" instead of understanding gas exchange processes)



Syntax	Process	Student Engagement	Misconception Reduction
Formulation	Students formulate findings, models, or temporary explanations based on experimental results.	Strengthens cognitive engagement (conceptual understanding, reasoning)	Learners replace superficial explanations with evidence-based scientific reasoning
Discussion	Students share findings, argue, and evaluate different perspectives in groups.	Improves social engagement (collaboration, communication) and emotional engagement (confidence, motivation)	Misunderstandings are corrected through peer interaction and teacher scaffolding.
Reconstruction	Students reconstruct knowledge by integrating results, theories, and peer input into a coherent understanding.	Deepens cognitive engagement (knowledge integration) and metacognitive engagement (reflection on learning)	Misconceptions are systematically reconstructed into accurate conceptual frameworks.
Evaluation	Students evaluate the whole process and outcomes, comparing them with initial assumptions.	Supports metacognitive engagement (self-assessment, reflection) and emotional engagement (sense of achievement)	Reflection consolidates corrected conceptions, preventing relapse into prior misunderstandings.

### Descriptive Analysis of the Reduction Misconception

#### True-True (T-T)

Table 7 shows the results of the descriptive analysis of reduction misconceptions in the experimental and control classes, based on T-T (True-True) answer patterns.

**Table 7.** Descriptive Analysis of T-T

Group	Plant Structure		Photosynthesis		Reproduction	
	Control	Experiment	Control	Experiment	Control	Experiment
EG1 (Two-Tier)	19.05	52.00	18.65	49.33	16.43	38.40
EG2 (Flipbook)	54.54	45.45	33.33	38.85	34.54	23.23
EG3 (Flashcard)	40.61	52.87	43.30	46.36	36.55	35.17
EG4 (Mind Map)	35.39	42.13	33.33	45.83	16.67	13.75

The T-T scores in the control and experimental classes were quite high across all groups. These results show that many students maintained correct answers. Effective learning interventions strengthen the consistency of student understanding.

#### False-True (F-T)

Table 8 presents the descriptive analysis of reduction misconceptions in the experimental and control classes, based on the F-T (False-True) answer pattern.

**Table 8.** Descriptive Analysis of F-T

Group	Plant Structure		Photosynthesis		Reproduction	
	Control	Experiment	Control	Experiment	Control	Experiment
EG1 (Two-Tier)	-11	-16	21	-20	-15	-20
EG2 (Flipbook)	-11	-15	-9	-12	-10	-13
EG3 (Flashcard)	-2	-3	-7	-11	-18	6
EG4 (Mind Map)	-8	-6	-2	-6	-2	-15

Most groups still recorded negative scores, indicating that many students failed to switch from incorrect to correct answers. EG3 (Flashcards) on Reproduction was the only real success, showing that this medium is more effective at overcoming misconceptions about reproduction than other strategies. There was a drastic decline in photosynthesis (especially EG1), indicating that the intervention needs to be evaluated.

### **True-False (T-F)**

Table 9 presents the results of the descriptive analysis of misconception reduction in the experimental and control classes based on True-False (T-F) answer patterns.

**Table 9.** Descriptive Analysis of T-F

Group	Plant Structure		Photosynthesis		Reproduction	
	Control	Experiment	Control	Experiment	Control	Experiment
EG1 (Two-Tier)	-23	-16	-25	-19	-25	-23
EG2 (Flipbook)	-13	-14	-13	-10	-11	-13
EG3 (Flashcard)	-7	-9	-18	-15	-40	-17
EG4 (Mind Map)	-16	-18	-38	-26	-5	-7

The main problem with T-F is that many students who initially answered correctly changed their answers to incorrect (all negative scores). The results show extreme cases in the control class for reproduction material (-40) at School 3 and photosynthesis material (-38) at School 4. The analysis results in the experimental class show a decrease in students who changed from correct to incorrect answers. Although the scores were negative, the pattern indicates that the intervention reduced the occurrence of new errors.

### **False-False (F-F)**

Table 10 presents the results of the descriptive analysis of misconception reduction in the experimental and control classes, based on the False-False (F-F) answer pattern.

**Table 10.** Descriptive Analysis of F-F

Group	Plant Structure		Photosynthesis		Reproduction	
	Control	Experiment	Control	Experiment	Control	Experiment
EG1 (Two-Tier)	-3	-13	-3	-8	-4	-7
EG2 (Flipbook)	-27	-15	-9	-13	-13	-8
EG3 (Flashcard)	-32	-30	-18	-21	-15	-28
EG4 (Mind Map)	-10	-15	-4	-13	-3	-4

Scores in the control class were variable and generally low, whereas experimental groups showed more stable outcomes despite some persistent incorrect responses. Some students continued to answer incorrectly even after the intervention, indicating residual misconceptions.

Based on the results of the descriptive analysis of T-T, F-T, T-F, and F-F, it is evident that T-T increased significantly, indicating that the Duo CCM science learning model successfully reinforced correct answers to maintain accuracy and prevented students from switching from correct to incorrect answers.

## **Discussion**

This study provides empirical evidence that the Duo CCM Science Learning Model, combined with multimodal resources such as two-tier diagnostic tests, flipbooks, flashcards,

and mind maps, effectively enhances students' conceptual understanding and reduces plant-related misconceptions. Descriptive analysis showed increased True–True (T-T) responses across experimental groups, while shifts in False–True (F-T) and True–False (T-F) patterns were smaller than in controls, demonstrating Duo CCM's role in maintaining correct conceptions. Results for RQ1–RQ4 highlight nuanced differences across modalities.

Integrating two-tier diagnostic tests (EG1) was particularly valuable for uncovering hidden misconceptions, as this format required students to select answers and justify their reasoning. This diagnostic precision enabled teachers to tailor instructional responses more effectively, which explains the observed conceptual gains (Taşçi, 2024). The Duo CCM + two-tier condition did not differ significantly from the control ( $p = 0.94$ ). Two-tier tests function primarily as diagnostic tools to uncover students' reasoning rather than directly improve posttest scores. Their effectiveness depends on subsequent instructional follow-up, including discussion, refutation, and conceptual reconstruction, which are crucial for addressing hidden misconceptions (Duit & Treagust, 2003). Thus, even with strong diagnostics, the immediate effect on conceptual understanding may be limited without follow-up instruction that utilizes the diagnostic data.

Flipbooks (EG2) facilitated sequential visualization of processes, leading to modest improvements but not outperforming other modalities. Duo CCM+flipbook showed a significant difference compared to the control group ( $p = 0.03 < 0.05$ ). At the same time, other multimodal conditions did not yield statistically significant differences when compared individually with the control, suggesting that multimodal integration's effectiveness is context-dependent. By their nature, Flipbooks provide sequential visual representations of scientific processes (e.g., photosynthesis, plant reproduction). Such representations reduce abstraction, support temporal reasoning, and make invisible processes visible to learners. The evidence that sequential visualization enhances understanding of dynamic biological processes and supports conceptual restructuring (Tippett & Lee, 2019).

Flashcards (EG3) demonstrated the strongest outcomes, producing the highest posttest scores and the widest improvement ranges. It can be attributed to the well-documented benefits of retrieval practice, which enhances memory consolidation and long-term conceptual retention (Ophuis-Cox et al., 2023; Roediger & Butler, 2011). Although the CCM Duo + flashcards showed a high average increase and were practically promising, a direct comparison with the control group did not reach significance ( $p = 0.06 > 0.05$ ). It may be due to variations between students, a moderate effect size, or an insufficient intervention duration to produce a statistically measurable difference. Theoretically, flashcards represent retrieval practice, a strategy for remembering information without looking at the material, which reinforces memory pathways and strengthens long-term retention. Research has shown that retrieval practice consistently results in better retention and integration of new concepts than rereading or passive elaboration strategies (Adesope et al., 2017). Several laboratory studies have also shown that recall practice can strengthen inferential and scientific reasoning abilities, not just memorizing facts (Yaşar et al., 2022).

In contrast, mind maps (EG4) yielded the weakest performance, likely due to the high cognitive load required to construct and interpret complex relational structures, which can exceed the developmental readiness of elementary learners (Merchie et al., 2022). These findings underscore the importance of aligning multimodal strategies with students' cognitive capacities. The Duo CCM + mind map condition also showed no significant difference compared to the control ( $p = 0.20$ ). It can be explained by cognitive load theory: constructing concept maps

requires students to organize relationships between concepts and explicitly select nodes and connections. This metacognitive and reflective process can be burdensome for students at the elementary level. Merchie et al. (2022) note that the effectiveness of mind maps depends heavily on their design and students' cognitive readiness; if students have not been equipped with structure or practice, conceptual maps can sometimes become a burden rather than a help. Studies on retrieval-based concept mapping show that creating concept maps after retrieval can be more effective, but generating maps directly before or during retrieval may not offer any advantages over retrieval alone (Lechuga et al., 2024).

Regarding RQ5, the comparative analysis across modalities confirmed that not all multimodal tools are equally effective. While all versions of Duo CCM outperformed control conditions in reinforcing correct conceptions, the flashcard-supported model clearly offered superior benefits. This finding aligns with prior meta-analyses demonstrating that interventions grounded in conceptual change principles are more effective than traditional expository methods in correcting misconceptions (Aleknavičiūtė et al., 2023; Naimah, 2022). However, the variability in outcomes across modalities suggests that the sequencing and design of multimodal integration are critical to maximizing effectiveness.

Turning to RQ6, this study highlights the reciprocal relationship between student engagement and conceptual change. Each stage of the Duo CCM syntax—detection, experimentation, formulation, discussion, reconstruction, and evaluation—systematically activated behavioral, cognitive, emotional, and metacognitive engagement. Multidimensional involvement appears to be a key mechanism for reducing persistent misconceptions, as students confront conflicting evidence and actively negotiate meaning and reconstruct knowledge. These results support the argument that conceptual change interventions are most effective when embedded in interactive, student-centered environments, rather than through isolated content delivery (Li et al., 2023).

The findings also carry important pedagogical implications. First, strengthening correct conceptions (T-T) should be prioritized in instructional design, as they provide a stable foundation for subsequent learning. Second, while cognitive conflict is essential, scaffolding must be provided to ensure that misconceptions are not merely challenged but effectively replaced with scientifically accurate ideas. Third, multimodal resources should be employed flexibly to accommodate diverse learning preferences and to balance engagement with cognitive load.

Despite these promising outcomes, limitations should be acknowledged. Residual F-T and T-F shifts suggest that certain misconceptions persisted, implying that longer, repeated, or spaced interventions may be necessary. Additionally, variability across groups indicates that contextual factors—such as teacher facilitation, classroom dynamics, and students' prior knowledge—moderate the effectiveness of multimodal strategies. Future research should therefore investigate the optimal sequencing of multimodal resources, the role of scaffolding intensity, and the potential of adaptive designs that account for cognitive load at different developmental levels.

In conclusion, this study supports the theoretical and empirical claim that combining conceptual change strategies with multimodal learning environments constitutes a powerful approach to addressing misconceptions in science education. By directly answering RQ1–RQ6, the findings demonstrate that Duo CCM reduces misconceptions and fosters engagement, curiosity, and reflective reasoning, thereby contributing to the broader goal of cultivating durable scientific

literacy in primary education.

## **Conclusion**

This study provides empirical evidence that the Duo CCM Science Learning Model, integrated with multimodal supports such as two-tier diagnostic tests, flipbooks, flashcards, and mind maps, can effectively strengthen elementary students' conceptual understanding of plant-related topics while reducing persistent misconceptions. Findings showed that the experimental groups outperformed the control group ( $M = 92.59$  vs.  $87.09$ ). Significant differences were found between Duo CCM+flipbook and control ( $p = 0.03 < 0.05$ ). In contrast, in other experimental classes, there was no significant difference between the experimental and control classes: Duo CCM+two tier ( $p = 0.94 > 0.05$ ), Duo CCM+flashcard ( $p = 0.06 > 0.05$ ), and Duo CCM+mind map ( $p = 0.20 > 0.05$ ). Across all multimodal groups ( $p = 0.00 < 0.05$ ). The consistent increase in True–True (T–T) responses across experimental groups confirms that Duo CCM promotes the retention of scientifically accurate conceptions, while the reduced negative shifts compared to control groups highlight its protective role in minimizing the emergence of new errors. The findings further demonstrate that multimodal tools serve complementary functions, with flashcards proving particularly powerful through retrieval practice. At the same time, mind maps were less effective due to higher cognitive demands on younger learners. Importantly, the study also illustrates that conceptual change is closely tied to multidimensional engagement—behavioral, cognitive, emotional, and metacognitive—fostered by the iterative steps of the Duo CCM syntax.

Several limitations should be acknowledged. First, although improvements were observed, residual False–True (F–T) and True–False (T–F) shifts indicate that some misconceptions were not fully resolved within the intervention's limited duration. Second, the study was conducted in a specific elementary school context, and results may not generalize to different educational settings with varied curricula, teacher expertise, or student backgrounds. Third, the differential effectiveness of multimodal tools suggests that not all resources were equally accessible to learners at this developmental stage, raising questions about the role of cognitive load and prior training. Finally, the study focused primarily on short-term conceptual change without longitudinal follow-up to assess retention and transfer over extended periods.

Future research should consider extending intervention duration and adopting spaced or repeated practice designs to address entrenched misconceptions more effectively. Investigations into the sequencing and scaffolding of multimodal tools are warranted to optimize their cognitive and motivational benefits, particularly for complex visual organizers such as mind maps. Teacher professional development should be emphasized to equip educators with the skills to implement Duo CCM strategies effectively, diagnose misconceptions using two-tier instruments, and provide adaptive scaffolding. Longitudinal studies are also recommended to examine the sustainability of conceptual gains and their transfer to new scientific contexts. Finally, integrating Duo CCM with digital platforms may provide scalable opportunities to enhance engagement and personalization in elementary science education.

In conclusion, this study reinforces the potential of combining conceptual change pedagogy with multimodal supports to advance science learning at the elementary level. Beyond reducing misconceptions, Duo CCM nurtures engagement, reflective reasoning, and durable scientific literacy, offering both theoretical contributions to the field and practical guidance for improving science instruction worldwide.



## Declarations

### **Ethics Statements:**

This research has followed the ethical standards accepted by this journal.

### **Conflict of Interest:**

The author declares that there is no conflict of interest in this publication

### **Informed Consent:**

All participants have agreed to participate in this study, as stated in the information consent, with their real names removed.

### **Data Availability:**

All the data collected from the participants' test and observation results.

## Reference

- Adesope, O. O., Trevisan, D. A., & Sundararajan, N. (2017). Rethinking the Use of Tests: A Meta-Analysis of Practice Testing. *Review of Educational Research*, 87(3), 659–701. <https://doi.org/10.3102/0034654316689306>
- Aleknavičiūtė, V., Lehtinen, E., & Södervik, I. (2023). Thirty years of conceptual change research in biology – A review and meta-analysis of intervention studies. *Educational Research Review*, 41, 100556. <https://doi.org/10.1016/j.edurev.2023.100556>
- Anderson, J. L., Ellis, J. P., & Jones, A. M. (2017). Understanding early elementary children's conceptual knowledge of plant structure and function through drawings. *CBE—Life Sciences Education*, 13(3), 375–386. <https://doi.org/10.1187/cbe.13-12-0230>
- Andini, S. A., & Kurniawati, W. (2024). Identifikasi miskonsepsi dan penyebab miskonsepsi terhadap materi sifat-sifat pada pembelajaran sekolah dasar. (Identify misconceptions and causes of misconceptions regarding material on properties in elementary school learning). *Jurnal Natural Science Educational Research* 7 (1) 2024, 7(1), 14–19. <https://doi.org/https://doi.org/10.21107/nser.v7i1.23495>
- Ariffia, C. N., & Kurniawati, W. (2025). Tes diagnostik miskonsepsi peserta didik pada materi tumbuhan kelas IV sekolah dasar. (Diagnostic test of students' misconceptions on plant material in fourth grade elementary school). *Edukasi*, 17(01), 615–632.
- California Foundation for Agriculture in the Classroom. (2013). *Plant parts purpose*. <https://www.learnaboutag.org>
- Çeken, B., & Taşkın, N. (2022). Multimedia learning principles in different learning environments: a systematic review. *Smart Learning Environments*, 9(1), 19. <https://doi.org/10.1186/s40561-022-00200-2>
- Chan, W. K., Zhang, L., & Oon, E. (2023). Classroom assessment that tailor instruction and direct learning: A validation study. *International Journal of Assessment Tools in Education*, 10(2), 376–394. <https://doi.org/10.21449/ijate.1155679>
- Christopher, C., & Newman, K. (2022). Exploring classroom practices associated with greater student engagement that may benefit low-income students in the early grades. *Frontiers in Education*, 7. <https://doi.org/10.3389/educ.2022.944731>
- Compan, P., Prommachan, T., Kongyok, C., Cheablam, O., & Socheath, M. (2025). Integrating local plant knowledge into elementary curriculum: A scalable model for community sustainability. *Sustainability*, 1, 1–25.
- Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). Sage.
- Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed.). Sage.
- Dimec, D. S., & Strgar, J. (2017). Scientific conceptions of photosynthesis among primary school pupils and student teachers of biology. *Center for Educational Policy Studies Journal*, 7(1), 49–68. <https://doi.org/10.26529/cepsj.14>

- Duit, R., & Treagust, D. F. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education*, 25(6), 671–688.
- Field, A. (2017). *Discovering statistics using IBM SPSS statistics* (5th ed.). Sage.
- Hutami, C. A., & Kurniawati, W. (2025). Identifikasi miskonsepsi siswa pada materi tumbuhan dengan two tier diagnostic test. (Identifying students' misconceptions about plant material using a two-tier diagnostic test). *Edukasi*, 17(01), 477–490.
- Kosel, C., Wolter, I., & Seidel, T. (2021). Profiling secondary school students in mathematics and German language arts using learning-relevant cognitive and motivational-affective characteristics. *Learning and Instruction*, 73, 101434. <https://doi.org/10.1016/j.learninstruc.2020.101434>
- Kurniawati, W., Prasetyo, Z. K., & Siswoyo, D. (2023). *Model pembelajaran sains berbasis duo ccm untuk mereduksi miskonsepsi. (Duo CCM-based science learning model to reduce misconceptions)*. UPY Press.
- Kwon, M. H. (2021). Analysis of plant species in elementary school textbooks in South Korea. *Journal of People, Plants, and Environment*, 24(5), 485–498. <https://doi.org/10.11628/ksppe.2021.24.5.485>
- Lampert, P., Scheuch, M., Pany, P., Müllner, B., & Kiehn, M. (2019). Understanding students' conceptions of plant reproduction to better teach plant biology in schools. *Plants, People, Planet*, 1(3), 248–260. <https://doi.org/10.1002/ppp3.52>
- Lechuga, M. T., Ortega-Tudela, J. M., & Gómez-Ariza, C. J. (2024). Retrieval-based concept mapping makes a difference as a retrieval practice activity: A study with high school students. *Frontiers in Education*, 9(March). <https://doi.org/10.3389/feduc.2024.1287744>
- Lensmire, T. J. (1993). Following the child, socioanalysis, and threats to community: Teacher response to children's texts. *Curriculum Inquiry*, 23(3), 265–290. <https://doi.org/10.2307/1179993>
- Li, X., Li, Y., & Wang, W. (2023). Long-lasting conceptual change in science education. *Science & Education*, 32(1), 123–168. <https://doi.org/10.1007/s11191-021-00288-x>
- Limón, M. (2001). On the cognitive conflict as an instructional strategy for conceptual change: a critical appraisal. *Learning and Instruction*, 11(4–5), 357–380. [https://doi.org/10.1016/S0959-4752\(00\)00037-2](https://doi.org/10.1016/S0959-4752(00)00037-2)
- Mahdiyah, L., Wahyuning S, N., & Marzuki, I. (2021). Identification of science subject misconception in elementary schools. *Journal Universitas Muhammadiyah Gresik Engineering, Social Science, and Health International Conference (UMGESHIC)*, 1(2), 27. <https://doi.org/10.30587/umgeshic.v1i2.3364>
- Merchie, E., Heirweg, S., & Van Keer, H. (2022). Mind maps: Processed as intuitively as thought? Investigating late elementary students' eye-tracked visual behavior patterns in-depth. *Frontiers in Psychology*, 13, Article 821768. <https://doi.org/10.3389/fpsyg.2022.821768>
- Muhammad, A. (2024). Photosynthesis: The key driver of plant growth and development. *Journal of Clinical Studies & Medical Case Reports*, 11(5), 1–4. <https://doi.org/10.24966/csmc-8801/1000253>
- Naimah, A. (2022). The use of video as a learning media in science learning: A systematic review. *Al-Ishlah: Jurnal Pendidikan*, 14(4), 6941–6950. <https://doi.org/10.35445/alishlah.v14i4.1565>
- Nurbaety, D., Rustaman, N. Y., & Sanjaya, Y. (2016). The use of drawing method for diagnosing students' misconception about plant structure in relation to photosynthesis. *AIP Conference Proceedings*, 1708, 080006. <https://doi.org/10.1063/1.4941192>
- Oesterlin, E. (2022). *Botanically inclined: Elementary students' knowledge of plant structures and their functions captured in drawings* (Master's thesis, University of Maine). DigitalCommons@UMaine.
- Olsen, R. B., Orr, L. L., Bell, S. H., & Stuart, E. A. (2013). External validity in policy evaluations that choose sites purposively. *Journal of Policy Analysis and Management*, 32(1), 107–121. <https://doi.org/10.1002/pam.21660>

- Ophuis-Cox, F. H. A., Catrysse, L., & Camp, G. (2023). The effect of retrieval practice on fluently retrieving multiplication facts in an authentic elementary school setting. *Applied Cognitive Psychology*, 37(6), 1463–1469. <https://doi.org/10.1002/acp.4141>
- Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Administration and Policy in Mental Health and Mental Health Services Research*, 42(5), 533–544. <https://doi.org/10.1007/s10488-013-0528-y>
- Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*, 66(2), 211–227.
- Prasad, R., Deshmukh, N., & Shaikh, R. (2025). Diagnosing and remediating elementary students' misconceptions about the growth of plants. *The Asian Journal of Biology Education*, 16, 2–14. [https://doi.org/10.57443/ajbe.17.0\\_2](https://doi.org/10.57443/ajbe.17.0_2)
- Prastyani, O. D., & Kurniawati, W. (2025). Tes diagnostik two-tier untuk mengidentifikasi miskonsepsi pada pelajaran IPAS materi tumbuhan di SDN Sonosewu. *Borobudur Educational Review*, 5(1), 36–46. <https://doi.org/10.31603/bedr.13319>
- Pratiwi, E., Nusantara, T., Susiswo, S., Muksar, M., & Subanji, S. (2019). Characteristics of students' cognitive conflict in solving a problem based on information processing theory. *International Journal of Learning, Teaching and Educational Research*, 18(2), 76–88. <https://doi.org/10.26803/ijlter.18.2.6>
- Putri, A. D., & Kurniawati, W. (2025). Analisis miskonsepsi melalui tes diagnostik two-tier pada materi tumbuhan kelas IV SD. (Analysis of misconceptions through a two-tier diagnostic test on plant material for fourth grade elementary school students). *Borobudur Educational Review*, 5(1), 47–56. <https://doi.org/10.31603/bedr.13318>
- Rahmawati, P., & Kurniawati, W. (2024). Miskonsepsi pembelajaran IPAS siswa kelas IV sekolah dasar. (Misconceptions about science learning among fourth-grade elementary school students). *Edukasi: Jurnal Penelitian & Artikel Pendidikan*, 16(2).
- Rençber, G. N., & Genç, G. (2024). Developing an achievement test on length measurement. *Education Mind*. <https://doi.org/10.58583/EM.3.3.8>
- Roediger, H. L., & Butler, A. C. (2011). The critical role of retrieval practice in long-term retention. *Trends in Cognitive Sciences*, 15(1), 20–27. <https://doi.org/10.1016/j.tics.2010.09.003>
- Ryoo, J. H., Park, S., Suh, H., Choi, J., & Kwon, J. (2022). Development of a new measure of cognitive ability using automatic item generation and its psychometric properties. *SAGE Open*, 12(2). <https://doi.org/10.1177/21582440221095016>
- Science and Plants for Schools. (2004). *Plants for primary pupils*. <https://www.saps.org.uk>
- Shadish, W. R., Cook, T. D., & Campbell, D. T. (2002). *Experimental and quasi-experimental designs for generalized causal inference*. Houghton Mifflin.
- Sinatra, G. M., Heddy, B. C., & Lombardi, D. (2015). The challenges of defining and measuring student engagement in science. *Educational Psychologist*, 50(1), 1–13. <https://doi.org/10.1080/00461520.2014.1002924>
- Taşçi, G. (2024). Development of a two-tier diagnostic test to assess misconceptions about biology concepts at primary school. *Science Insights Education Frontiers*, 25(2), 4099–4122. <https://doi.org/10.15354/sief.24.or652>
- Tippett, T. P., & Lee, J. J. (2019). Looking back to move forward: Understanding progressive education in the 21st century. *Journal of Applied Learning in Higher Education*, 8, 79–97. [https://doi.org/10.57186/jalhe\\_2019\\_v8a5p79-97](https://doi.org/10.57186/jalhe_2019_v8a5p79-97)
- Treagust, D. F. (1988). Development and use of diagnostic tests to evaluate students' misconceptions in science. *International Journal of Science Education*, 10(2), 159–169.
- Wati, P. A., & Mahendra, Y. (2025). The effectiveness of flashcard media in enhancing science learning outcomes among elementary school students. *Mimbar PGSD Undiksha*, 13(1), 180–188. <https://doi.org/10.23887/jjgsd.v13i1.91831>

- Wynn, A. N., Pan, I. L., Rueschhoff, E. E., Herman, M. A. B., & Archer, E. K. (2017). Student misconceptions about plants: A first step in building a teaching resource. *Journal of Microbiology & Biology Education*, 18(1). <https://doi.org/10.1128/jmbe.v18i1.1253>
- Yaşar, O., Maliekal, J., Veronesi, P., Little, L., Meise, M., & Yeter, I. H. (2022). Retrieval practices enhance computational and scientific thinking skills. *Frontiers in Psychology*, 13, Article 892276. <https://doi.org/10.3389/fpsyg.2022.892276>