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Metacognitive Guidance-Based Instruction for Sustainable Food and Climate Change Literacy: A Classroom-Based Quasi-Experimental Study Among Ninth-Grade Students

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Abstract

Despite the growing attention paid to sustainability education, limited quasi-experimental research has examined how metacognitive guidance can integrate cognitive, affective, and agency-oriented learning in food-related climate education. This classroom-based quasi-experimental study, complemented by student interviews, investigated a six-lesson metacognitive guidance-based unit designed to strengthen ninth-grade students' sustainable food literacy (SFL), climate-change perceptions and attitudes, and constructive hope. Participants were 59 students from two intact classes in northern Israel; one class received the intervention, and the other received traditional instruction on the same content. Quantitative data were collected through a sustainable food and climate change knowledge test and a climate change literacy questionnaire and were analyzed using mixed-design repeated-measures ANOVA, *t*-tests, and multiple regression. Qualitative data were obtained from individual semi-structured interviews with students in the experimental group. Results indicated significant intervention-related gains in SFL knowledge, climate-change perceptions, climate-change attitudes, and constructive hope, with moderate-to-large time $\times$ group effects across the main outcomes (partial $\eta^2 = 0.16$ – 0.33). Climate-change perceptions emerged as the strongest post-intervention predictor of constructive hope ($\beta = 0.92$, $p < 0.001$). Interviews illustrated how reflective prompts, self-monitoring, discussion, and learning artifacts supported conceptual understanding, moral responsibility, perceived agency, and self-reported short-term intentions for sustainable food choices. The findings suggest that metacognitive guidance can support integrative, hope-oriented sustainability learning among adolescents. These findings should be interpreted cautiously given the small non-random sample, the use of two intact classes, the short six-lesson intervention, and the reliance on short-term self-reported outcomes. The study's novelty lies in integrating sustainable food literacy, climate-change perceptions and attitudes, and constructive hope within a metacognitively guided food–climate unit in a culturally underrepresented Druze school context.



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Keywords: metacognitive guidance; sustainable food literacy (SFL); climate change literacy (CCL); constructive hope; education for sustainability (EfS); climate change education

1. Introduction

Education for sustainable development is increasingly central to preparing learners to address interconnected challenges spanning environment, health, and society

(Akinsemolu & Onyeaka, 2025). However, many sustainability programs remain primarily knowledge-oriented, emphasizing content acquisition more than reflective, behavioral, and attitudinal transformation (Adler et al., 2016; Zion & Cohen, 2021). Recent experimental evidence reinforces this concern, showing that knowledge-focused environmental instruction may improve conceptual understanding without necessarily producing attitudinal change, while affective and action-oriented engagement is needed to address the sustainability knowledge–action gap (Erhabor & Reis, 2026; Sejdiu & Ramadan, 2026).

Although previous studies have shown that metacognitive guidance can support science learning, self-regulation, and sustainability-related reflection, limited quasi-experimental evidence has examined whether explicitly guided metacognitive instruction can simultaneously enhance adolescents' sustainable food literacy, climate-related perceptions and attitudes, and constructive hope. This gap is important because food-related climate education requires students not only to acquire scientific knowledge, but also to monitor their reasoning, evaluate everyday choices, and develop realistic agency for action.

Meeting urgent sustainability demands requires pedagogies that cultivate higher-order thinking, self-regulation, and agency. Metacognitive guidance, which supports learners in planning, monitoring, and evaluating their reasoning, has therefore been positioned as a promising approach for deep understanding and critical reflection (Zion & Cohen, 2021). Recent sustainability frameworks likewise emphasize metacognitive reflection as a core mechanism for connecting knowledge with action (Hanisch & Eirdosh, 2023). Empirical work in sustainability-related contexts suggests that metacognitive guidance can strengthen comprehension and motivation (Adler et al., 2016) and may also support collaboration, responsibility, and constructive behavioral engagement (Sadykova et al., 2024). From a metacognitive perspective, strengthening awareness of one's reasoning may not only improve literacy but also support constructive hope, thereby linking cognition with motivation for climate action (Ojala, 2015; Hanisch & Eirdosh, 2023).

This issue is especially salient in Israel, where sustainability challenges are shaped by limited natural resources and centralized energy infrastructure (Eitan, 2021), while sustainability education remains fragmented and often focused on environmental-technical dimensions with less emphasis on social, ethical, and cultural perspectives (Zuzovsky, 2021). Although whole-school approaches that embed sustainability in school culture and teachers' professional identity are widely recognized as important (Gan & Alkaher, 2021), implementation remains limited, and climate-engaged youths increasingly view school climate education as outdated and ineffective (Gan & Nathan, 2025).

Substantively, the present study focuses on two interrelated literacies: sustainable food literacy (SFL) and climate change literacy (CCL). SFL is critical because food production, consumption, and waste are major contributors to greenhouse gas emissions; developing SFL can help learners understand these connections and adopt practices that reduce ecological footprints and support climate resilience (McManus et al., 2025). Food systems, therefore, require literacy that includes environmental and ethical dimensions (Silva et al., 2023). CCL extends beyond factual climate knowledge to include moral responsibility and orientation toward action (Kumar et al., 2023; Simpson et al., 2021). In this study, CCL is operationalized through climate-related perceptions, attitudes, and constructive hope, which represent the affective, evaluative, and agency-oriented dimensions of students' engagement with climate change. Constructive hope, understood as realistic, efficacy-based optimism in the face of environmental challenges, is especially relevant because it may help students transform concern into reflective and action-oriented engagement (Ojala, 2012, 2015). Limited classroom-based quasi-experimental research has examined whether metacognitively guided food–climate instruction can simultaneously strengthen sustainable food literacy knowledge, climate-change perceptions and attitudes,

and constructive hope. Addressing this gap is important because food-related climate education requires students to connect scientific understanding with reflection, everyday decision-making, and realistic agency for action.

Although previous studies have shown that metacognitive guidance can support science learning, self-regulation, and sustainability-related reflection, limited quasi-experimental evidence has examined whether explicitly guided metacognitive instruction can simultaneously enhance adolescents' sustainable food literacy, climate-related perceptions and attitudes, and constructive hope. Recent climate literacy research shows that cognitive knowledge alone has limited explanatory power for students' willingness to engage in climate action, whereas psycho-social factors such as risk perception and values are stronger predictors (Garrecht et al., 2026). This gap is important because food-related climate education requires students not only to acquire scientific knowledge, but also to monitor their reasoning, evaluate everyday choices, and develop realistic agency for action. This rationale is reinforced by recent climate literacy research showing that students' willingness to engage in climate action is explained more strongly by psycho-social factors such as risk perception and value orientations than by cognitive knowledge alone (Garrecht et al., 2026).

The present study addresses this gap in a culturally underrepresented Druze school context in Israel by examining a six-lesson metacognitively guided sustainable food–climate unit. Using a classroom-based quasi-experimental pre–post design with two intact ninth-grade classes, complemented by interviews with students from the experimental group, the study assessed changes in sustainable food literacy knowledge, climate-change perceptions, climate-change attitudes, and constructive hope compared with traditional instruction. The interviews contextualized how students described reflection, self-monitoring, perceived agency, and food–climate connections during the unit.

The conceptual model guiding the study positions metacognitive guidance as the instructional approach and students' planning, monitoring, and self-evaluation as the reflective learning processes supported by the unit. Sustainable food literacy knowledge, climate-change perceptions, climate-change attitudes, and constructive hope are treated as measured outcomes, while post-intervention associations among these variables are examined to clarify how they relate within the study context.

The purpose of the study was therefore to examine whether the metacognitively guided food–climate unit improved ninth-grade students' cognitive, affective, and agency-oriented sustainability learning outcomes, and to explore how students in the experimental group described the reflective processes embedded in the intervention. The contribution is intentionally bounded to the evidence generated by this design: comparative pre–post differences between groups, post-intervention associations among measured variables, and students' contextual accounts of their learning experiences. Within these boundaries, the study extends prior international work by examining metacognitive guidance not only in relation to general science learning or environmental attitudes, but within an integrated food–climate unit that connects sustainable food literacy, climate-change perceptions and attitudes, and constructive hope in a culturally underrepresented school context.

1.1. Literature Review

1.1.1. Metacognition and Metacognitive Guidance

Over recent decades, educational paradigms have increasingly emphasized the development of learners who are environmentally aware, personally responsible, and capable of addressing global challenges such as climate change and food crises. Within this context, metacognition—the ability to plan, monitor, and evaluate one's thinking (Flavell, 1979)—has become a central pedagogical principle that supports deep understanding, critical think-

ing, and problem solving. Explicit metacognitive guidance helps students regulate their learning, gain cognitive autonomy, and make informed decisions (Zion & Cohen, 2021).

Adolescence is a pivotal period for developing reflective and strategic thinking, as learners acquire abstract reasoning and self-reflection that allow them to grasp complex socio-environmental issues such as sustainability (Piaget, 1972). Instruction that cultivates self-reflection, planning, self-monitoring, and strategic flexibility promotes both cognitive growth and personal agency, laying the foundation for metacognitive awareness and responsible environmental decision making (Schneider et al., 2022; Silva et al., 2023). In sustainability contexts, such metacognitive awareness enables students to critically evaluate human–environment interactions and the long-term consequences of their choices. Metacognition is therefore not only a cognitive skill but also a moral and reflective capacity that may shape cognitive understanding, emotional regulation, and moral responsibility in sustainability learning (Sadykova et al., 2024; Ojala, 2023), although the pathways through which metacognitive guidance turns awareness into ethical and sustainable behavior remain underexplored, particularly in adolescence. Jeronen and Jeronen (2026) similarly emphasize that biology education for sustainability should move beyond factual and conceptual knowledge toward critical thinking, reflection, systems thinking, and responsible action.

1.1.2. Advantages and Mechanisms of Metacognitive Guidance

In contrast to traditional teacher-centered instruction (Raja & Najmonnisa, 2018), metacognitive teaching positions the educator as a facilitator who promotes reflection and self-regulation (Dignath & Veenman, 2021). Guided reflection and self-assessment foster flexibility, independence, and lifelong learning competencies (Muijs et al., 2014). Fischer and Said (2021) showed that learners' confidence in their climate knowledge predicted belief in anthropogenic climate change beyond factual understanding, indicating that metacognitive judgment links knowledge, confidence, and environmental attitudes. Together, these findings suggest that metacognitive guidance improves cognitive outcomes and connects understanding, confidence, and environmental attitudes, providing a foundation for the present study. Consistent with Sadykova et al. (2024), metacognition-based instruction enhances comprehension, metacognitive processing, and collaborative engagement, yet the mechanisms through which it leads to sustained pro-environmental attitudes and behaviors, particularly in adolescence, remain insufficiently understood and closely aligned with the aims of Education for Sustainability.

1.1.3. Education for Sustainability in Schools

Education for sustainability (EfS) in schools seeks to develop students' understanding of environmental, social, and economic interdependencies and their capacity to act responsibly toward future generations (Olsson et al., 2022). Effective EfS is interdisciplinary and inquiry-oriented, integrating sustainability across subjects while drawing on experiential and project-based learning and school-community partnerships to promote systems thinking and creative problem solving (Figueiró et al., 2022).

Teachers play a central role in mediating sustainability values and designing learning environments that foster reflection and student agency. Their personal commitment, modeling of sustainable behavior, and professional preparation strongly influence student outcomes (García-González et al., 2020). Within this broader framework, food literacy has emerged as a practical, everyday domain through which learners can translate sustainability principles into action, providing the pedagogical context for the present study.

1.1.4. Sustainable Food, Food Literacy, and Climate Change Literacy

Sustainable food systems seek to ensure nutritional well-being, equitable livelihoods, and environmental stewardship (Mensah et al., 2024). They align economic viability with

ecological responsibility by reducing food waste, protecting biodiversity, and strengthening local production (Shabir et al., 2023). Progress toward these systems depends on technological innovation and consumer awareness (Li & Kallas, 2021), yet priorities differ globally: high-income contexts often emphasize waste reduction, whereas low- and middle-income contexts must balance food security with environmental conservation (Pawlak & Kołodziejczak, 2020).

Sustainable food literacy (SFL) operationalizes this systems perspective by integrating knowledge, behavioral competencies, and socio-emotional dispositions (McManus et al., 2025). Food literacy provides a practical foundation that helps individuals and communities maintain diet quality and build dietary resilience over time (Vidgen & Gallegos, 2014). Higher SFL is associated with healthier and more sustainable dietary choices, including preferences for local and plant-based foods, and sustainability-oriented nutrition education strengthens awareness and environmental responsibility (Park et al., 2020; Silva et al., 2023). Metacognitive reflection, such as analyzing one's own eating habits, can deepen understanding and strengthen agency for change (McManus et al., 2025; Park et al., 2020). However, evidence remains limited regarding how explicit metacognitive guidance further enhances SFL through reflective awareness and value-based decision making. Recent agri-food sustainability education research further highlights the need for curriculum models that embed sustainability principles within authentic food-system contexts and develop green and transversal competencies (McDonagh et al., 2026).

Climate change literacy (CCL) complements SFL by encompassing knowledge of climate systems, human impacts, and moral responsibility to act (Kumar et al., 2023; Simpson et al., 2021). Beyond factual understanding, CCL includes emotional regulation and constructive hope—an efficacy-based optimism that motivates pro-environmental behavior (Ojala, 2023). Metacognitive guidance may connect cognition and motivation by helping students monitor and evaluate both their reasoning and emotions. Constructive hope, framed as a reflective and efficacy-based process, can transform climate-related anxiety into meaningful engagement and action competence (Ojala, 2012; Finnegan & d'Abreu, 2024). Sejdiu and Ramadani (2026) found that affective engagement, particularly empathy and hope, can help explain the movement from sustainability learning toward self-reported pro-environmental behavior.

Food and climate systems are tightly coupled because dietary patterns and food-production practices are closely linked to greenhouse gas emissions and resource use. High red-meat diets disproportionately increase emissions and resource depletion, whereas plant-based dietary patterns can reduce environmental burdens (Kumar et al., 2023). Instruction that makes these connections explicit can support students in linking dietary choices to environmental outcomes and adopting more sustainable practices (Kolenatý et al., 2022). Accordingly, SFL and CCL are interdependent: understanding how food systems contribute to and are affected by climate change enables informed choices that reduce emissions and support sustainable lifestyles (McManus et al., 2025).

This interdependence highlights the need to integrate sustainability education with metacognitive reflection so that students connect knowledge, emotion, and behavior in ethical, sustained action. Yet empirical research remains limited on how metacognitive guidance bridges SFL and CCL by linking cognitive understanding with emotional engagement and constructive hope. The present study addresses this gap by examining the effects of metacognitive guidance on adolescents' SFL, climate-related perceptions, and constructive hope.

In this study, SFL refers to knowledge and competencies related to food systems, nutrition, and sustainable consumption, whereas CCL focuses on climate-related perceptions, attitudes, and constructive hope. Taken together, the literature suggests that metacogni-

tive guidance may support sustainability learning by connecting knowledge, reflection, emotion, and agency. However, it remains unclear whether such instruction can simultaneously strengthen sustainable food literacy, climate-related perceptions and attitudes, and constructive hope among adolescents. The present study addresses this issue through a classroom-based quasi-experimental design complemented by student interviews.

1.2. Theoretical Framework

Drawing on contemporary research, this study integrates metacognitive theory, Education for Sustainability (EfS), and constructive hope into a single framework for explaining how metacognitive guidance may strengthen students' sustainability literacy, emotional engagement, and agency for climate action. Metacognitive guidance is conceptualized as an instructional catalyst that connects cognition, emotion, and behavior, supporting a shift from awareness to value-driven, sustainable action. In line with [Wood et al. \(1976\)](#), scaffolding is understood here as structured instructional support that enables learners to engage with tasks that would initially be difficult to complete independently, while gradually shifting responsibility back to the learner. In this study, metacognitive guidance refers to structured instructional supports—such as guiding prompts, reflective tasks, learning artifacts, and self-evaluation activities—that help students plan, monitor, evaluate, and reflect on their thinking about food, climate, and action.

Metacognition, awareness, and regulation of one's thinking enable learners to plan, monitor, and evaluate cognitive processes ([Flavell, 1979](#)). Within the MASRL model, [Efklides \(2011\)](#) distinguishes metacognitive knowledge (awareness of strategies and conditions), metacognitive experiences (affective experiences during learning), and metacognitive control (regulation of effort and strategy use), highlighting that self-regulation inherently includes motivational and affective components. Evidence from meta-analytic work suggests that metacognitive interventions can yield meaningful gains in self-regulated learning and academic performance, with particularly robust longer-term effects on self-efficacy, indicating that reflective monitoring and planning may help sustain motivation and confidence ([Eberhart et al., 2025](#)).

In EfS contexts, metacognitive reflection serves both cognitive and affective functions. Cognitively, it can deepen systems thinking and support two interrelated literacies—sustainable food literacy (SFL) and climate change literacy (CCL)—that connect everyday lifestyle decisions with broader environmental systems. Critical and reflective learning is especially important for developing the cognitive, behavioral, and socio-emotional dimensions of SFL and for supporting behavior-related outcomes ([McManus et al., 2025](#)). By structuring reflection and ethical reasoning, metacognitive instruction may help learners integrate nutrition, health, and environmental considerations into coherent decision frameworks.

Affectively, metacognitive reflection can cultivate constructive hope, an efficacy-based optimism grounded in realistic appraisal and perceived agency. In this study, constructive hope refers to realistic, efficacy-based optimism about addressing climate challenges and is treated as a measured agency-oriented outcome. Perceived agency refers to students' belief that individual and collective actions can contribute to climate solutions; it was explored mainly through students' interview accounts and reflected in the constructive hope items rather than measured as a separate scale. Emotional engagement refers to students' concern, care, and motivational involvement with sustainability and climate issues; in this study, it was reflected in climate-change attitudes and qualitative interview themes rather than treated as a separate quantitative construct. Constructive hope in sustainability education has been described as an integration of cognitive, emotional, and ethical dimensions that supports action competence and identity development ([Furu et al., 2026](#)). Related evidence shows that hope is most strongly associated with engagement and well-

being when accompanied by concern (Rizeq & Ojala, 2024), and that worry, rather than purely positive affect, can be central to sustained climate activism; emotional ambivalence (worry combined with positive affect) may best predict pro-environmental behavior (Bechtoldt & Schermelleh-Engel, 2025). Within Transformative Climate Change Education, constructive hope is further framed as an embodied, communal practice nurtured through collective meaning-making (e.g., narrative, storytelling) and critical reflection that translates insights into coordinated action (Ibourk & Morrison, 2026).

The present study conceptualizes metacognitive guidance as an instructional catalyst that links cognitive understanding with emotional engagement, ethical responsibility, and perceived agency. Within this framework, sustainable food literacy knowledge, climate-change perceptions, climate-change attitudes, and constructive hope are treated as measured outcomes or associations that reflect the cognitive, affective, and agency-oriented dimensions of sustainability learning. The quasi-experimental pretest–posttest design, therefore, examined changes in these outcomes, while the interviews contextualized how students described reflection, self-monitoring, and perceived agency during the unit. Because the design assessed pre–post group differences and post-intervention associations, it did not test mediation effects among SFL, CCL, and constructive hope.

1.2.1. Objectives of the Study

This study examined whether a six-lesson metacognitively guided sustainable food–climate unit improved ninth-grade students’ sustainable food literacy knowledge, climate-change perceptions and attitudes, and constructive hope compared with traditional instruction. The study used a quantitatively driven quasi-experimental pretest–posttest design, complemented by semi-structured interviews with students in the experimental group to illuminate their experiences of reflection, self-monitoring, and perceived agency during the unit.

1.2.2. Research Questions

This study explores both the cognitive and affective impacts of metacognitive guidance on ninth-grade students’ sustainability learning. The investigation seeks to capture not only measurable changes in knowledge and attitudes but also students’ reflective experiences within the learning process. Specifically, the study addresses the following questions:

RQ1: To what extent does the metacognitively guided food–climate unit, compared with traditional instruction, improve ninth-grade students’ sustainable food literacy knowledge?

RQ2: To what extent does the metacognitively guided food–climate unit, compared with traditional instruction, improve ninth-grade students’ climate-change perceptions?

RQ3: To what extent does the metacognitively guided food–climate unit, compared with traditional instruction, improve ninth-grade students’ climate-change attitudes?

RQ4: To what extent does the metacognitively guided food–climate unit, compared with traditional instruction, improve ninth-grade students’ constructive hope?

RQ5: How do interviewed students from the experimental group describe the role of reflection, self-monitoring, and self-evaluation in their understanding of food–climate connections, responsibility, and perceived agency?

1.2.3. Research Hypotheses

Drawing on prior studies indicating that sustainability-oriented metacognitive instruction can enhance environmental awareness, reflective thinking, and responsible action (Zion & Cohen, 2021; Eitan, 2021), the hypotheses were developed in line with the proposed conceptual framework. H1–H3 were framed as primary hypotheses examining expected intervention-related pre–post group differences in the main measured outcomes, rather than as definitive causal claims. H4 was treated as a secondary exploratory hypothesis ex-

aming theoretically guided post-intervention associations among the measured variables, with particular attention to the relationship between climate-change perceptions and constructive hope. The design therefore tests outcome differences and statistical associations, but does not test causal mediation pathways.

H1. *Students in the experimental group will show greater gains in sustainable food literacy knowledge than students in the control group.*

H2. *Students in the experimental group will show greater gains in climate-change perceptions and climate-change attitudes than students in the control group.*

H3. *Students in the experimental group will show greater gains in constructive hope than students in the control group.*

H4. *Post-intervention climate-change perceptions will be more strongly associated with constructive hope than sustainable food literacy knowledge or climate-change attitudes.*

2. Materials and Methods

2.1. Research Design

This study used a quantitatively driven quasi-experimental pretest–posttest design with a complementary qualitative component. The quantitative strand compared two intact ninth-grade classes: an experimental group that completed a metacognitively guided unit and a control group taught through conventional, content-centered lessons. The hypotheses were derived from the theoretical framework and prior empirical literature before data collection and were tested using quantitative pretest and posttest data, as well as post-intervention associations among the measured constructs. Individual semi-structured interviews were conducted only after the intervention and posttesting with students from the experimental group. These interviews were used to contextualize students' experiences of the intervention and to illuminate the reflective and agency-related processes theorized in the framework. Thus, the qualitative component supported interpretation of the quantitative outcomes but did not constitute a fully integrated mixed-methods design, generate hypotheses, or independently test intervention effects. Integration occurred primarily at the interpretation stage, where qualitative findings were used to illuminate students' learning experiences in relation to the quantitative results.

Qualitatively, semi-structured interviews were conducted with a purposeful subsample from the experimental group to explore how metacognitive strategies—planning, monitoring, and self-evaluation—shaped students' understanding of connections among food, health, and the environment. The instructional unit integrated explicit reflective activities within lessons on sustainable nutrition and climate change, whereas the control group received teacher-led instruction without structured reflection. Quantitative outcomes were analyzed using mixed-design repeated-measures ANOVA, paired-samples and independent-samples *t*-tests, and multiple linear regression, while interview data were analyzed thematically.

Because the quantitative component involved two intact classes, assignment was not random, and groups were determined in advance by school scheduling and administrative constraints. Both classes received the same duration and instructional time (six lessons; see Section 2.2.3), reducing history-related threats. To limit contamination, intervention materials and reflective artifacts (e.g., journals, concept maps, consumption diaries) were used only in the experimental class, and students were asked not to share materials until study completion. Given that teacher effects cannot be fully excluded in a two-class design,

results are interpreted primarily as comparative pre–post differences and associations, with appropriate caution regarding causal inference beyond the measured outcomes.

2.2. Participants

Two intact ninth-grade classes were used because the intervention was implemented under authentic school conditions and class assignment was determined by existing school scheduling, which preserved ecological validity but limited randomization and generalizability. Participants were ninth-grade students (ages 14–15) from the Arab-Druze community and generally reflected a middle socio-economic background. Instruction was delivered in Arabic, while Hebrew was used for national assessments. Students learned in academically heterogeneous classes; prior science achievement was typically average to above average, and formal exposure to sustainability education had been limited.

Two intact classes participated: an experimental group ($N = 28$; 47.5%) and a control group ($N = 31$; 52.5%), for a total of 59 students (22 boys, 37 girls). No a priori power analysis was conducted because the sample size was determined by the availability of two intact classes in the participating school; therefore, the study should be interpreted as a small-scale classroom intervention rather than as a fully powered trial. Both classes were taught by the same experienced biology and chemistry teacher (an in-service teacher pursuing a master's degree). This reduced between-group variability attributable to teacher differences but increased the risk of expectancy effects; to mitigate this risk, administration and instructional procedures were standardized across groups (see Section 2.2.3).

The experimental group completed a metacognitive guidance-based unit incorporating structured reflection, planning, and self-assessment. The control group learned the same content through teacher-centered instruction without explicit metacognitive components.

2.2.1. Quantitative Instruments

Climate Change Literacy Questionnaire

A 33-item questionnaire assessed three dimensions of environmental and health literacy—perceptions, attitudes, and constructive hope—on a five-point Likert scale (1 = strongly disagree, 5 = strongly agree).

- Perceptions (12 items) measured understanding of climate change effects on health, environment, and natural resources.
- Attitudes (15 items) evaluated emotions, concerns, and willingness to act on sustainability issues.
- Constructive hope (6 items) captured students' sense of responsibility for climate problems, their perceived ability to contribute to solutions, and their confidence in collective and technological responses to climate change. Example items included: 'We need to take responsibility for climate problems and take them seriously', 'I can change my behaviour, and together we can positively influence the climate', and 'I can contribute to reducing climate change in different ways'. Higher scores reflected stronger constructive hope.

The instrument was adapted and translated from three validated sources (Akaygun & Adadan, 2021; Nepras et al., 2023; Ratinen, 2021) and reviewed by two experts in science and sustainability education to ensure content validity. Inter-item and inter-subscale correlations were examined to assess internal consistency and dimensional coherence. Cronbach's alpha values indicated strong reliability: perceptions ($\alpha = 0.94$), attitudes ($\alpha = 0.85$), and constructive hope ($\alpha = 0.93$). Accordingly, CCL in this study refers specifically to students' climate-related perceptions, attitudes, and constructive hope, as measured by the questionnaire subscales.

The instruments were translated into Arabic and back-translated into English, and the final Arabic version was reviewed by bilingual science-education experts familiar with the local Druze-Arab school context to ensure semantic equivalence, cultural appropriateness, age suitability, and conceptual alignment with the original constructs.

Sustainable Food and Climate Change Test (Knowledge Test)

This 26-item assessment, comprising 10 multiple-choice, 6 true/false, and 10 open-ended items, measured students' conceptual and applied understanding of sustainable food systems and nutrition in the context of climate change. The items addressed key concepts, including human nutritional needs, the digestive system, trophic levels and food chains, greenhouse gas emissions from livestock, and the relationship between dietary patterns and climate change, for example, explaining how beef production contributes to climate change. The assessment was aligned with national lower-secondary science curriculum topics related to human nutrition and human impacts on ecosystems.

Because no existing instrument integrated these domains, the tool was developed collaboratively by the researcher and the school science coordinator. Content validity was supported through expert review, and items were designed at varying levels of difficulty to capture both conceptual depth and discrimination among students. Internal consistency for the total score was good (Cronbach's $\alpha = 0.81$). Open-ended items were independently scored by two raters using a predefined rubric, with high inter-rater reliability ($r > 0.85$).

2.2.2. Qualitative Instrument

Because the questionnaires could identify changes in measured outcomes but could not capture how students interpreted and experienced the intervention, individual semi-structured interviews lasting approximately 30 min were conducted with ten purposively selected students from the experimental group, representing a range of academic performance levels and perspectives. The interviews were included to provide contextual insight into students' experiences of the intervention, particularly how they described reflection, self-monitoring, perceived agency, and the connection between food choices and climate change. The interviews explored students' conceptual development, emotional engagement, and perceptions of the interconnections among nutrition, sustainability, and climate change, using guiding questions such as *'How did this learning experience influence your view of the link between food and the environment?'* and *'Do you feel capable of influencing climate change, and in what ways?'*

The interview guide was developed to align with the study objectives, the theoretical constructs, the quantitative outcome domains, and the activities included in the six-lesson food-climate unit. The questions were designed to elicit students' descriptions of reflection, self-monitoring, perceived agency, and food-climate connections during the intervention, thereby contextualizing the learning processes related to sustainable food literacy knowledge, climate-change perceptions and attitudes, and constructive hope. The guide was reviewed by two specialists in science and sustainability education to ensure conceptual alignment, clarity, linguistic appropriateness, and age suitability. The interviews were not developed from the posttest results and were not used to generate or independently test additional hypotheses. The researcher and academic supervisor jointly coded the data, achieving inter-rater agreement above 85% across major categories, while credibility and trustworthiness were supported through data triangulation and peer debriefing. Thematic analysis identified recurring patterns in students' reflective learning processes, attitudinal shifts, and perceived agency in sustainability and climate action, providing explanatory depth on how metacognitive engagement translated cognitive understanding into motivation and value-based behavior.

The control group was not interviewed because the interview questions focused on students' experiences of the metacognitive guidance activities—such as reflective prompts, self-monitoring, self-evaluation, and learning artifacts—which were implemented only in the experimental group. Accordingly, the qualitative evidence is used to contextualize students' experiences of the intervention and perceived learning processes, rather than to compare groups or explain control-group outcomes.

2.2.3. Procedure

Pre-Intervention Phase

Before the intervention, both groups completed the “Sustainable Food and Climate Change Test” followed by the “Climate Change Literacy Questionnaire”. The knowledge test was administered first during regular class time across two class sessions (90 min total) and completed individually in class. On the following day, the Climate Change Literacy Questionnaire was administered under the same classroom conditions; students completed it individually in approximately 50 min. In both sessions, the same teacher distributed and collected the paper-and-pencil instruments and delivered standardized instructions.

To minimize expectancy and Hawthorne-related influences, given that the same teacher participated in both conditions, administration procedures were standardized across groups (identical instructions, timing, and classroom conditions), and the assessment sessions were framed as routine class activities. Scoring procedures for the knowledge test were defined in advance, and open-ended responses were evaluated using an agreed-upon scoring rubric with inter-rater reliability checks ($r > 0.85$), reducing subjectivity in outcome scoring.

Before data collection, students were informed that participation was voluntary, anonymous, and confidential, that they could discontinue at any point without penalty, that the data would be used solely for research purposes, and that participation would not affect their science grades. The questionnaires contained no identifying information, and only aggregated results were reported.

2.2.4. Educational Intervention

The instructional intervention consisted of a six-lesson unit, Sustainable Food Literacy in the Context of Climate Change, developed by the researcher under academic supervision and in collaboration with the school's science coordinator (Table 1). The unit aimed to deepen ninth-grade students' understanding of the relationships among dietary choices, human health, environmental sustainability, and climate change. Both the experimental and control groups studied the same curriculum content on sustainable nutrition and climate change; however, only the experimental group received explicit metacognitive guidance through structured planning, monitoring, self-evaluation, and reflection activities. This scaffolding was operationalized through a progressive sequence of prompts and artifacts: students began with guided reflection on familiar food choices, then used concept maps, food-label analysis, food-climate mapping, and consumption diaries, and finally applied these supports in a sustainable daily menu and personal action plan.

Table 1. Structure of the six-lesson intervention unit, including content focus, metacognitive focus, and student artifact.

Lesson	Content Focus	Metacognitive Focus	Student Artifact
1	Personal food choices and factors shaping eating decisions	Planning and prior-knowledge activation	Food-choice reflection
2	Nutrition, health, and body systems	Monitoring understanding	Concept map

Table 1. *Cont.*

Lesson	Content Focus	Metacognitive Focus	Student Artifact
3	Food labels and critical evaluation using De Bono's Six Thinking Hats	Questioning, comparison, and perspective taking	Label-analysis task
4	Food systems, greenhouse gas emissions, and climate change	Systems thinking	Food-climate map
5	Consumption patterns and environmental implications	Self-monitoring	Consumption diary
6	Sustainable daily menu and personal climate action	Self-evaluation and agency	Personal action plan

To strengthen transparency and reproducibility, each lesson was organized around a content focus, an explicit metacognitive component, and a student learning artifact. The sequence progressed from personal food choices and nutrition to food-system impacts, climate change connections, and personal sustainable action planning.

Throughout the unit, students engaged with reflective food journals, concept maps, consumption diaries, structured discussions, guided questioning, and collaborative menu-design tasks. These tools helped students plan their learning, monitor their understanding, evaluate their reasoning, and reflect on the personal and environmental implications of food choices. Consistent with the scaffolding model, these supports were designed to reduce task complexity, maintain students' direction toward the learning goals, highlight critical features of food-climate relationships, and support students' gradual movement toward independent reflection and action planning (Wood et al., 1976). Across sessions, metacognitive prompts supported self-regulation and constructive hope by emphasizing that informed individual and collective food choices can contribute to climate mitigation. This intervention structure is consistent with recent recommendations for sustainability education that combine applied practice, learner reflection, and local food-system contexts to support green and transversal competencies (McDonagh et al., 2026).

The unit was delivered over six weeks within regular science lessons, with equivalent instructional time in both groups. Implementation fidelity was monitored through structured observation checklists, teacher reflection logs, and coordination meetings. Fidelity checks focused on coverage of the planned lesson sequence, enactment of the core metacognitive components, and use of the intended learning artifacts. The checklist documented key elements in each session, including reflective prompts, completion of student artifacts, and brief whole-class debriefs. Fidelity materials were reviewed throughout implementation to verify that all six sessions were delivered as planned and that the core reflective tools were implemented largely as intended.

2.2.5. Post-Intervention Phase

After the six-week program, both groups completed a parallel version of the Sustainable Food and Climate Change knowledge test and the same climate change literacy questionnaire. The parallel test followed the same structure and content domains as the pre-intervention version, while using different item wording to reduce recall effects. In addition, individual semi-structured interviews were conducted with a purposive subsample of ten students from the experimental group to represent a range of academic achievement levels and participation styles. The interviews were held in a quiet room on the school premises after regular lessons, and each lasted approximately 30 min. All interviews were conducted by the researcher in the students' language of instruction using an interview guide that was validated by two experts in science and sustainability education. With

students' and parents' consent, interviews were audio-recorded and transcribed verbatim for analysis.

2.3. Data Analysis

2.3.1. Quantitative Analysis

All quantitative analyses were conducted in SPSS (version 30). Students' understanding of sustainable food, across health, environmental, and social dimensions, was assessed using a dedicated knowledge test. Multiple-choice and true/false items were scored dichotomously (1 = correct, 0 = incorrect). Open-ended items were scored using a predefined rubric and then coded dichotomously (1 = correct, 0 = incorrect) for inclusion in the total score. Total test scores were normalized to a 0–100 scale. Climate change literacy outcomes (perceptions, attitudes, and constructive hope) were measured using a five-point Likert scale (1 = strongly disagree, 5 = strongly agree), with higher scores indicating higher levels on each construct.

Analyses began with descriptive statistics (means, standard deviations), followed by inferential tests examining change over time (pre–post) and differences between instructional conditions. The primary analysis used a repeated-measures mixed-design ANOVA to test the time $\times$ group interaction. Complementary paired-samples and independent-samples *t*-tests were conducted to examine within-group and between-group differences, respectively.

To examine associations with constructive hope, multiple linear regression analyses tested whether post-intervention knowledge, climate change perceptions, and attitudes predicted constructive hope. Effect sizes were reported consistently: Cohen's *d* for within-group pre–post comparisons and partial η^2 for time $\times$ group interaction effects. Assumptions of normality and homogeneity of variance were checked before inferential testing. Asterisks in the tables indicate unadjusted *p*-values, whereas multiple within-group comparisons were interpreted cautiously using Bonferroni-adjusted significance levels.

2.3.2. Qualitative Analysis

Interview transcripts were read repeatedly to identify meaning units related to conceptual understanding, reflection, emotional engagement, and perceived agency. These units were initially coded, compared, and refined, and related codes were then grouped into broader categories reflecting students' perceived learning processes during the intervention. Credibility was supported through joint coding by the researcher and academic supervisor, inter-rater agreement above 85% across major categories, peer debriefing, and triangulation with the quantitative findings. The qualitative findings enriched the quantitative results by revealing how the intervention shaped students' understanding, attitudes, and sense of agency toward sustainability, providing contextual insight into students' perceived cognitive and affective learning processes during the intervention.

3. Results

This section evaluates the impact of the intervention on ninth-grade students' SFL knowledge test scores (*Sustainable Food and Climate Change Test*), perceptions, and attitudes toward climate change, and levels of constructive hope. Using mixed-design repeated-measures ANOVA, paired-samples *t*-tests, and independent-samples *t*-tests, pre- and post-intervention data were analyzed to examine within-group changes and between-group differences. The qualitative findings complemented these results, revealing conceptual growth, heightened moral awareness, and self-reported behavioral intentions and initial short-term changes, such as reduced meat consumption and a preference for local produce. Given the quasi-experimental design and modest sample size, the findings are interpreted

as intervention-related group differences and post-intervention statistical associations rather than definitive causal effects.

3.1. Quantitative Results

Before testing the hypotheses, we first examined pre-intervention equivalence between the experimental and control groups using independent-samples *t*-tests. As shown in Tables 2–4, no statistically meaningful baseline differences were found for SFL knowledge, climate-change perceptions, climate-change attitudes, or constructive hope. To improve clarity, the quantitative results are presented in the following sequence: baseline comparisons, intervention-related changes in SFL knowledge (H1), climate-change perceptions and attitudes (H2), constructive hope (H3), and the regression model predicting constructive hope (H4). Within-group pre–post changes, between-group differences, and time $\times$ group interactions are reported separately where relevant.

To test H1, a repeated-measures ANOVA compared pre- and post-test scores between the experimental and control groups. As summarized in Table 2, students in the experimental group showed a statistically significant improvement in the SFL knowledge test score, $t(27) = 5.14$, $p < 0.001$, Cohen's $d = 0.97$, indicating a large effect. Within-group pre–post results for each condition are reported in Table 2. The time $\times$ group interaction was significant, $F(1,57) = 10.69$, $p = 0.002$, partial $\eta^2 = 0.16$, suggesting a meaningful instructional impact of the unit.

Table 2. Descriptive and inferential statistics of SFL scores by group and time ($N = 59$).

Group	N	Pre M (SD)	Post M (SD)	Within-Group <i>t</i>	Between-Group <i>t</i> at Pretest	Between-Group <i>t</i> at Posttest	Time $\times$ Group <i>F</i>	Partial η^2
Experimental	28	65.68 (15.25)	83.93 (14.09)	$t(27) = 5.14$ ***	$t(57) = 1.22$	$t(57) = 2.38$ *	$F(1,57) = 10.69$ **	0.16
Control	31	70.68 (16.07)	74.97 (14.66)	$t(30) = 1.73$	—	—	—	—

Note. Values are presented as M (SD). Within-group *t*-tests compare pretest and posttest scores within each group. Between-group *t*-tests compare the experimental and control groups at each time point. The Time $\times$ Group *F* value refers to the repeated-measures interaction. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

To test H2, a repeated-measures ANOVA examined the effect of the unit on students' climate change perceptions and attitudes. As shown in Table 3, the experimental group demonstrated significant improvements on both measures, $p < 0.001$, with a very large effect for perceptions, Cohen's $d = 2.74$, and a large effect for attitudes, Cohen's $d = 1.13$. The time $\times$ group interactions were significant for climate change perceptions, $F(1,57) = 28.64$, $p < 0.001$, partial $\eta^2 = 0.33$, and for climate change attitudes, $F(1,57) = 11.31$, $p = 0.001$, partial $\eta^2 = 0.17$, suggesting a meaningful instructional impact of the intervention on the measured CCL dimensions.

Table 3. Means, standard deviations, and inferential statistics for climate-change perceptions and attitudes by group and time point ($N = 59$).

Outcome	Group	N	Pre M (SD)	Post M (SD)	Within-Group <i>t</i>	Between-Group <i>t</i> at Pretest	Between-Group <i>t</i> at Posttest	Time $\times$ Group <i>F</i>	Partial η^2
Climate-change perceptions	Experimental	28	3.25 (0.57)	4.78 (0.21)	$t(27) = 14.51$ ***	$t(57) = 1.78$	$t(37.17) = 7.74$ ***	$F(1,57) = 28.64$ ***	0.33
Climate-change perceptions	Control	31	3.57 (0.79)	3.85 (0.63)	$t(30) = 2.49$ *	—	—	—	—
Climate-change attitudes	Experimental	28	3.34 (0.65)	4.12 (0.12)	$t(27) = 5.96$ ***	$t(57) = 1.07$	$t(34.27) = 3.62$ ***	$F(1,57) = 11.31$ **	0.17
Climate-change attitudes	Control	31	3.53 (0.71)	3.77 (0.52)	$t(30) = 1.35$	—	—	—	—

Note. Values are presented as M (SD). Within-group *t*-tests compare pretest and posttest scores within each group. Between-group *t*-tests compare experimental and control groups at each time point. Time $\times$ Group *F* values refer to the repeated-measures interaction. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

To test H3, a repeated-measures ANOVA assessed the impact of the intervention on students' levels of constructive hope regarding climate change. As presented in Table 4, the experimental group showed a statistically significant post-intervention increase in constructive hope, $t(27) = 8.71$, $p < 0.001$. The time $\times$ group interaction was significant, $F(1,57) = 13.28$, $p < 0.001$, partial $\eta^2 = 0.19$, suggesting a meaningful instructional impact of the intervention on students' constructive hope toward climate action.

Table 4. Means and standard deviations of students' constructive hope by group and time point (scale 1–5), with inferential test results ($N = 59$).

Group	N	Pre M (SD)	Post M (SD)	Within-Group t	Between-Group t at Pretest	Between-Group t at Posttest	Time $\times$ Group F	Partial η^2
Experimental	28	3.51 (0.88)	4.97 (0.09)	$t(27) = 8.71$ ***	$t(57) = 0.59$	$t(30.94) = 6.35$ ***	$F(1,57) = 13.28$ ***	0.19
Control	31	3.63 (0.97)	4.13 (0.73)	$t(30) = 2.48$ *	—	—	—	—

Note. Values are presented as M (SD). Within-group t -tests compare pretest and posttest scores within each group. Between-group t -tests compare the experimental and control groups at each time point. The Time $\times$ Group F value refers to the repeated-measures interaction. * $p < 0.05$, *** $p < 0.001$.

To test H4, a multiple linear regression analysis examined whether students' post-intervention SFL knowledge, climate change perceptions, and climate change attitudes predicted constructive hope. As shown in Table 5, the model significantly predicted constructive hope, $F(3,55) = 59.61$, $p < 0.001$, $R = 0.875$, $R^2 = 0.765$, adjusted $R^2 = 0.752$, indicating that the model accounted for 76.5% of the variance in constructive hope. Climate change perceptions emerged as the only significant predictor, $B = 0.94$, $\beta = 0.92$, $t = 11.72$, $p < 0.001$, whereas SFL knowledge, $\beta = -0.02$, $t = -0.25$, $p = 0.80$, and climate change attitudes, $\beta = -0.10$, $t = -1.34$, $p = 0.19$, did not make significant unique contributions. These results suggest that students' climate change perceptions were the strongest statistical correlate of constructive hope in this sample.

Table 5. Multiple linear regression model predicting constructive hope based on SFL, climate change perceptions, and attitudes ($N = 59$).

Predictor	B	β	t	p
Constant	1.22	—	2.65	<0.05
SFL knowledge	0.00	−0.02	−0.25	0.80
Climate-change perceptions	0.94	0.92	11.72	<0.001
Climate-change attitudes	−0.16	−0.10	−1.34	0.19

Note. Dependent variable: post-intervention constructive hope. $R = 0.875$, $R^2 = 0.765$, adjusted $R^2 = 0.752$, $F(3,55) = 59.61$, $p < 0.001$.

While the quantitative results provide evidence of intervention-related gains, they do not fully capture the underlying processes through which students internalized these changes, which were further clarified by the qualitative findings.

3.2. Qualitative Findings

The qualitative findings illustrate how students in the intervention group experienced the metacognitive activities and how they described changes in understanding, reflection, responsibility, and perceived agency during the unit. These findings complement the quantitative results but are not used to make causal or comparative claims about the control group. The themes are interpreted as contextual accounts of students' perceived learning processes during the intervention, particularly in relation to food journals, concept maps, consumption diaries, structured discussions, and personal action planning. All participant

excerpts were translated into English for reporting purposes while preserving the meaning of the original statements. Three themes emerged: (1) deepened conceptual understanding through reflection, (2) strengthened environmental attitudes and emotional engagement, and (3) development of agency and constructive hope.

Theme 1: *Deepened Conceptual Understanding through Reflection*

This theme relates to interview questions asking students how the unit influenced their understanding of the relationship between food choices, health, sustainability, and climate change. Students reported that reflective components of the unit, particularly journaling, question formulation, and peer discussion, helped them connect food, health, and environmental systems. Analyzing their own dietary choices made patterns visible and linked personal behavior to broader sustainability concepts. For example, Student 1 (male) explained how the unit broadened his understanding of sustainable food: “When I thought about sustainable food, I used to think about expensive things. . . now I understand that it is also related to how food is produced and where we buy it.” Similarly, Student 2 (male) connected food choices with environmental systems, stating: “Now I understand that it is not only what we eat, but how it is produced and what effect it has on the environment. The meat industry contributes a lot to emissions.”

Students also noted that planning and monitoring their thinking improved their ability to evaluate information critically. Activities such as mapping ideas and comparing viewpoints helped them recognize the wider relationships among food, health, production, transport, and environmental impact. This was reflected in Student 3’s (female) explanation: “We now see how everything we eat is connected not only to our health, but also to entire ecological systems.” Overall, students described a move from memorizing facts to reasoning about relationships among systems and recognizing the complexity of sustainability.

Theme 2: *Strengthened Environmental Attitudes and Emotional Engagement*

This theme relates to interview questions asking students how the unit influenced their concern, responsibility, and willingness to engage with sustainability and climate-related issues. Across interviews, students described stronger emotional involvement and concern regarding sustainability issues. They expressed growing feelings of responsibility and care for the environment, supported by discussions and group work. Many reported that they had started to notice unsustainable behaviors around them and felt motivated to consider changes, such as reducing food waste or encouraging family members to buy more local food.

Collaborative tasks and open discussions were experienced as spaces where students could voice their opinions and hear others’ perspectives. Sharing personal experiences highlighted the potential impact of small individual actions on broader environmental goals. For example, Student 4 (female) described a shift from seeing food mainly as a personal or economic issue to understanding its environmental meaning: “I did not know much before the program. . . it seemed complicated to me. Now I understand that it is not only a matter of price, but also how we produce food and where we buy it.” Student 5 (female) expressed a stronger sense of personal responsibility, explaining: “Sustainable food is not only healthy food; it is also food that does not harm the environment.” Student 6 (female) linked dietary choices directly to climate responsibility: “If I eat more vegetables and less processed food, I can help prevent climate change.”

Theme 3: *Development of Agency and Constructive Hope*

This theme relates to interview questions asking students whether they felt capable of contributing to climate solutions and how they understood their individual and collective agency after the unit. Students described a growing belief that their everyday food choices

could contribute to sustainability and climate action. They emphasized a sense of personal responsibility and described practical changes that they had begun to consider or implement. For example, Student 7 (male) described translating the learning into everyday food choices: “I try to avoid eating meat every day. I choose more vegetables and make more salads. . . when I have the option, I try to choose local or organic food.” Similarly, Student 8 (female) emphasized gradual but intentional change: “I try to buy local vegetables when I can. . . and to eat less processed food.” Student 6 (female) also described an emerging sense of agency through personal decision-making: “I decided to eat more vegetables and less meat. . . I also try to buy local food.” These accounts reflected a cautious or partial form of change rather than a complete behavioral transformation. Students used expressions such as “I try” and “when I can,” suggesting that their actions were shaped by everyday possibilities, habits, and contextual constraints.

Through ongoing reflection and self-evaluation, students described a shift from passive awareness to more active engagement. Class discussions and self-assessment tasks supported them in setting personal goals for sustainable behavior and planning concrete steps to achieve them. Although these accounts do not demonstrate sustained behavioral change, they suggest that students began to view everyday food choices as a meaningful arena for personal responsibility, environmental awareness, and agency-oriented climate action.

3.3. Summary of Findings

The findings show that the unit was associated with significant improvements in students’ SFL knowledge, climate change perceptions, attitudes, and constructive hope. Quantitative analyses revealed consistent advantages for the experimental group across the measured outcomes. Regression analysis indicated that climate change perceptions were the strongest predictor of constructive hope, with the model explaining 76.5% of the variance, whereas SFL knowledge and climate change attitudes did not make significant unique contributions once perceptions were included in the model.

The quantitative results indicate what changed following the intervention: students in the experimental group showed greater gains in sustainable food literacy knowledge, climate-change perceptions, climate-change attitudes, and constructive hope than students in the control group. The qualitative findings contextualize these outcomes by illustrating how students described the reflective activities through which they connected food choices, climate change, responsibility, and perceived agency. Taken together, the findings suggest that the intervention supported an integrated learning process linking knowledge, reflection, emotion, and agency in students’ sustainability learning, while the qualitative evidence is interpreted as contextual rather than as independent evidence of causal mechanisms or between-group differences.

4. Discussion

This study examined whether a six-lesson metacognitively guided sustainable food–climate unit was associated with short-term changes in ninth-grade students’ sustainable food literacy knowledge, climate-change perceptions, climate-change attitudes, and constructive hope. The quantitative findings indicated greater pre–post gains in the experimental group than in the control group across the measured outcomes. The qualitative findings complemented these results by showing how students in the experimental group described reflection, self-monitoring, discussion, and learning artifacts as supporting their understanding of food–climate connections, responsibility, and perceived agency. Taken together, the findings suggest that metacognitive guidance may help connect cognitive, affective, and agency-oriented dimensions of sustainability learning. However, given the quasi-experimental design, the use of two intact classes, and the short-term nature

of the measures, these findings should be interpreted cautiously as intervention-related associations rather than definitive causal evidence.

4.1. Hypothesis 1—Sustainable Food Literacy and Reflective Understanding

In line with H1, students in the experimental group demonstrated a substantial improvement in SFL compared with those receiving traditional instruction, whereas the control group showed smaller and less consistent changes that were interpreted cautiously in light of multiple comparisons. Students in the experimental group moved from treating nutrition mainly as a health or economic issue to understanding food as part of an interconnected health–environment system. This shift was reflected in interviews, where students described how reflective journaling, question formulation, and peer discussion helped them analyze their own diets, recognize patterns, and connect personal food choices with broader sustainability concepts. They emphasized that these activities made learning ‘clearer’, ‘more personal’, and ‘connected to real life’. These experiences mirror mechanisms identified in prior metacognitive research. Metacognitive guidance-based instruction encourages learners to act in a planful way, monitor progress, adjust strategies, and reflect on their learning, thereby strengthening both understanding and long-term self-efficacy (Eberhart et al., 2025). Structured metacognitive questioning and guided reflection have been shown to enhance comprehension, self-regulation, and collaborative reasoning (Sadykova et al., 2024), and nutrition and food literacy are increasingly framed as multidimensional constructs that integrate cognitive, behavioral, and communicative skills (Silva et al., 2023).

Consistent with McManus et al. (2025), the present findings suggest that when SFL is taught through critical and reflective pedagogies, students are better able to connect nutrition, health, and environmental systems and to see food as a concrete arena for ethical and sustainable decision-making. This interpretation should also be balanced against evidence showing that knowledge-oriented environmental instruction may improve conceptual understanding without producing comparable attitudinal or behavioral change, suggesting that knowledge gains alone may be insufficient for sustainability-oriented engagement (Erhabor & Reis, 2026; Sejdiu & Ramadani, 2026).

4.2. Hypothesis 2—Climate-Related Perceptions, Attitudes, and Emotional Engagement

H2 was supported: relative to the control group, the experimental group showed significantly greater gains in climate change perceptions and attitudes. Interview data complemented these quantitative patterns by illustrating students’ deeper emotional and ethical engagement with sustainability and climate change issues. Students described heightened concern, a stronger sense of responsibility, and increased sensitivity to unsustainable practices in daily life. Many reported motivation to act (e.g., reducing food waste, encouraging local purchasing) and emphasized that collaborative discussions helped them exchange perspectives and recognize how small actions can contribute to broader climate goals.

These patterns are consistent with research showing that metacognitive strategies strengthen self-efficacy, confidence, and meaningful learning by enabling learners to monitor and regulate both cognition and emotion (Zimmerman & Moylan, 2009). In the present study, reflective activities such as questioning, self-explanation, discussion, and self-monitoring appear to have supported students’ attitudinal and emotional engagement with climate change issues. Domain-specific metacognition research further suggests that confidence in one’s climate knowledge predicts belief in anthropogenic climate change and openness to climate-related information beyond factual understanding alone (Said et al., 2023).

In sustainability education, explicit metacognitive guidance has been argued to deepen ethical commitment and moral awareness (Adler et al., 2016) and to support learning that connects conceptual understanding with reflection on human behavior in a sociocultural context (Hanisch & Eirdosh, 2023). The student narratives in the present study—combining awareness, responsibility, and willingness to act—illustrate this integration of cognition, affect, and values, aligning with work showing that reflective and critical dialog supports learners in positioning themselves as active agents rather than passive observers (McManus et al., 2025).

The findings also resonate with recent theoretical accounts of climate worry and hope. Rizeq and Ojala (2024) report that climate worry can relate positively to climate-friendly behavior when paired with hope, whereas hope without concern is less predictive of engagement. Similarly, Finnegan and d’Abreu’s (2024) Hope Wheel model proposes that emotionally honest, reflective, action-oriented pedagogy can transform anxiety into agency. In this light, metacognitive guidance-based instruction may provide practical “handrails” by prompting students to articulate, evaluate, and refine their views, thereby linking climate knowledge to emotionally grounded attitudes and responsibility.

4.3. Hypothesis 3—Constructive Hope and Agency

H3 predicted that the intervention would enhance constructive hope and perceived agency for climate action. Quantitatively, the experimental group showed a statistically significant increase in constructive hope, while the control group showed a smaller and less central change. This pattern is notable in light of evidence that climate worry is widespread among young people and often disrupts daily functioning, accompanied by fears about the future and perceptions of governmental failure (Hickman et al., 2021). Importantly, climate anxiety can coexist with hope, implying that distress can be transformed rather than suppressed. In this context, the present focus on constructive hope highlights a possible pathway for channeling justified worry into reflective, efficacy-based engagement by linking climate perceptions to agency and meaningful action.

Qualitative findings converged with these results. Students described feeling more confident and capable of change, emphasizing that action could begin with small steps and extend outward through influence on family and community. They reported shifting from passive awareness to active engagement by setting personal goals and planning concrete actions aligned with more sustainable behavior.

These patterns align with theoretical accounts that conceptualize constructive hope as an outcome of cognitive appraisal, emotional awareness, and perceived agency (Ojala, 2023; Azevedo, 2020). Metacognitive reflection may support this process by helping learners interpret concern realistically, regulate emotion, and sustain engagement through efficacy-based optimism. In climate education, constructive hope has been linked to mitigation knowledge, perceived response efficacy, and opportunities to act (Ratinen, 2021). More broadly, hope is often treated as a component of self-regulated learning (Schunk & Zimmerman, 2012).

Consistent with this view, the present findings suggest that increased concern, strengthened climate perceptions, and guided self-reflection supported students’ beliefs that collective action can make change possible. This interpretation accords with evidence that hope most strongly predicts behavior and well-being when paired with realistic awareness of climate threats (Rizeq & Ojala, 2024), and with accounts positioning constructive hope in sustainability education as rooted in care, relational responsibility, and commitment to both people and planet (Furu et al., 2026). Moreover, while purely positive affect without concern may undermine genuine engagement (Bechtoldt & Schermelleh-Engel, 2025), the hope observed here appears reflective and informed rather than naïve. This interpretation is supported by recent evidence that hope and empathy can strengthen sustainability en-

agement when they are embedded in dialogic, reflective, and action-oriented learning processes (Sejdiu & Ramadani, 2026).

4.4. Hypothesis 4—Perceptions as Predictors of Constructive Hope

H4 proposed that SFL, climate change perceptions, and attitudes would jointly predict constructive hope, with perceptions showing the strongest association. The regression model explained substantial variance in constructive hope ($R^2 = 0.765$). However, only climate change perceptions made a unique contribution ($\beta = 0.92$, $p < 0.001$); SFL and attitudes were not significant once perceptions were included ($p = 0.80$; $p = 0.19$). Thus, H4 was partially supported: perceptions emerged as the dominant predictor, whereas SFL and attitudes did not contribute uniquely at the multivariate level. These null findings are important because they suggest that knowledge and positive attitudes alone were not sufficient to explain unique variance in constructive hope once climate-change perceptions were included in the model. Because the regression analysis was based on post-intervention scores, this finding identifies the strongest statistical association in the model rather than a causal driver of constructive hope. In this study, climate change perceptions captured students' appraisal of climate impacts on health, ecosystems, and natural resources, thereby reflecting how personally and socially meaningful climate change appeared to them. This pattern is consistent with Garrecht et al. (2026), who found that risk perception was the strongest predictor of students' willingness to engage in climate action, while cognitive factors had weaker explanatory power.

Substantively, this pattern suggests that constructive hope was shaped less by knowledge or positive attitudes in isolation and more by students' appraisal of climate-change impacts—how they understood the seriousness, consequences, and personal and social relevance of climate change. In the present study, the perceptions subscale captured students' appraisal of climate impacts on health, ecosystems, and natural resources, whereas perceived agency and efficacy were assessed as part of constructive hope. Thus, the regression finding suggests that students' understanding of climate-change impacts was closely linked to their agency-oriented hope. This accords with prior work emphasizing cognitive appraisal and meaning-making as central to climate-related hope and engagement (Ojala, 2012, 2015, 2023), and with domain-specific metacognition research showing that judgments about one's climate knowledge shape acceptance of anthropogenic climate change and openness to new information beyond factual accuracy alone (Fischer & Said, 2021).

Within the proposed framework, the findings imply that the unit may influence constructive hope primarily by reshaping climate-related perceptions. Through activities such as food-label analysis, mapping food–climate connections, and structured debate about dietary impacts, students may have integrated food, health, and environmental knowledge into more coherent, efficacy-oriented climate narratives. In this light, SFL and attitudes may contribute indirectly—by informing perceptions and broader efficacy beliefs—rather than exerting strong independent effects once perceptions are accounted for. This interpretation is consistent with evidence that sustainability competencies and emotions are most likely to support engagement when anchored in a clear understanding of how individual and collective actions can make a difference (Kumar et al., 2023; McManus et al., 2025; Ratinen & Uusiautti, 2020). Pedagogically, these results underscore the need for instruction that goes beyond promoting “pro-environmental attitudes” or isolated knowledge. Metacognitively guided sustainability education should explicitly scaffold students' construction of well-grounded, efficacy-oriented climate perceptions by prompting them to monitor and evaluate their reasoning, interrogate scientific and media claims, and connect abstract concepts to concrete contexts such as everyday food choices.

4.5. From Literacy to Action: Integrating Cognitive, Emotional, and Behavioral Change

In line with research question 5, the qualitative themes illustrate how students experienced shifts in understanding, emotions, and agency as a result of the unit. The qualitative themes provide insight into how students connected the statistical gains with lived experience, perceived agency, and self-reported intentions for action. The participant accounts reported in the qualitative findings suggest that students experienced the unit not only as content learning, but also as a reflective process through which they connected food choices, climate responsibility, and perceived agency. This interpretation aligns with prior work emphasizing that sustainability education requires the integration of knowledge, reflection, affective engagement, and opportunities for agency-oriented action. These changes reflect the development of systems thinking and metacognitive learning processes described by Schuster et al. (2020) and are compatible with multidimensional sustainability frameworks that integrate health, environment, and equity. They also illustrate sustainability learning as a process that weaves together knowledge, values, identity, and civic responsibility (Rieckmann, 2018).

At the same time, some students acknowledged difficulties sustaining behavioral change, pointing to persistent contextual barriers. This tension echoes the well-documented ‘knowledge-action gap’ in environmental behavior (Kollmuss & Agyeman, 2002) and supports Ojala’s (2015) argument that lasting transformation requires not only knowledge but also emotional engagement, identity reinforcement, and supportive social environments. Lundholm et al. (2026) add that climate change education should also address public-sphere and policy-oriented forms of action, because students’ perceptions of effectiveness and fairness are positively related to support for climate policies. The present findings suggest that metacognitive guidance-based instruction can nurture informed literacy, agency, and constructive hope, but its long-term behavioral impact will depend on ongoing reinforcement by families, communities, and institutions (Newell et al., 2021).

Importantly, these findings should not be interpreted only in terms of private-sphere food choices; rather, they suggest that classroom-based sustainability education can inspire broader change by helping students connect personal responsibility, collective agency, and everyday action with the vision of a more sustainable and greener future.

The students’ reflections also resonate with futures-oriented, inquiry-based approaches that help learners envision desirable and sustainable futures and transform anxiety into agency (Liu & Château, 2025). Their accounts of caring for people, nature, and community, and of feeling responsible for future generations, parallel Furu et al.’s (2026) description of hope and care as foundational to professional and moral growth in sustainability education. Taken together, the quantitative and qualitative findings support a coherent picture: metacognitive guidance-based sustainability education can foster the cognitive, affective, and behavioral integration necessary for transformative learning and sustained climate engagement.

As such, this classroom-based case contributes to broader sustainability debates on how school science education can operationalise education for sustainable development and climate change education through concrete, metacognitively oriented pedagogical designs. Overall, the findings address the research questions by showing that the unit was associated with larger gains in SFL knowledge, climate-related perceptions and attitudes, and constructive hope than traditional instruction. The regression results further showed that climate-change perceptions were the strongest post-intervention predictor of constructive hope, while the qualitative findings illustrated how reflection, self-monitoring, and discussion helped students connect scientific understanding with responsibility, agency, and initial self-reported action intentions.

These findings suggest a possible pathway through which metacognitive guidance may help connect sustainability knowledge with reflection, perceived agency, and constructive hope. The six-lesson intervention was sufficient for examining short-term classroom outcomes, but not for determining whether students' self-reported intentions or initial food-choice changes were sustained over time. For classroom practice, this suggests that teachers can embed brief metacognitive prompts, concept maps, food-label analysis, reflection journals, and self-evaluation tasks into sustainability lessons to help students connect abstract climate concepts with everyday food choices and perceived agency.

5. Conclusions, Limitations, and Future Research

Based on the measured outcomes, this study provides short-term classroom-based evidence that the metacognitively guided food–climate unit was associated with greater gains in sustainable food literacy knowledge, climate-change perceptions, climate-change attitudes, and constructive hope than traditional instruction. The regression results further showed that climate-change perceptions were the strongest post-intervention correlate of constructive hope, whereas sustainable food literacy knowledge and climate-change attitudes did not make significant unique contributions once perceptions were included. The interview data support a cautious interpretation by illustrating how students described reflection, self-monitoring, discussion, and learning artifacts as helping them connect food choices with climate responsibility and perceived agency. These conclusions are consistent with literature emphasizing that sustainability education requires not only factual knowledge, but also reflective, affective, and agency-oriented engagement.

Qualitative evidence complemented these results by showing how students internalized reflection, self-regulation, and ethical reasoning during the unit. Participants described not only strengthened conceptual understanding but also heightened emotional involvement, increased responsibility, and self-reported shifts in consumption intentions and practices (e.g., reducing meat intake; preferring local or minimally processed foods). Taken together, the quantitative and qualitative strands suggest that metacognitive guidance-based instruction may help connect knowledge, reflection, and self-reported action intentions, making sustainability education more value-driven, emotionally grounded, and oriented toward constructive hope. Food, in this framework, functions as a powerful pedagogical context for linking scientific understanding with moral reasoning and civic responsibility.

In summary, the study provides short-term classroom-based evidence that metacognitive guidance can support sustainable food literacy by promoting critical thinking, planning, and self-regulation. Empirically, the intervention group showed gains in SFL knowledge, climate-change perceptions and attitudes, and constructive hope, while climate-change perceptions emerged as the strongest correlate of constructive hope once SFL knowledge and attitudes were included in the regression model. Practically, the findings suggest that food–climate learning can serve as an integrative context for connecting nutrition, health, climate education, reflection, and perceived agency. Future research should examine these relationships in larger and more diverse samples, include more classrooms with random assignment at the class or school level where feasible, use longer interventions and delayed posttests, and incorporate direct behavioral measures alongside additional qualitative sources such as observations, portfolios, or reflective journals.

Despite these contributions, findings should be interpreted in light of limitations. The small, non-random sample of 59 students from two intact classes in a single Druze school limits statistical power, generalizability, and the ability to conduct more complex analyses such as mediation or multilevel modeling. The findings may also reflect local cultural, linguistic, curricular, and community characteristics of this Druze school context and should therefore be generalized cautiously to other educational settings. Transferability

is most plausible for lower-secondary science classrooms using food–climate content and teacher-guided reflection, and should be tested before applying the findings to other age groups, school systems, or cultural settings. The brief six-lesson duration, short-term self-report measures, teacher–researcher role, and use of intact classes mean that novelty effects, teacher expectancy, class-level differences, and short-term enthusiasm may also have contributed to the observed results. These constraints may limit generalizability and may have inflated observed effect sizes. Because sustainability-related action was assessed only through students’ self-reported short-term intentions and initial food-choice changes shortly after the intervention, the study cannot determine whether these intentions translated into sustained climate-related behavior. The very high post-intervention constructive hope scores in the experimental group suggest a possible ceiling effect and may also reflect short-term enthusiasm or social desirability; therefore, these findings should be interpreted cautiously. Because only the experimental group completed the structured reflection activities and only students from that group were interviewed, the qualitative findings should be interpreted as contextual accounts of perceived intervention experiences rather than as comparative evidence about differences between the experimental and control groups. The study, therefore, cannot determine whether similar reflections would have emerged among control-group students under comparable interview conditions. In addition, because interviews were conducted only with students from the experimental group, the qualitative findings should be interpreted as contextual accounts of perceived intervention experiences rather than as comparative evidence about differences between the experimental and control groups.

Because the study involved only two intact classes, the intervention condition was partly confounded with class membership, and class-level influences cannot be fully ruled out. Accordingly, the findings should be interpreted as classroom-based comparative pre–post evidence rather than as evidence from an individually randomized trial or a fully integrated mixed-methods design. The absence of a delayed posttest or longitudinal follow-up further limits the ability to determine whether gains in knowledge, attitudes, constructive hope, or students’ self-reported intentions were sustained beyond the immediate post-intervention period. Future studies should include more classrooms, random assignment at the class or school level where feasible, and longitudinal follow-up measures.

Future research should replicate the study with larger and more diverse samples, longer interventions, and designs that better address clustering and expectancy threats. Methodologically, combining additional qualitative sources (e.g., classroom observations, portfolios, and student reflective journals) would strengthen process-level understanding of how metacognitive guidance cultivates SFL and constructive hope across contexts. Overall, the findings should be understood as short-term evidence from one classroom-based intervention, and they should not be generalized to sustained behavioral change or to all educational and cultural contexts. This conclusion aligns with recent calls for sustainability education to move beyond content mastery toward pedagogies that integrate knowledge, reflection, affective engagement, and agency for action (Sejdiu & Ramadani, 2026).

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