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College Students' Plausibility Perceptions about Global Climate Change: Implementation of Model Evidence Link Diagram

Gizem Ozyazici[1] · **Gaye Defne Ceyhan**[2]

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Abstract
Human-induced climate change intensifies extreme weather events due to its profound impact on the Earth's atmospheric balance. Despite its global relevance, research on climate education predominantly focuses on K-12 levels or college science majors, leaving a significant gap in understanding how non-science majors engage with this critical issue. Addressing this gap, this study examines the impact of a scaffolding activity, the Extreme Weather Model-Evidence Link (EW-MEL) diagram activity, on non-science major college students' perceptions of global climate change and its connection to extreme weather events. The research was conducted with 62 college students from a research university in the United States. The study employed a pre-post quasi-experimental design to examine whether students' plausibility perceptions about climate change alter after participating in the EW-MEL activity. The findings indicated a statistically significant change in students' plausibility perceptions after the MEL activity. Moreover, in the EW MEL activity, while more students found the scientific explanation plausible, many also found the alternative explanation plausible. This indicates that despite students' acknowledgement of the human impact on global climate change, misunderstandings may still exist. The study highlights the need for explicitly teaching critical evaluation in higher education to enhance students' understanding of evidence-based decision making.

Keywords Climate change · MEL diagram · Plausibility perceptions · Conceptual change

✉ Gizem Ozyazici
gozyazic@syr.edu

Gaye Defne Ceyhan
gdceyhan@gmail.com

[1] Department of Science Teaching, Syracuse University, Syracuse, NY, USA

[2] Department of Mathematics and Science Education, Bogazici University, Istanbul, Turkey

Introduction

Global climate change (GCC) is a controversial socio-scientific issue (SSI) that affects all members of society (Dawson & Carson, 2020), not just those working in scientific fields. Thus, every individual needs to have a fundamental understanding of GCC. Research demonstrates the benefits of teaching climate change (Sullivan et al., 2014). However, research shows that students have alternative conceptions and scientifically incorrect understandings (Reinoso Tapia et al., 2019), about GCC, for instance, confusing weather with climate (Boon, 2010; Bozkurt, 2019; da Rosa, 2022). In addition, students may mistakenly believe that short-term weather changes indicate long-term climate patterns (Lombardi et al., 2020; Lowther, 2023). These alternative conceptions arise from individuals' everyday experiences and are particularly common among youth (Reinoso Tapia et al., 2019). Students' alternative conceptions related to GCC are also related to extreme weather (EW) events and considering that extreme weather events have increased since the industrial revolution, and the increase in GCC and EW events are related (Wagner, 2020), it is important to eliminate non-scientific conceptions related to GCC. GCC education plays an important role in helping people understand the causes, impacts, risks, mitigation, and adaptation strategies of GCC. However, there is evidence that GCC education in the U.S. is still a work in progress, and K-12 education is insufficient to effectively articulate scientific agreement at the national level (Plutzer et al., 2016). Researchers have also explored the level of student concern about GCC in different studies (Kuppa, 2018; Marlon et al., 2022). One study found that a significant portion of American youth lack a basic understanding of GCC concepts and show limited concern about it, despite some schools incorporating GCC education (Leiserowitz et al., 2011; Marlon et al., 2022). Survey responses indicate that both youth and adults have non-scientific or alternative conceptions and gaps in their knowledge of this critical issue, which may contribute to skepticism among youth who often struggle to understand climate science (Monroe et al., 2019). In addition, a large proportion of Americans believe that scientists cannot predict the future climate (Leiserowitz et al., 2010), and willingness to act on GCC tends to be lower United States than in other countries (Lee et al., 2020). GCC education on college level is crucial since college students often engage with complex topics, making this an ideal time to explore the multifaceted nature of GCC (Anderson, 2012). Also, colleges foster critical thinking, and argumentation skills that are critical to addressing GCC (Sinatra & Lombardi, 2020). Therefore, it is important to examine both science and non-science college students' perceptions related to GCC, since it concerns every citizen.

Research highlights the important role of plausibility, a critical component of conceptual change in GCC education. Sinatra and Lombardi (2020) found that plausibility judgments are critical to how individuals evaluate evidence and information about climate change, directly influencing their understanding and decision-making processes. Similarly, Lombardi et al. (2016) demonstrated that students' plausibility perceptions are strong predictors of their engagement and conceptual change when learning about climate change. Literature highlights the need to integrate plausibility into pedagogical strategies to enhance GCC understanding (Hanedar et al., 2024). Model-Evidence Link (MEL) diagrams have been shown to effectively support plausibility studies by emphasizing the coordination of evidence, models, and ideas (Ceyhan et al., 2021). Critical evaluation, a core aspect of science education, involves assessing the relationship between evidence and alternative descriptions (Can & Saribas, 2019). MEL diagrams act as scaffolds to make this practice explicit through argumentation (Governor & Villarin, 2024). Lombardi et al. (2018) showed that

MEL activities improved high school students' plausibility judgments and knowledge in earth science topics by fostering evidence-based evaluations. Despite these successes, challenges remain. For instance, a study involving college pre-service teachers revealed that some groups struggled with critical thinking and cognitive elaboration when evaluating the credibility of scientific and alternative claims (Ceyhan et al., 2021). While the MEL diagram has been studied in K-12 and science-focused classrooms, there is a notable gap in research exploring its application among college students, especially non-science majors. Further investigation is needed to understand how such tools can enhance critical evaluation.

According to a recent study, human-induced GCC has increased the frequency and severity of daily temperature extremes (Fazel-Rastgar, 2020; Lombardi et al., 2020) and Lombardi and colleagues (2020) developed the EW MEL, which focuses on weather-related events, such as the number of annual precipitation events in the U.S. during the twentieth century. It is important to investigate non-science major college students' plausibility perceptions about GCC because it is a global crisis affecting every citizen. This study aims to address the gap in understanding students' perceptions and evaluations of GCC, with a particular focus on non-science majors. The main significance of this study is the use of the EW-MEL diagram as a treatment and bridging the gap in the literature. The primary purpose of the current study is to examine whether college students' plausibility perceptions of the climate crisis change after the MEL diagram intervention. In addition, the secondary purpose of this study is to examine how college students evaluate competing explanations of current GCC by addressing the following research questions:

1) How do, if any, college students in non-science majors' plausibility perceptions about GCC change after the implementation of the EW MEL diagram?
2) How do college students in non-science majors evaluate scientific and alternative explanations about global climate change and extreme weather events?
3) How plausible do college students in non-science majors find the models in the EW MEL activity about extreme weather events and global climate change?

Conceptual Change Theory (CCT)

Understanding of climate dynamics is important for climate literacy (Hornsey & Fielding, 2020). CCT, a commonly used approach in the field of GCC education (Ceyhan & Mugaloglu, 2020; Lombardi & Sinatra, 2012), has been crucial in addressing and eliminating non-scientific conceptions (Ceyhan & Mugaloglu, 2020; Dole & Sinatra, 1998). According to CCT, new knowledge must be intelligent, fruitful, and plausible (Dole & Sinatra, 1998). In this context, plausibility emerges as a central element in conceptual change (Sinatra & Lombardi, 2020), as it promotes conceptual understanding, which is defined as an individual's subjective perspective on the veracity of a message (Lombardi & Sinatra, 2012). Plausibility has been emphasized (Dole & Sinatra, 1998; Posner et al., 1982), particularly in CCT, to achieve robust shifts in understanding. This theory involves the reconstruction of concepts, both theoretically and empirically, and provides a robust framework for reducing non-scientific conceptions (Dole & Sinatra, 1998). Plausibility is integral to the process of overcoming non-scientific conceptions (Sinatra & Lombardi, 2020) and research has shown that there is a strong relationship between plausibility and understanding of GCC (Ceyhan & Mugaloglu, 2020).

Literature shows there are still several non-scientific conceptions about GCC (Maertens et al., 2020). Understanding and addressing these in science education is essential and conceptual change is at the heart of both learning science because to truly grasp scientific principles, one must undergo conceptual shifts, transforming everyday understandings into expanded concepts. To achieve a level of scientific literacy on climate-related issues, individuals must have a concept also essential to the refinement of science education itself (Russell & Martin, 2023). One study claims that students come to science class with some non-scientific views of science that are incongruent and have non-scientific conceptions that resist change (Treagust & Duit, 2008). CCT can be used to remove this resistance. For example, Beeth (1998) implied that using conceptual change elements, intelligibility, and plausibility, helped students to have a better understanding of their ideas. Conceptual change explores how students perceive the nature of the concept. It helps to examine how students consider scientific concepts in relation to their views of reality. Students' dissatisfaction with an existing concept catalyzes significant or revolutionary conceptual change (Duschl & Gitomer, 1991). This perspective, which emphasizes the importance of an individual's conceptual development, is consistent with radical constructivist epistemological views. When a learner experiences dissatisfaction with the prior conception, and an alternative conception that is intelligible, plausible, and/or fruitful is available, adaptation to the new conception may occur. This process underscores the dynamic nature of conceptual change, which is influenced by both ontological considerations about the nature of the concept and epistemological factors related to prior knowledge (Mortimer &El-Hani, 2014; Treagust & Duit, 2008).

Addressing challenges, Lombardi and Danielson (2018) suggest that these instructional difficulties may happen. However, they also suggest strategies for overcoming these challenges, such as use of argumentation and model-based reasoning. Therefore, the implementation of instructional scaffolds, such as MEL diagram, is crucial to facilitate conceptual change (Ceyhan et al., 2021). Researchers have found MEL diagrams to be valuable in assessing students' critical evaluations (Can & Saribas, 2019). Research supports that students must explicitly reevaluate their plausibility judgments to successfully reconstruct their understanding of complex issues (Lombardi et al., 2013) for conceptual change to occur. CTT underscores the need to design educational interventions that encourage students to critically evaluate and reframe their beliefs, thereby fostering deeper engagement and understanding of scientific concepts.

MEL Diagram on the Extreme Weather (EW) Events

MEL diagrams have been shown to help students make connections, evaluate some evidence and models, and improve their ability to critically evaluate scientific arguments and deepen their understanding (Chinn & Buckland, 2012; Lombardi et al., 2013). According to a recent study, human induced GCC has increased the frequency and severity of daily temperature extremes (Lombardi et al., 2020). EW events can be classified as floods, droughts, tropical cyclones heat waves and cold waves (Walsh et al., 2020). There has also been an increase in certain extreme weather and climate events, such as more intense hurricanes, floods, droughts, and heat waves (Stott et al., 2016). In addition, GCC may alter the frequency, timing, intensity, and duration of these events. Moreover, there has been an increase in heavy precipitation over the past century. Future climate scenarios suggest an increase in the intensity and frequency of extreme precipitation events, including

precipitation during hurricanes, increasing the risk of flooding (Huang et al., 2021). Even though these changes are observable and experienced by many people, one study found that students may believe that long-term climate patterns can be inferred from short-term weather trends (Lombardi & Sinatra, 2012) and that students often confuse weather and climate and are unaware of the types and sources of radiation involved in the greenhouse effect. (Ozdem et al., 2014). As climate-related extreme events have persisted longer than weather events and EW events have increased in recent years, the relationship between EW events and climate change has come to the forefront. For these reasons, Lombardi and colleagues (2020) created the EW MEL, which focuses on weather-related events, such as the number of annual precipitation events in the U.S. during the twentieth century.

In the EW MEL diagram activity, there are three parts. The first part includes plausibility rankings of Model A (scientific model) and Model B (non-scientific, alternative model). In the second part, four lines of scientific evidence and two different models (Model A and Model B) are provided, and students are expected to draw lines about the connections between the evidence and the models (Lombardi et al., 2020). For this part, a document with more explanation about each piece of evidence is provided in a separate document that students can access to better understand each piece of evidence. For the model evidence connections, there are four types of arrows that students can use to make a connection: strongly supports, supports, contradicts, and has nothing to do with. Students are expected to draw two arrows for each piece of evidence in each model. The final part of the activity is explanation tasks where students are asked to evaluate the evidence connections and plausibility ratings of their model.

Method

Design

The current study uses a pre-post, one-group quasi-experimental design to examine college students' plausibility perspectives, allowing researchers to apply a treatment and assess participants' views on a specific topic (Miller et al., 2020). In this study, the treatment is the EW MEL diagram activity, implemented in a non-science college classroom in the topic of GCC. The goal of the science course is to provide a basic level of scientific knowledge and understanding to non-science majors. Since the current classroom uses materials online, the virtual version of EW MEL diagram has been used in this study. Moreover, the updated Plausibility Perception Measure (PPM) scale, used to assess students' plausibility perceptions before and after the treatment. The scale focuses on students' views regarding GCC. The PPM scale is Likert scale (1: Greatly implausible, 10: Highly plausible) with 15 items from The Intergovernmental Panel on Climate Change report (Hanedar et al., 2024). The PPM scale's emphasis on extreme weather events and human induced GCC aligns with the study's focus, making it an appropriate tool for measuring student perceptions.

The MEL is appropriate for the instructional design of the current lesson, as it fosters critical thinking by encouraging students to engage in deep cognitive processing and re-evaluate relationships between evidence and explanations (Lombardi et al., 2020). Research indicates that students often enter science classes with naive beliefs that may not align with current scientific understanding (Bahar, 2003). Therefore, assessing students' plausibility perceptions is crucial. Given the importance of science education for all students, this study design is well-suited for the context. To complement the quantitative data,

qualitative data were also collected during the EW MEL diagram activity, focusing on students' explanation tasks to provide a comprehensive analysis of their understanding. The EW MEL activity includes structured prompts that guide students to justify their model-evidence associations and compare their reasoning with alternative explanations. This process encourages students to critically assess the quality of evidence and consider how it supports or contradicts each model, promoting evidence-based decision-making (Lombardi et al., 2016). The inclusion of EW-related items in the PPM scale further supports the appropriateness of using the EW MEL diagram activity in this study.

The MEL scaffold enhances higher-order thinking by requiring students to analyze evidence, identify relationships, and articulate reasoning in written explanations (Lombardi et al., 2016). MEL diagrams also facilitate argumentation, helping students build and evaluate arguments (Governor & Villarin, 2024). Research shows that argumentation can promote critical thinking, and the MEL diagram scaffold plays a key role in supporting students' evaluative skills (Ceyhan et al., 2021). Furthermore, the MEL activity aligns with the goals of the undergraduate science course, which emphasizes the development of both basic scientific knowledge and critical evaluation skills. By encouraging students to reflect on their connections and justify their judgments, the MEL activity directly fosters critical thinking, making it an effective tool for addressing real-world scientific challenges.

Participants

The current study was conducted in the spring of 2023 with 62 college students at a private university in the U.S. who were enrolled in an undergraduate science course for non-majors and who volunteered to participate in the study. This study received approval from the Institutional Review Board (IRB) before the data collection. The goal of the course was for students to be able to develop their own, more scientific models and explanations of how the world works. Students participated in the pretest, MEL diagram activity, and posttest. Purposive sampling was used in the current study since it refers to a sampling method with characteristics that you need in your sample (Rahi, 2017) and participants are specifically selected as non-science major college students in the current study. Demographic information showed that 35 participants identified as female, 25 as male, 1 participant identified as non-binary, and 1 identified as transgender. 47 of the participants were first-year students, 6 were sophomores, 3 were juniors, and 5 were seniors. In addition, 51 of the participants had never taken an environmental course, while 11 had.

Instruments

Demographic Form

The online demographic questionnaire was used to collect data about the participants. Participants were asked about their gender, class year, major field of study, and whether they had taken courses on environmental issues. A consent form was also included on the first page of the questionnaire.

EW MEL Diagram

The increase in the frequency of extreme weather events is a critical issue we face in today's world related to GCC (Lombardi et al., 2020). The EW MEL diagram (Lombardi et al., 2020)

is a type of MEL diagram used as a treatment in this research. Students were asked to rank the plausibility of models, evaluate the connections between the data and competing hypotheses about the relationship between extreme weather and climate change in the EW MEL diagram.

Plausibility Perception Measure (PPM)

The PPM tool was developed by Lombardi and Sinatra (2012) following the IPCC Fourth Assessment Report 2007 to assess participants' plausibility perceptions of human induced GCC (Lombardi & Sinatra, 2012). However, the IPCC 2022 report includes different factors. Therefore, the updated PPM is well suited for the current study because it effectively measures GCC plausibility perceptions (Hanedar et al., 2024) that have been examined in the literature (Can & Saribas, 2019).

Data Collection and Procedure

Students enrolled in an undergraduate science course at a private research university in the United States participated in the current study. The primary goal of this science course is to provide a basic level of scientific knowledge and understanding to students who may not have a specific academic focus on science as their major. Because the researcher had access to the Blackboard technology program used in the current course, Blackboard was used to provide the links and access to the documents. In total, data collection took three weeks. For data collection, students first voluntarily completed the consent form and demographic form provided on the first page of the PPM scale using the Google Forms link provided by the researcher. Then, students individually completed the PPM scale using the Google Forms link provided by the researcher. In the following lesson, students worked in class on the EW MEL activity. This activity was designed to encourage a deep understanding by providing students with different models and evidence about GCC and the critical concept of plausibility checking and reassessing their ratings at the end. In the current study, since students use their computers or tablets in each classroom activity, a virtual version of EW MEL is used. The researcher explained the EW MEL activity and provided a link to the activity using the Blackboard system at the beginning of the EW MEL activity. Given the researcher's role as a teaching assistant and her access to the Blackboard educational technology program used in this course, this platform was used to provide the necessary links and access, and the necessary links for the activity were added to the system by the researcher for student access. The EW MEL activity has three main parts. First, the students completed plausibility ratings in the MEL activity. In this activity, there are two models, and students are asked to rate their plausibility. Students completed the MEL activity individually (Fig. 1).

Students then began working together in their regular small groups (of two or three) during class. Together, they engaged in the EW MEL Model-Evidence Diagram activity, as shown in Fig. 2, the diagram contained four evidence texts and two models, and students were asked to select two arrows for each piece of evidence and link them to the corresponding models. Participants completed the EW MEL diagram by inserting arrows of different shapes to symbolize their assessment of the level of agreement between each piece of evidence and a model. This process involved careful examination of the evidence text-document link. A straight arrow with an "X" indicated inconsistent evidence with the model, a dashed arrow indicated disagreement, a squiggly arrow indicated strong support for the model, and a straight arrow indicated support. Students used the virtual PowerPoint version of the model evidence link association. This portion of the activity was completed

Plausibility of Models Explaining Increases in Extreme Weather Events

Name_____**Date**_____**Teacher**_____**Period**_____

Please work on this individually and read the following information carefully.

Humans create *models* to help explain things.

Below are two models. These provide different explanations for increases in extreme weather events over the last 50 years. These events include intense hurricanes, heavier rainfall and flooding, dangerous wildfires, and heat waves.

Model A: Increases in extreme weather events are linked to climate change. Current climate change is mainly caused by human activities, such as fossil fuel use.

A person who supports this model makes the following argument:

Human activities are increasing the amount of carbon in the atmosphere and changing Earth's climate. Increases in extreme weather events must then be linked to current climate change and human activities that cause this change.

Model B: Over time, increases and decreases in extreme weather events are mainly caused by changes in Earth's orbit around the Sun.

A person who supports this model makes the following argument:

The number and strength of extreme weather events varies over time. The amount of sunlight received by Earth also varies over time. Because energy from sunlight is a major contributor to Earth's climate and weather, changes in extreme weather are a result of orbital variations.

Plausibility is a judgment we make about the potential truthfulness of one explanatory model compared to another. The judgment may be tentative (not certain). You do not have to be committed to that decision.

Circle the plausibility of each model. [Make three circles, one for each model.]

	Greatly implausible (or even impossible)									Highly plausible
Model A	1	2	3	4	5	6	7	8	9	10
Model B	1	2	3	4	5	6	7	8	9	10

Fig. 1 MEL diagram model plausibility ratings

within an estimated timeframe of one hour. Concurrently, the researcher addressed questions posed by students. Upon completion, participants saved the final version as a slide and uploaded it to Blackboard. Notably, students were not required to provide their names; instead, they used the last four digits of their university ID number for all data collection.

The final stage of the EW MEL diagram entailed an explanation task, in which students were tasked with evaluating their links between models and evidence, providing reasoning about their associations, and reassessing the plausibility ratings for both models using the same models from the initial task. Additionally, students were required to justify their selection of the more plausible model. The MEL scaffold fosters higher-order thinking through tasks that require students to critically analyze evidence, identify relationships, and articulate reasoning in written explanations (Lombardi, Sinatra, & Nussbaum, 2016).

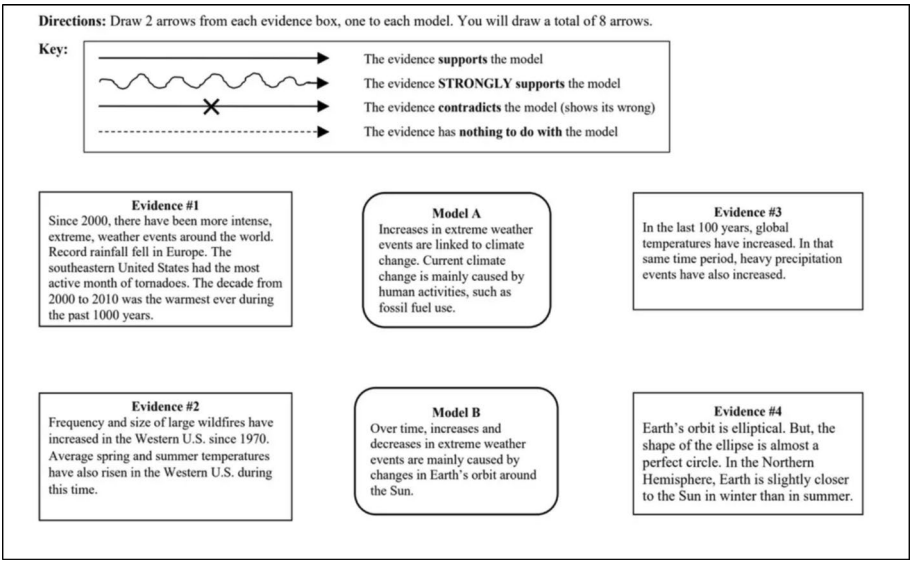

Fig. 2 EW MEL diagram model evidence links associations

Each student independently completed this explanation task using the Google Form link provided by the researcher in the Blackboard system, with the goal of critically evaluating their connections and developing a comprehensive understanding. A revised version of this rubric was used in this study, and the application process took approximately 30 min.

Data Analysis

The data analysis was conducted in three parts in the current study. Analysis of pre-post PPM, MEL activity including associations and explanation tasks, pre-post model plausibility ratings in the MEL activity. To explore non-science majors' plausibility perceptions and see if there is a significant difference, pre-post PPM analyzed. For statistical analysis, assumptions such as paired observations, normality of differences and absence of outliers were checked to ensure the validity of the paired sample t-test. First, a descriptive analysis for the pre- and post-PPM scale was conducted to examine students' plausibility perceptions. The mean scores from the pre- and post-PPM scale were then compared through the SPSS program. Secondly, the paired sample t-test was employed to determine whether there was a significant difference between the pre- and post-test scores for the group (Dugard & Todman, 1995) (Table 1).

Table 1 The number of correct and false associations between evidence lines and models

	MA-E1	MA-E2	MA-E3	MA-E4	MB-E1	MB-E2	MB-E3	MB-E4
Correct	28	27	29	24	15	14	12	7
False	2	3	1	6	15	16	18	23

For the MEL activity, to maintain consistency and reliability in the scoring process, two subject-matter experts independently evaluated model-evidence associations. In accordance with the established consensus, the inter-rater reliability was subsequently calculated, yielding nearly perfect agreement. Thereafter, the appropriate model-evidence associations for each line of evidence were determined. In the analysis, model-evidence links were categorized into three groups: supports/strongly supports, which were combined into a single group to streamline the analysis; nothing to do with, indicating no connection between the model and evidence, and contradicts. When students answer questions with model evidence association answers suggested by experts, it is accepted as a correct model evidence association. To help students make informed decisions, explicit criteria were provided during the activity to distinguish between support and strong support, such as the amount, consistency, and reliability of the evidence. For example, for Model A, evidence 1 should be linked with Model A by using supports or strongly supports link. For the explanation task part, the students' explanations for the MEL associations were evaluated using a rubric adapted from Lombardi et al. (2016) with four explanation categories (Table 2). For students' plausibility perceptions regarding the models given in the MEL activity, the means of the ratings for Model A and Model B at the beginning of the activity and at the end of the explanation task were analyzed.

Results

How do College Students in Non-Science Majors' Plausibility Perceptions about GCC Change after the Implementation of the EW MEL Diagram?

Descriptive statistics and paired sample t-tests were used to compare the pre-and post-test scores of a group in the current study. Descriptive statistics of the PPM scale, Likert scale from 0 to 10 with 15 items, before and after the implementation of EW MEL diagram results showed that for the pre-test, the mean score was found to be $M = 118.48$ $SD = 22.83$, and for the post-test, the mean score was $M = 124.74$ $SD = 18.29$. Also, for both the pre-test and post-test the maximum score was found to be 150 while the minimum score for the pre-test was found to be 64, and the minimum score for post-test was found to be 90 while the maximum PPM score was 150. The current study used an updated PPM scale to assess students' perceptions of the GCC before and after the EW MEL diagram (Hanedar et al., 2024). It analyzed the difference between pre- and post-test scores. The mean score in the post-test was higher than the mean score in the pre-test. A paired samples t-test was conducted to determine if there was a statistically significant difference between pre and post-test scores. Results showed that there was a statistically significant difference between pre- and post-test, $t\ (df\ (61)) = -3.37$, $p = 0.001$). The effect size, calculated using Cohen's d, was 0.35, indicating a medium effect (Wilcox & Tian, 2011). According to the pre-post PPM results, students' plausibility perceptions about GCC increased significantly after the EW MEL activity, which was supported by the literature indicating MEL activities were found useful in developing students' critical evaluations (Ceyhan et al., 2021; Lombardi et al., 2018).

Table 2 Sample student statements for each category

Category	Students' Answer	Score
Erroneous evaluation	Evidence 1 contradicts Model A	1
Descriptive evaluation	Evidence 2 supports Model A. It talks about the frequency and size of wildfires in the western US	2
Relational evaluation	Evidence 1 shows that EW patterns have occurred since the industrial revolution and shows a correlation with climate change	3
Critical evaluation	Evidence 1 strongly supports Model A since the increasing temperature showed a change in climate (e.x. heavier precipitations) showing the impact of humans and human induced climate change resulting and the warming of the climate and extreme events	4

How do College Students in Non-Science Majors Evaluate Scientific and Alternative Explanations about Global Climate Change and Extreme Weather Events?

Students completed the EW MEL diagram and explanation task and were asked to provide explanations for the models and evidence links. If students' answers lie in the same category determined by experts, it is accepted as correct. Table 1 shows that the MEL diagrams were analyzed, and most groups correctly associated the lines of evidence and model A in the EW MEL diagram. However, for the evidence lines and model B, most groups made an incorrect association. The model-evidence associations for MB-E2, MB-E3, and MB-E4 were mostly incorrect (Table 1). In total, 156 correct and 84 incorrect model-evidence associations were found in the EW MEL activity, and the incorrect associations were mostly related to model B. Thus, although the number of correct associations was almost twice the number of incorrect associations, the number of incorrect associations was very high, especially for evidence lines and model B. The number of incorrect model-evidence associations was almost twice the number of correct associations.

An explanation task scoring rubric, revised by the researcher and originally developed by Lombardi et al. in 2016, was used for analysis, which included four increasing levels of scoring from incorrect to critical (Lombardi et al., 2016; Lombardi, 2018). Table 2 shows examples of student statements for each category.

Even though students showed more accurate model-evidence links in the EW MEL, as shown in Fig. 3, their explanations mainly fell into the category of erroneous evaluation. This pattern suggests an initial lack of comprehension necessary for conducting a meaningful assessment, as highlighted by Lombardi et al. (2016). For instance, an erroneous explanation involved a student asserting, "Evidence 4 supports Model B because they both discuss the Earth's orbit around the Sun". The second most prevalent group of explanations was characterized by descriptive evaluation, indicating a correct identification of relationships without further elaboration or an accurate interpretation of evidence

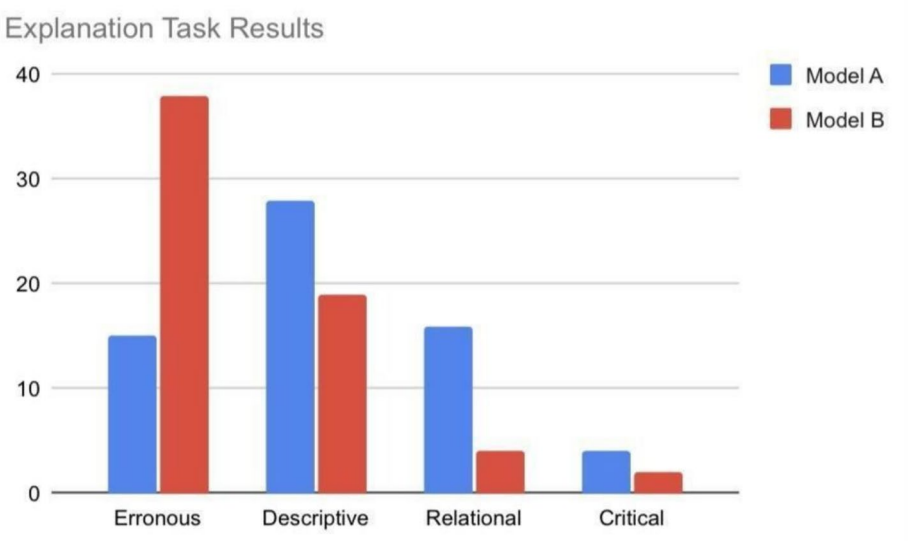

Fig. 3 Explanation task results of the participants

without explicitly stating the relationship (Lombardi et al., 2016). Furthermore, during the explanation task, some students reported a shift in their plausibility judgments after engaging with the EW MEL diagram. For example, one student reported, "Evidence two and three have greatly changed the plausibility of model A." Overall, although many students perceived Model A to be more plausible than Model B, their explanations for Model B were predominantly erroneous, indicating a lack of understanding of Model B. Conversely, explanations for Model A were mostly characterized as descriptive.

Another notable finding was that although students mostly demonstrated accurate model-evidence connections, their explanations tended to fall into the incorrect rating category during the EW MEL analysis. Students often provided incorrect explanations despite making correct model-evidence matches. Similar findings were reported by Can and Saribas (2019), indicating a common challenge in students' critical evaluation skills. The results also showed that students' evaluations were mostly found to be descriptive for model A (scientific model), similar to Can and Saribas (2019), whereas their explanations were mostly found to be erroneous for model B (see Fig. 3).

In the current study, students demonstrated success in constructing accurate connections in MEL diagrams related to EW and GCC. However, their evaluation of model-evidence relationships was often limited to error and descriptive levels. This highlights the need for improved understanding and critical assessment of GCC and EW events, especially given their societal significance. Lastly, since the students in this study are studying in a field other than science, these results are very important because these students will become politicians, economists, artists etc. and they will be part of guiding the citizens in the future.

How Plausible do College Students in Non-Science Majors Find the Models in the EW MEL Activity about Extreme Weather Events and Global Climate Change?

In the plausibility ratings, the mean plausibility rating of Model A was 8.3, while the mean plausibility rating of Model B was 5.4 before the EW MEL intervention. Results showed that 87% of the participants found Model A (scientific explanation) more plausible than Model B (alternative explanation). Figure 4 shows plausibility ratings for Model A and Model B before and after the intervention.

It can be concluded that students mostly linked the increase in EW events to GCC correctly. However, they have misunderstandings about the relationship between GCC and EW events as well as main causes about EW events. It is supported in explanation task results; their evaluations were mostly found erroneous and descriptive level about their answers. Specifically, their explanations for Model B (alternative model) were predominantly erroneous, and their model link associations were accepted as false more than correct (see in Table 1).

Moreover, in the plausibility ratings section, Model A received an average rating of 8.3, while Model B received an average rating of 5.4 prior to the implementation of the EW MEL intervention. After the MEL diagram, the mean plausibility rating of Model A was 8.5, while the mean plausibility rating of Model B was 5.1, which shows students' plausibility perceptions related to model has shifted with the EW MEL diagram. In addition, although the majority of participants found Model A more plausible, Model B was rated as plausible by many students even though it is considered as non-scientific consensus.

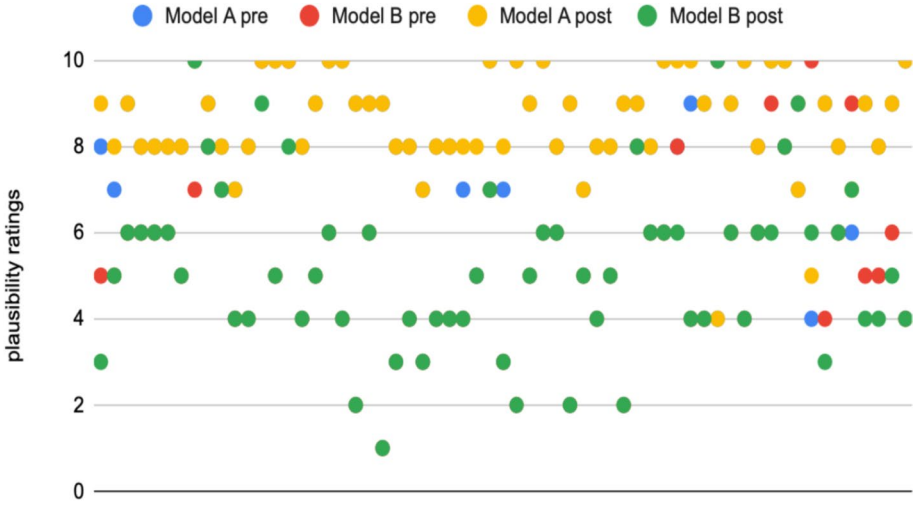

Fig. 4 Plausibility ratings before and after the implementation of the MEL diagram

Discussion and Conclusion

This study contributes valuable insights to GCC education by demonstrating using scaffolds, such as EW-MEL diagram, in improving students' perceptions of GCC (Can & Saribas, 2019; Ceyhan et al., 2021). It also provides practical guidance for incorporating MEL diagrams into non-science college classrooms. The significant difference found between the pre- and post-test PPM scores in the paired-samples t-test indicated that the instructional interventions, such as the EW MEL diagram, had a positive effect on the plausibility perceptions of the non-science majors. This supports the literature, as previous studies have demonstrated the effectiveness of MEL diagrams in improving students' evaluation and argumentation skills, especially in connecting evidence to alternative models (Ceyhanet al., 2021; Saribas & Akdemir, 2019). In a recent study with middle school students, researchers used the MEL diagram, and the paired samples t-test revealed no significant shifts in plausibility from pre- to post-teaching (Klavon et al., 2023). In the current study, however, there was a significant difference between the pre- and post-test scores on the PPM scale. Undergraduate students' plausibility perceptions of GCC increased significantly after the EW MEL activity, which was supported by the literature (Ceyhan et al., 2021; Lombardi et al., 2013, 2018).

Students' alternative and critical explanations of EW MEL showed that students' model-evidence connections were mostly correct. However, their explanations were mostly in the incorrect evaluation category, indicating a lack of critical evaluation during the explanation of the MEL. Overall, in the EW MEL treatment, it was found that students' responses to the explanation task were mostly incorrect, and although they had more correct evidence-model links for Model A, they had more incorrect evidence-model links for Model B. The results of this study underscore the complexity of students' perceptions of GCC and the persistence of alternative conceptions even after exposure to educational interventions. Despite the statistically significant change in students' plausibility perceptions following the implementation of the EW MEL activity, it is evident that alternative conceptions may persist among non-science majors. This finding is supported by the existing literature,

which may indicate students' non-science conceptions of GCC (Chang & Pascua, 2016; Klavon, 2023). It also highlights the existence of alternative conceptions that hinder a comprehensive understanding of the material and the importance of improving scientific literacy among college students, especially through explicit teaching methods that promote critical evaluation skills (Saribas & Akdemir, 2019). The findings are consistent with discussions emphasizing that presenting scientific issues alone isn't enough to improve argumentation skills (Can & Saribas, 2019). Moreover, understanding risk in decision-making about SSIs such as GCC requires critical evaluation beyond information acquisition. The study highlights the importance of addressing alternative conceptions and improving students' ability to critically evaluate evidence and explanations related to SSIs.

In the plausibility ratings for the models, participants were asked to evaluate the plausibility of two models. Overall, students rated the scientific explanation (Model A) as more plausible than the alternative explanation (Model B). However, the fact that many students still found Model B plausible indicates that alternative conceptions persist despite educational interventions. This underscores the need for more targeted and comprehensive approaches to teaching GCC in higher education (Barton & Tan, 2021). By incorporating explicit instruction in critical evaluation skills, educators can better equip students to distinguish between scientifically valid explanations and erroneous beliefs. In addition, emphasizing evidence-based decision-making in the context of GCC education can empower students to critically evaluate information and make informed decisions about environmental policies and actions (Ceyhan et al., 2021). By fostering a deeper understanding of evidence-based decision making, educators can empower students to navigate complex issues (Saribas & Akdemir, 2019) more effectively. Moreover, the result of this study shows the effectiveness of scaffolding activities in influencing students' perceptions of GCC and related EW events. The statistically significant change in students' plausibility perceptions following the implementation of the EW MEL activity suggests that scaffolding can play a critical role in facilitating conceptual change among non-science majors, similar to literature (Ceyhan et al., 2021). The MEL scaffolds create an environment that leads to critical thinking (Ceyhan et al., 2021; Klavon et al., 2023), which is significantly different from the traditional method (Can, 2017).

The EW-MEL activity emphasizes evidence-based decision making in the context of GCC education by engaging students in group work to collaboratively linked evidence and models, evaluate connections between evidence and alternative explanations (Lombardi et al., 2013). This collaborative process fosters discussion and critical analysis, allowing students to explore multiple perspectives and refine their reasoning (Governor & Villarin, 2024). In addition, the explanation task supports critical reflection by requiring students to articulate their plausibility judgments and justify the connections they make between evidence and explanatory models. This task encourages students to analyze their decision-making process individually. By integrating these reflective components, the activity promotes deeper engagement with the content and actively supports the development of critical thinking skills in the context of evaluating climate-related evidence. The use of scaffolds such as MEL diagrams has been shown in the literature to improve students' critical thinking skills and ability to evaluate reasoning (Ceyhan et al., 2021; Can & Saribas, 2019; Lombardi et al., 2020). This is further supported by the plausibility ranking results, where more students rated model A (scientific explanation) as more plausible and model B (alternative explanation) as less plausible after the intervention. In addition, the PPM scale scores also showed significant improvement, indicating the effectiveness of the MEL activity in promoting evidence-based reasoning. Therefore, according to the results of the current study, it can be argued that the activity supports the expected outcomes by

improving students' GCC perceptions. However, given the complexity of GCC as a social science issue, a single lesson could be insufficient to fully develop students' understanding or ability to critically evaluate their responses. While the MEL activity demonstrated its usefulness in improving students' perceptions, more science classrooms should be using approaches that foster critical thinking and fosters argumentation with instructional scaffolds (Can & Saribas, 2019; Lombardi et al., 2013). Current findings underscore the importance of using pedagogical scaffolding and addressing perceptions of plausibility to improve students' understanding of climate change issues.

In conclusion, this study highlights the importance of integrating MEL diagrams into GCC classrooms to address alternative conceptions and promote students' scientific understanding of GCC. There is an ongoing need for effective GCC education that promotes critical thinking. The results of the current study show that college students struggle to critically evaluate different models of GCC and extreme weather events. With such approaches, educators can play a critical role in raising awareness and promoting climate-smart behaviors to positively impact environmental issues in the GCC region. By examining university students' plausibility of GCC and using a MEL diagram, this research shows that such tools have a significant impact on students' perceptions of plausibility and helps to identify where students are still lacking by asking for their explanations. This is important for science education because MEL diagrams provide important information to instructors by presenting students' evaluations (Lombardi et al., 2018). The results of this study have significant implications for promoting critical evaluation skills in science topics. It is critical to understand students' plausibility perceptions and scientific evaluations of GCC, as these perceptions influence conceptual understanding and behavior. Leal (2023) mentioned the increasing importance of students' plausibility perceptions, highlighting their impact on understanding and behavior. Using tools such as the MEL diagram, educators can guide students in scientifically evaluating their judgments, thereby increasing awareness and fostering a more scientific approach to addressing GCC. The implementation of student-centered approaches is emerging as a promising way for educators to enhance the learning experience and facilitate meaningful knowledge acquisition among students (Klavon et al., 2023).

Limitations and Suggestions

The first limitation is related to generalizability because the current study used a purposive sampling method to select participants. Specifically, the study was limited to a single private research university in the U.S. To increase generalizability, future research could replicate the study with a larger and more diverse sample from both public and private universities. A limitation of the MEL activity is that students may have made correct model-evidence link associations based on prior knowledge or chance rather than understanding GCC. This limitation highlights the importance of the explanation task, which requires students to articulate their reasoning and engage in argumentation, thereby strengthening the activity's ability to promote critical thinking. However, the low number of critical and relational explanations observed in this study suggests that there is still significant room for improvement in GCC education in the United States. Future research could explore the plausibility perceptions of different SSIs or the perceptions of different groups of GCC. As a recommendation, it is suggested that MEL diagrams such as the EW MEL diagram be integrated into climate change education. This MEL diagram can emphasize

the importance of both EW events and GCC. Since EW events are observable in daily life, their inclusion in GCC training allows individuals to critically evaluate these events. This approach can increase the effectiveness of climate change education by linking it to tangible, real-world experiences.

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Data Availability The datasets analyzed in the current study are available from the corresponding author on reasonable request.

Declarations

Human Ethics and Consent to Participate This study was conducted in accordance with ethical guidelines and received approval from the Institutional Review Board (IRB), number IRB-23–135. Informed consent was obtained from all participants prior to their involvement in the study.

Competing Interests The authors declare no competing interests.

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