Received: 16 November 2022 | Revised: 5 July 2023 | Accepted: 3 August 2023

DOI: 10.1002/sce.21826

RESEARCH ARTICLE

Science Education WILEY

Student reasonings and cognitive biases in climate change predictions

Kaela Clabaugh Howell | **Emily A. Holt**

Department of Biological Sciences, University of Northern Colorado, Greeley, Colorado, USA

Correspondence
Kaela Clabaugh Howell and Emily A. Holt, Department of Biological Sciences, University of Northern Colorado, Greeley, CO, USA.
Email: kaela.clabaugh@gmail.com and emily.holt@unco.edu

Abstract

Undergraduate biology educators strive to understand how to best teach students the concepts of climate change. The root of this understanding is the establishment of what students know about climate change. This research aims to describe undergraduate biology students' conceptions of climate change and their argument practices and associated cognitive biases in how they think about the topic. We used qualitative conception interviews to obtain data from 26 American biology undergraduate students who predicted how climate change would affect a forested ecosystem after an average of 1° increase in Fahrenheit (0.5°C change) over 25 years. Through deductive coding, we found the majority of students' predictions agreed with expert ideas. However, the students used various argument strategies (i.e., Reasoning and Cognitive Biases) in defending their choices, including Ecological Explanations, Observations, Anchoring, and Contrast Effects.

KEYWORDS

anchoring, contrast effect, ecology, observations, reasoning, science education

1 | INTRODUCTION

Climate change is a global priority that will have severe, negative impacts on both the natural and human world (IPCC, 2023). The Paris Agreement demanded that the 192 participating, "Parties shall cooperate in taking measures, as appropriate, to enhance climate change education, training, public awareness, public participation and public access to information," (United Nations, 2015, p. 16). Keller et al. (2019) noted how combining transdisciplinary and moderate constructivist approaches in the classroom increases climate change understanding in teenagers. Holt et al. (2021) found that students enrolled in an introductory biology class or ecology class were able to identify three biotic outcomes of climate change, changes to an animal's growth and survival, their reproduction, or their distribution. Unfortunately, despite acceptance of climate change (Fleming et al., 2021) or climate-focused education, many undergraduate students hold alternative conceptions (Driver & Easley, 1978) about climate change, such as the hole in ozone being the cause of global warming and climate change (Wachholz et al., 2014) or conflation of weather and climate (Bostrom, 2017). Additionally, students may also hold the alternate conception that climate change is primarily a natural variability of climate (Fleming et al., 2021). Huxster et al. (2015) found undergraduates had some basic understanding of the science behind climate change, but gaps exist in some students' ability to discriminate climate change from other environmental issues.

Complicating the push for climate change education, research linking climate change education interventions with actionable outcomes by students is contradictory. Harring and Jagers (2018) noted after only one semester that college students are less likely to support policy changes related to climate change, such as regulation and information. Other research has found that knowledge of climate impacts do not correlate with willingness to act on climate change (Tolppanen et al., 2021). There seems to be limited findings where education alone leads to action. As a notable exception, students reported that an intensive 1-year university course affected their daily activities after taking the course (Cordero et al., 2020). However, some research suggests that even when students are willing to act, their responsiveness greatly depends on the type of environmental action (Skamp et al., 2013; Tolppanen et al., 2021). Collectively, these findings suggest that education may be a starting point towards eliciting students' action to mitigating climate change, but itself is often not enough.

2 | THEORETICAL BACKGROUND

2.1 | Students' ability to argue in science

Toulmin (1958) developed a model for argumentation, framing claims as assertions of knowledge, which is still tested and used today across multiple fields (Liu & Wan, 2020). These claims are then backed by a warrant that uses data as evidence to explain or support the claim (Osborne, 2010). Basel et al. (2013) used Toulmin's foundation to build a system for argument complexity, where the lowest complexity includes an unjustified claim accompanied by only unreasoned statements (e.g., observations, definitions) or a single warrant. Meanwhile, the most complex arguments include a claim justified by multiple evidence (i.e., warrants) or possibly justifies claims with rebuttals of counterclaims (Basel et al., 2013). A discourse analysis framework devised by Russ et al. (2008) aligns with these patterns in students' mechanistic reasoning about physics concepts, where students begin by describing and identifying entities as part of the context of the problem—representing evidence of their claim—and then progress to linking this information together by "chaining."

Analysis and defense of claims using data is a critical part of the field of science (Driver et al., 2000). Argumentation, as a learned skill set, can help students develop critical thinking skills required in their professional lives (Gültepe & Kılıç, 2021); thus, educational interventions using argumentation are common. Classroom interventions have shown that students' argumentation skills can be improved with instruction (Erduran et al., 2004; Nurinda et al., 2018). Gülen and Yaman (2019) found that when science classes were integrated into Toulmin's model, students had higher scores. Likewise, frequent argumentation activities have a positive effect on student biology content knowledge (Dorfner et al., 2018).

In education and research contexts, the literature has debated the synonymy of and discrepancy between argumentation and explanation (Berland & McNeill, 2012; Osborne & Patterson, 2011). Some define an argument as a tentative conclusion aimed to persuade, whereas an explanation is a definite conclusion not in doubt that offers possible causal mechanisms (Osborne & Patterson, 2011). In a classroom, students may construct explanations using prior knowledge and information teachers provide (Osborne & Patterson, 2011). Ideally, students will attempt to establish and defend what they believe to be the truth through arguments beyond their education, in their everyday life (Osborne, 2010). Another viewpoint describes arguments as trying to convince others but also specifies how people use reasoning skills to evaluate arguments (Mercier, 2016). As researchers, we can also use students' construction of arguments, specifically their reasonings, as a window into their thinking about how and what data they use to support claims about the world around them.

Gaining this window into student thinking is especially critical when investigating topics, including socioscientific issues (SSIs; e.g., genetically modified organisms, vaccines, evolution, climate change; Zeidler & Sadler, 2023), which can be strife with alternative conceptions, such as believing vaccines give you the disease or that individuals evolve. Numerous research studies use open-ended interviews to investigate student thinking and argumentation capacity about SSIs (Jarrett & Takacs, 2020; Shah et al., 2022; Wu, 2013). Likewise, this research lends insight into how curricula could be constructed to engage students in productive discourse on complex and controversial topics (Basel et al., 2013). However, preservice teachers often prefer monologic discourse when it comes to SSI instruction in the classroom (Kilinc et al., 2017). This preference may explain the limited number of studies where argumentation is used as a central intervention in SSI instruction. However, Lederman et al. (2023) handbook reports on accounts from Christodolou and Grace (2019), which detail the importance of argumentation in the context of SSIs. Even so, some research has shown the use of discussion and argumentation can advance student learning on climate change (Mason & Santi, 1998). The ability to reason and argue with data about SSIs is important for students. Zeidler et al. (2005) suggest that in the construction of scientific knowledge, students need exposure to and the ability to analyze SSIs.

The ability for students to discuss scientific issues is an important skill both professionally and personally. Specifically, argumentation is an important aspect of defending scientific work and criticizing scientific information, which is done not only in science careers but during public life (Driver et al., 2000). Argumentation is a key skill in the field of science and thus important to scaffold skill-building through educational efforts (Driver et al., 2000). The analysis of argumentation and explanations provided by students on scientific subjects, such as SSIs, can help provide deeper understanding of how students are constructing their knowledge in science classrooms.

2.2 | Influence of cognitive biases in SSIs

Everyday decision-making involves the use of mental shortcuts or heuristic principles to reduce the complexity of prediction tasks, but these may also lead to cognitive biases (Tversky & Kahneman, 1974). Although heuristics ideally narrows potential prediction choices to the best answer, bias may lead individuals to an incorrect or an incomplete response. Furthermore, cognitive bias can lead to everyday errors in work settings, including diagnostic medicine and governmental intelligence (O'Sullivan & Schofield, 2018; Tee et al., 2021; Whitesmith, 2020). In education, cognitive biases can shortcut learning and lead to alternative conceptions about various aspects of biology (Coley & Tanner, 2012; Heine et al., 2017; Pobiner et al., 2019). Furthermore, cognitive biases are negatively affecting acceptance and action about important topics including climate change (Mazutis & Eckardt, 2017). However, there is research into situations in which cognitive biases are used rationally and productively (Lieder et al., 2017; Todd & Gigerenzer, 2000).

Research describes how cognitive biases influence climate change belief and/or action at the individual and social levels (Gifford, 2011; Lorenzoni et al., 2007; Mazutis & Eckardt, 2017). Much of this literature focuses on how these biases affect behavioral decision-making that leads, or fails to lead, individuals into climate action. Some examples of the many reported cognitive biases linked to climate change are discounting the future (Shu & Bazerman, 2010) where current concerns are overweighted over future concerns, perception bias (Mazutis & Eckardt, 2017) where psychological distance (Trope & Liberman, 2010) limits individuals from conceptualizing climate change as a problem, and status quo bias (Palmucci & Ferraris, 2023) that limits individuals from acting for fear of failure. Gifford (2011) summarized these biases as "dragons of inaction," which encompass a multitude of psychological barriers that then block people from action against climate change. These barriers or biases led to prevention of climate change acceptance as a true issue and/or action against it (Gifford, 2011; Lorenzoni et al., 2007; Mazutis & Eckardt, 2017). Interestingly, most of these biases are linked to behavioral decision-making about climate action and few are investigated in the role they play in an individual's understanding of climate change itself. As an exception, Mazutis and Eckardt (2017) describe how anchoring bias (see below) can challenge the public's understanding of climate change dependent upon the presentation of temperature and time of climate change data.

Anchoring bias occurs when people make estimates by anchoring their ideas on initial information they are given and adjust accordingly (Tversky & Kahneman, 1974). Frederick and Mochon (2012) describe how an individual's decision may be anchored by the scale, or unit of measurement, they are given. Anchors can be numerical (e.g., weight, number of calories) or perceptual (e.g., touch, auditory) information provided to an individual (Frederick & Mochon, 2012; Jain et al., 2021). These anchors can cause the individual to incorrectly estimate their prediction due to the initial value influencing their predictions (Givi & Galak, 2019). Anchoring has further been demonstrated to affect decision-making and establishment of beliefs about climate change (Joireman et al., 2010). The degree of increase in global temperatures acts as an anchor; the higher the increase values provided by researchers results in greater beliefs in climate change by participants (Joireman et al., 2010). Anchoring related to climate change has been studied in a variety of ways, such as anchoring by expert consensus and emotional anchoring in media reports (Goldberg et al., 2019; Höijer, 2010). Similar to formatting in the IPCC report (IPCC, 2018), a two-anchor system minimizes the effect of an anchor on climate science beliefs, in addition to verbal probability expressions (i.e., likely, unlikely) so that less regression occurs in interpretations (Harris et al., 2017). Although anchoring with concepts such as climate change can lead to errors or alternative conceptions, the literature is unclear of the effects anchors, as a form of cognitive bias, have on undergraduate student predictions and understanding of climate change.

Contrast effects are another type of heuristic and can lead to other cognitive biases that may relate to one's understanding or reasoning about climate change. Contrast effects arise when individuals are provided an array of choices from which to choose and are swayed to one choice because of the array rather than qualities of the single option chosen (Simonson & Tversky, 1992). Given the nature of contrast effects, they are critical in behavioral studies in marketing fields (Neumann et al., 2016). Simonson and Tversky (1992) proposed one specific type of contrast effect affecting decision-making for consumers in these situations is extremeness aversion. Extremeness aversion occurs when an individual's choice purposely avoids the most extreme options (Neumann et al., 2016). Extremeness aversion can manifest in two possible behaviors, polarization where consumers select one extreme over the opposing end or compromise where the middle option is selected (Simonson & Tversky, 1992). The latter is a symmetric effect of extremeness aversion (Neumann et al., 2016) and aims to be a compromise of the other options (Simonson, 1989). Although contrast effects may benefit individuals in consumer settings, these cognitive biases may interfere with learning and productive argumentation in educational settings.

Climate change is an important social issue with which students will be faced throughout their lives. The ability to decipher evidence and articulate reasoning is key in interpreting climate change information. Moreover, identifying potential cognitive biases students may use in their arguments and decision-making on climate change is a first critical step in climate change education. Future educational materials and interventions could be designed to minimize potential cognitive biases resulting from anchoring and the contrast effect. Our eventual goal is that students are able to intentionally evaluate information or choices about climate change rather than merely comparing them or being anchored by a certain value. We hope that climate literate students who avoid cognitive biases will contribute to a more climate literate public whose decision-making and understanding of climate change could impact society.

3 | RESEARCH OBJECTIVES

The aim of this research is to describe undergraduate biology students' conceptions of climate change and their argument practices and associated cognitive biases in how they think about the topic. Our specific research objectives were: (1) To determine whether American biology undergraduate students have an accurate conception of how climate change will affect forested ecosystems. (2) To describe students' argumentation about how climate change will affect a forested ecosystem, including categorizing Reasoning as Ecological Explanations or explanations based on Observations. (3) To explore types of cognitive biases that occur in student arguments about climate change effects, including categorizing biases as anchors of numerical information from the prompt, or contrast effects as they compare possible answers to select their response.

4 | METHODS

Our research was designed to identify trends in students' argumentation processes about how climate change might potentially affect organisms. We used qualitative interviews to probe student conceptions about these topics. The Institutional Review Board of the University of Northern Colorado approved the procedures for this study (IRB# 1288162-4). Consent was secured for all participants before the interview process via an online survey. To preserve confidentiality, individual participant names are replaced with pseudonyms, and quotes presented in this study are anonymized and edited for clarity. We assigned pseudonyms using a random name generator to represent a diversity of voices, but these names do not necessarily reflect the actual identity of the participants.

4.1 | Sampling

We used purposeful sampling (Merriam & Tisdell, 2015) and recruited students from both introductory biology classes and more advanced ecology courses at the university level. Through professional contacts, we identified instructors from 10 different institutions across the United States, who recruited students in their 11 courses. Thirty-seven students responded to our request for interviews and 26 students in a 4-year undergraduate program were successfully recruited as participants. Our sample contains 13 first-year undergraduate students, six second-year undergraduate students, four third-year undergraduate students, and three fourth-year undergraduate students. There are 19 participants who identify as women and seven who identify as men. There were 13 participants who identified as White, seven as Hispanic, two as Asian, one as African American or Black, one as Asian/Native Hawaiian/other Pacific Islander, and two students who preferred not to say and/or noted "other." Eleven of the participants were in introductory classes for biology majors, seven in introductory biology for nonmajors, seven in introductory or general ecology, and one in upper-division ecology.

4.2 | Interview methods

We chose to use one-on-one interviews, which are noted as a successful technique to gauge student conceptions and alternative conceptions in science (Soeharto et al., 2019). Our research team conducted several rounds of revisions with our interview protocol (see Holt et al., 2021) to narrow student responses about biotic impacts of climate change. The current study was part of a larger research project aimed at clarifying student conceptions about the biotic impacts of climate change with the ultimate goal of developing a concept inventory on this topic (Holt et al., unpublished). The portion of the protocol analyzed in the current study is available in Appendix A. Interviews for the present study were collected in Fall 2020 using our semistructured protocol. The interviews were conducted and recorded online via a video conferencing platform.

In the interview, students were presented with a drawing of a forested ecosystem (Original [also Scene W], Supporting Information: Appendix A). The interviewer then proposed that the original scene underwent climate change by experiencing an average increase of 1°F over 25 years. Fahrenheit was chosen as the unit of temperature, as our sample comprised students in the United States, where Fahrenheit is used in everyday situations. Then, students were shown variations of what the scene might resemble 25 years in the future under these conditions, each new scene (we called Scene W, Scene X, Scene Y, or Scene Z; Supporting Information: Appendix A) was displayed individually, side-by-side with the original scene. A description of the goal and changes of each scene is enumerated in Table 1 (images of each scene are available in Supporting Information: Appendix A). In every interview, the scenes were shown in the same order and all were shown before the next prompt. The students were then prompted to select which scene they thought was most likely to represent what the original scene would look like after a total of 1° average increase in Fahrenheit over 25 years. They were then prompted to give their arguments and explanations for why they chose their answer. Most interviewees were prompted to explain their choice for every scene, including scenes they did not select, before continuing with the interview. At the conclusion of the interview, a survey collected demographic data and educational backgrounds of participants. The survey also included a multiple-choice question asking if they accepted that climate change is occurring and that it is at least partially human-caused (alternative options allowed participants to state that they did not accept that climate change is occurring or that it is occurring but is only naturally caused). Each interview was audio recorded and transcribed.

4.3 | Exploratory transcript review

The interview data analyzed in the current study were collected for a larger project aiming to describe student conceptions about the biotic impacts of climate change. Through iterative revisions based on novice and expert responses to earlier phases of data collection (Holt et al., unpublished), we revised our interview protocol to focus student thinking on options of possible outcome scenarios (Supporting Information: Appendix A). These constrained

TABLE 1 Explanation of illustrated scenes used as prompts in interviews.

Scene name	Goal of scene	Examples of changes from original scene
Original scene	Depicts a temperate deciduous forest ecosystem with an ecotone to grassland in the midground.	NA
Scene W	To represent in absence of any change.	None (i.e., it is identical to the original)
Scene X	To represent a plausible scenario where slight species turnover is evident due to an increase in 1°F over 25 years.	Landscape shifts (i.e., more grasslands and less forests in the background), species replacements (mushroom species, top predators [e.g., bear to cougar], forb species), increase abundance and change population structure of some species (e.g., more male deer), loss of some species (e.g., quail)
Scene Y	To represent the site immediately (i.e., a few months or a year) following a medium-sized fire, which represents a short-lived disturbance where recovery is possible.	Evidence of fire (e.g., burned trees, log, patchy burned grasslands with slight regrowth), species replacements (e.g., mushrooms), loss of some species (e.g., bear, quail), increase abundance of some species (e.g., fox), addition of new species (e.g., woodpecker, vultures), change in population structure of some species (e.g., more male deer)
Scene Z	To represent a barren wasteland (similar to 2008 Disney movie, *WALL-E* (Stanton, 2008) reflecting catastrophist thinking about climate change.	Loss of all living species (grass, trees, animals), evidence of dead organisms (charred tree remains), stream is dry, persistent, anthropogenic trash is present

Abbreviation: NA, not applicable.

options (i.e., prepared, illustrated scenes) increased comparability across student responses, and allowed for the interviewer to probe deeply into why students made particular choices. Our goals with the current analysis were to primarily track student accuracy in their choices and describe their argumentation practices about this socioscientific topic. We planned to deductively code student reasoning using an adaptation of Russ et al.'s (2008) coding framework, which itself was adapted from Machamer et al. (2000), on mechanistic reasoning. We sought to explore whether students were relying on processes and principles to rationalize their choice or if instead they simply leveraged visual elements of the scene that did not rely on ecological knowledge. However, an exploratory review of the transcripts suggested that student arguments frequently included instances of cognitive bias in addition to mechanistic reasoning (Russ et al., 2008).

Although the literature describes many types of cognitive biases associated with climate change, most are linked to climate action (e.g., Luo & Zhao, 2021). Yet, our interview data captured student explanations of their understanding of climate change, where some types of bias are not relevant (e.g., attentional bias). Using the literature, we determined that the most applicable cognitive biases that the students may use to describe their understanding of climate change were anchoring (Tversky & Kahneman, 1974) and contrast effect (Simonson & Tversky, 1992). We further believed that the framing in our interview protocol (Supporting Information: Appendix A), that is, including a predetermined temperature and time that represented climate effects, provided plausible anchors, which we believed students might use in their reasoning. Previous literature has demonstrated that similar anchors can affect climate change understanding (Mazutis & Eckardt, 2017). Additionally, our interview setup provided students with options from which they were asked to select the choice that most aligned with their thinking. During our exploratory review of transcripts, we noticed that many students verbally compared the scenes, thus we also identified contrast effect as another relevant cognitive bias worth exploring.

4.4 | Data analysis

NVivo Release 1.5.1 (QSR International, 2021) was used to deductively code interview transcripts, that is, identify and organize student arguments, including Reasoning and Cognitive Biases. Each distinct idea within a participants' argument was coded, which may have included a short phrase, a few sentences, or a section of text. These ideas as our unit of analysis meant that responses could be double-coded. We used deductive coding with the predefined codebook, developed to establish coding parameters related to Cognitive Biases and Reasoning (Supporting Information: Appendix B). In this study, we began with two researchers parallel coding students' responses. After initial rounds of coding, coders discussed any discrepancies and revised code assignments and the codebook as necessary. Responses were coded as to whether or not the student chose a specific scene as a likely outcome of climate change (Scene W [original scene], X [accurate change], Y [postforest fire], or Z [wasteland]), that is, if they felt the original scene would most likely look like the chosen scene after an average of 1° increase in temperature following 25 years. Student arguments in favor or against each specific scene were then coded in two separate rounds based on the Type of Reasoning (Basel et al., 2013; Russ et al., 2008) and/or a Type of Cognitive Bias (Tversky & Kahneman, 1974) present. First, each argument was coded by the Reasoning Theme. Responses that coded into this Theme were further separated into Subthemes of either Ecological Explanations or Observations. The responses coded as Observations, similar Russ et al.'s (2008) adaptation to Machamer et al. (2000) description of target phenomena, were further coded into Type (Supporting Information: Appendix B). Second, each individual argument (i.e., explanation why a scene was selected as their prediction or not) was coded by the Cognitive Bias Theme (Supporting Information: Appendix B). During this round, we noted any Subthemes of either Anchoring (*sensu* Tversky & Kahneman, 1974) or Contrast Effects (*sensu* Simonson & Tversky, 1992). Within each Subtheme, responses were coded into each Type (Supporting Information: Appendix B). Student responses could be double coded into more than one Theme, Subtheme, or Type, or coded into only one Theme, Subtheme, or Type. Student quotes included in the codebook and in text are lightly edited for clarity, and all Themes and Subtheme titles are capitalized throughout. Participant pseudonyms are italicized throughout the text.

We use the language of "accuracy" in our findings to reflect expert and researcher opinion of the optimal choice, but we recognize the choices we deem as "accurate" may not necessarily represent how climate change will unfold as these are predictions of the future. We determined that Scene X was the most likely outcome, thus the most accurate participant response, considering the original scene following 25 years and an average 1°F increase in temperature. This determination was also supported by six of seven external experts that were interviewed as a separate data collection effort, but not described here.

5 | RESULTS

5.1 | Accuracy in student conceptions

We found that 19 of the 26 student participants, in the current study, chose Scene X as the most likely response following warming over a quarter of a century. Of those that chose Scene X (accurate change) as their most likely response, three participants chose one other scene as a close runner-up or equal potential answer, one of who also selected Scene W (original scene) and the other two participants selected Scene Y (postforest fire) as their alternative to Scene X (accurate change).

Through analysis of the interviews, we discovered seven students selected Scene Y (postforest fire) as a possible outcome. We recognize that Scene Y (postforest fire) could be a secondary viable response following 25 years and an average increase of 1°F, assuming that drier environments will be more flammable (Mansoor et al., 2022; Van et al., 2021; Varela et al., 2019). As fires are generally more infrequent and patchy across a landscape, we felt that Scene X (accurate change) was the best response, yet Scene Y (postforest fire) could have been an accurate depiction, if a student were to articulate their understanding of the scientific link between fire and climate change. Three of the participants who chose Scene Y (postforest fire) clearly articulated their choice was due to their accurate understanding of climate change. We deemed all other choices as less accurate outcomes resulting from an average of 1°F increase in temperature over 25 years. Of all the inaccurate responses, three participants chose Scene W (original scene) as their most likely response, four chose Scene Y (postforest fire) but did not articulate accurate responses to justify how climate change resulted in this scene, and one participant chose Scene Z (wasteland). Overall, 80.8% of our participants' choices reflected accurate understanding of the biotic impacts of climate change and 30.8% reflected inaccurate conceptions. These percentages do not sum to 100%, because several participants selected two options as their most likely outcome and two of those students selected both "accurate" and "inaccurate" responses.

5.2 | Students' reasoning about their choices

We reviewed the 26 interviews and coded student responses into the Reasoning Theme, if it occurred, and mentions of ecological processes or patterns (Ecological Explanations) and/or identification of scene elements (Observations) were coded into respective Subthemes (Supporting Information: Appendix B). Of the 26 participants, 24 used Ecological Explanations (alone or in combination with Observations) to justify their choice for or against at least one scene, whereas only four participants strictly used Ecological Explanations across all their arguments. Likewise, 22 participants used Observations (alone or in combination with Ecological Explanation) as an argument for why they selected for or against at least one scene and only two participants strictly used Observations in their reasoning across scenes. The majority of participants used a mix of Reasoning Subthemes in their arguments for or against scenes (i.e., 20 of 26 participants).

TABLE 2 Frequency of Reasoning used for participants' chosen scene, tallied by Subtheme (Ecological Explanation, Observation).

	Chosen scene	Ecological explanations only	Observations only	Both ecological explanations and observations	Neither ecological explanations or observations
Accurate chosen choices	X	2	2	14	1
	Y - accurate	1	0	2	0
Inaccurate chosen choices	Y - inaccurate	2	0	1	1
	W	2	0	0	1
	Z	1	0	0	0
Total[a]		8	2	17	2

Note: Numbers represent the number of students using each Subtheme in reasoning for that scene as their choice.
[a]As some participants chose two scenes as equally reasonable for their choice, the below numbers do not sum to 26.

We noted that a majority of students used both Ecological Explanations and Observations to defend their chosen scene (65%, Table 2). The use of Ecological Explanations alone was the next most frequent Subtheme of Reasoning with chosen scenes, regardless of whether their choice was accurate or not. Students with inaccurate choices mostly used Ecological Explanations alone. Student ideas of these Ecological Explanations were often that "nature is really resilient" as noted by *Tau* and *Lyssa*, who also said that there must be "a way to…rewind time and make it level out", or that the animals would not be affected, because "one degree wouldn't make that much of a drastic difference" (*Xabier*). Several inaccurate choices, notably participants who preferred Scenes Y and Z, used Ecological Explanations as a central argument, referring to eroding species interdependence yet rarely clearly articulated what those interactions were and believed those changes would be more extreme than Scene X. For example, *Salomé* who chose Scene Y (postforest fire) described "if one species that…wasn't able to handle that 1° change, then that can, like, lead to, like, that chain effect–domino effect".

For participants with accurate choices, their Reasoning primarily used a combination of Ecological Explanations and Observations. There was not a clear pattern among the correct arguments supporting their choices, rather they reference several different processes at several levels of ecology. For example, some participants mentioned processes at the population level (e.g., invasive species, life cycles, migration patterns), at the community level (e.g., biodiversity, trophic dynamics, succession), and ecosystem level (e.g., changing water systems). We noted this diversity in ecological processes used as warrants to support their claims; however, as deeply exploring these finer-detailed patterns at various ecological scales was not the research aim of this study, we did not enumerate nor further investigate these trends. For example, *Zigor* started with Observation cues about changes in abundance and composition, then they analyzed the scene to explain these patterns, drawing on several levels of ecosystem responses (Figure 1) This quote illustrates more complex ideas used by a participant leveraging a mix of Observation and Ecological Explanations to defend their chosen scene.

We then analyzed the Reasoning participants used to explain why they did not choose other scenes as the best outcome. Our interviewer failed to prompt 8 participants to explain at least one of their rationales for why they did not select scenes as their choice; thus, we cannot fully summarize Reasoning for every non-chosen scene for all participants. For participants who were asked to explain why they did not choose a scene, the majority did not use Reasoning within their arguments, regardless of the scene (Table 3).

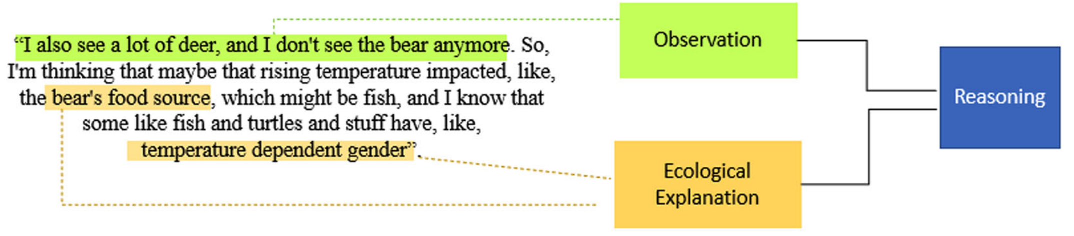

FIGURE 1 Example student quote describing their chosen scene and the highlights represent the Reasoning Subthemes of Observation and Ecological Explanations coded in the quote.

TABLE 3 Frequency of Reasoning used for not-chosen Scene(s), tallied by Subtheme (Ecological Explanation, Observation, Nonrelevant Observation).

Scenes not chosen	Ecological Explanations only	Observations only	Both Ecological Explanations and Observations	Both Ecological Explanation and Nonrelevant Observations	None
X	2	2	2	1	0
Y	0	1	1	1	14
W	9	1	0	0	10
Z	2	1	1	2	14
Total	14	5	4	4	38

Note: Numbers represent the number of students using each Subtheme in reasoning for that Scene(s) as not their choice.

5.3 | Students' cognitive biases in their choices

The next set of coding was the presence of Cognitive Biases in students' arguments for their chosen scenes. Of the 19 participants that chose Scene X accurate change) as their most likely outcome following an average of 1°F increase in temperature over 25 years, 15 used a form of Cognitive Bias either through Anchoring or use of the Contrast Effect. The Anchoring Subtheme was analyzed to clarify whether students anchored their arguments on temperature (i.e., 1°F) or time (i.e., 25 years). We noted that a majority of students anchored using temperature for their chosen Scene (Table 4). *Enver* noted, "I just think…that one degree difference wouldn't drastically change things on the outside [like in Scene X], but would put things in place that would, later on, change it to those other scenes [that is, Scenes Y and Z]." Of the three participants that chose Scene Y (postforest fire) for climate change-related reasons, two were anchored: one by time and the other by temperature. The temperature anchor was used more often than the time anchor for all chosen scenes (Table 4). Next, we enumerated whether or not participants compared scenes in their argumentation, using a Contrast Effect. We noted that the Contrast Effect was primarily used by participants that chose Scene X (accurate change) (Table 4). Overwhelmingly, these participants used the Middle contrast, illustrated by *Zigor's* quote (Figure 2).

Students relied heavily on anchors and the contrast to the other scenes when explaining why they did not choose a scene (Table 5). Overall, temperature was the more frequently used anchor, just as it was for the chosen Scenes. The majority of students recognized that Scene W (original scene) was not correct, and their rationale was that "…there has to be change if there's going to be a little shift in degree [temperature], so I don't think it would be the same [like in Scene W (original scene)]." In addition, most students described that Scenes Y (postforest fire) and Z (wasteland) were too extreme (i.e., A lot/Too much change). For example,

TABLE 4 Frequency of Anchoring (Temperature or Time) and Contrast Effects used for participants chosen scene, tallied by Subtheme.

		Anchoring		Contrast Effects		
	Chosen scene	Temperature	Time	A lot/Too much change	Middle	No/little change
Accurate Chosen Choices	X	12	7	0	10	0
	Y - Accurate	1	1	0	0	0
Inaccurate Chosen Choices	Y - Inaccurate	2	1	0	1	0
	W	2	1	0	0	2
	Z	1	0	0	0	0
TOTAL		18	10	0	11	2

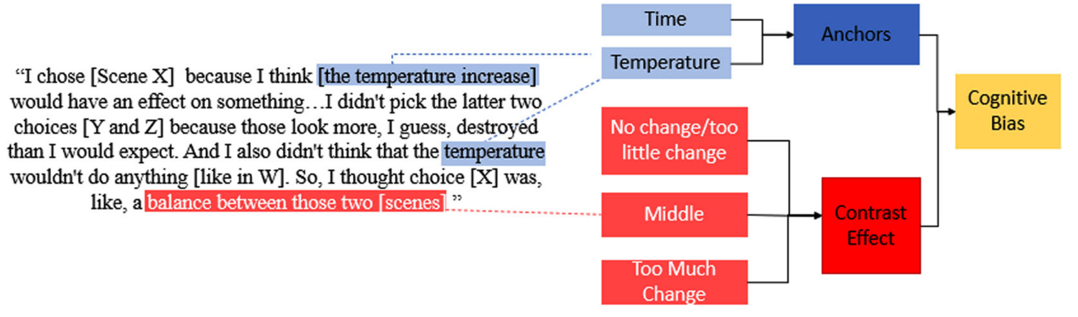

FIGURE 2 Example student quote describing their chosen scene and the highlights represent the Cognitive Bias Subthemes and Types coded in the quote.

TABLE 5 Frequency of Anchoring and Contrast Effect, by type, used in arguments for scenes not chosen by participants, tallied by Type within each Subtheme.

	Anchoring		Contrast Effects		
Not chosen scene	Temperature	Time	A lot/Too much change	Middle	No/little change
W	8	1	0	0	17
X	1	3	2	0	4
Y	7	3	13	0	0
Z	11	5	18	0	0
TOTAL	29	11	27	0	20

Note: Numbers represent the number of students using each Type for that scene as not their choice.

Daniella stated "When I think of [an average of one degree increase in temperature over 25 years], I don't think, it doesn't seem like a lot. So, I don't think [it's] really, really drastic where everything is dried out, but I do think that it does have an effect…" Of note, the Middle contrast was never used in an argument for why a scene was not chosen. As noted above, the interviewer did not prompt for arguments justifying why scenes were not chosen with all participants.

5.4 | Overlap of reasoning and cognitive biases

A majority of students, regardless of their scene choice, used both Cognitive Biases and Reasoning in their arguments for the chosen Scenes (Table 6). Just under half of participants used both Types of Cognitive Biases (i.e., Anchoring, Contrast Effect), nine used Anchoring alone, and only two participants used the Contrast Effect alone in defending their chosen Scene (Figure 3). Just over half of the participants used both Types of Reasoning (i.e., Observations, Ecological Explanations), less than a third used Ecological Explanations alone, and only two students used Observations alone to defend their chosen Scene (Figure 3).

In reviewing the individual participants' arguments and the intersection of the Types of Cognitive Biases and Reasoning they used to defend their chosen and other scenes, we identified six unique groups of student argument patterns. Students with similar argument patterns were grouped together. Different groups used varying

TABLE 6 Frequency of Cognitive Biases compared with Reasoning in student arguments for their chosen scenes.

Chosen scene	Cognitive Bias only	Reasoning only	Both
W	1	0	2
X	1	4	14
Y-Accurate	0	1	2
Y-Inaccurate	1	0	3
Z	0	0	1
Total	3	5	22

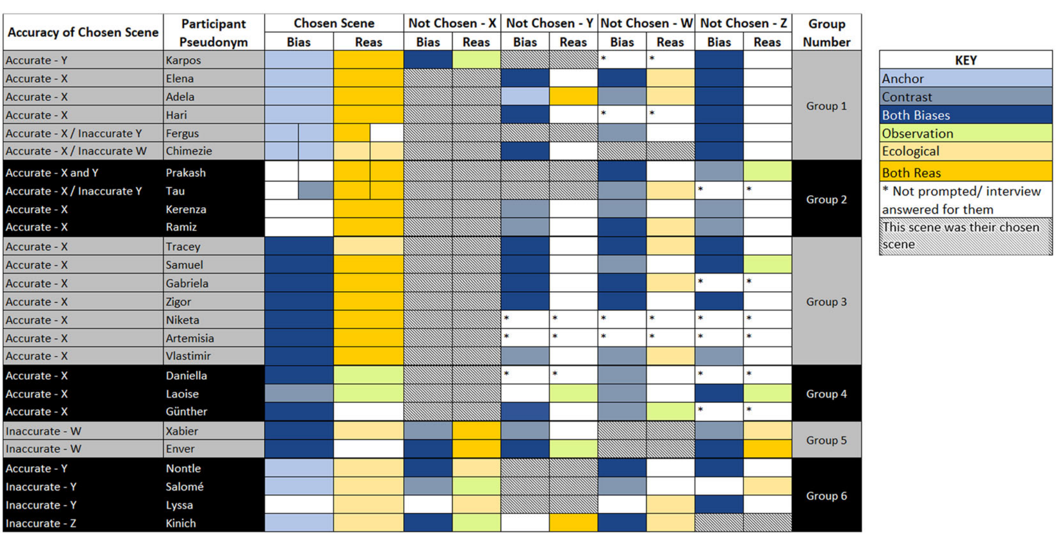

FIGURE 3 Color-coded chart to represent Cognitive Biases (labeled Bias) and Reasoning (labeled Reas) on a student-by-student basis to highlight the 6 groups of varying types of explanations. The far left column indicates the scene chosen by each participant and its accuracy according to experts. Cognitive Biases are coded in blue and gray colors and Reasoning Themes are coded in yellow and green colors, similar to color-coding in Figure 4. The far right column indicates the group number for clusters of students who responded using similar strategies and choices for their most likely scene.

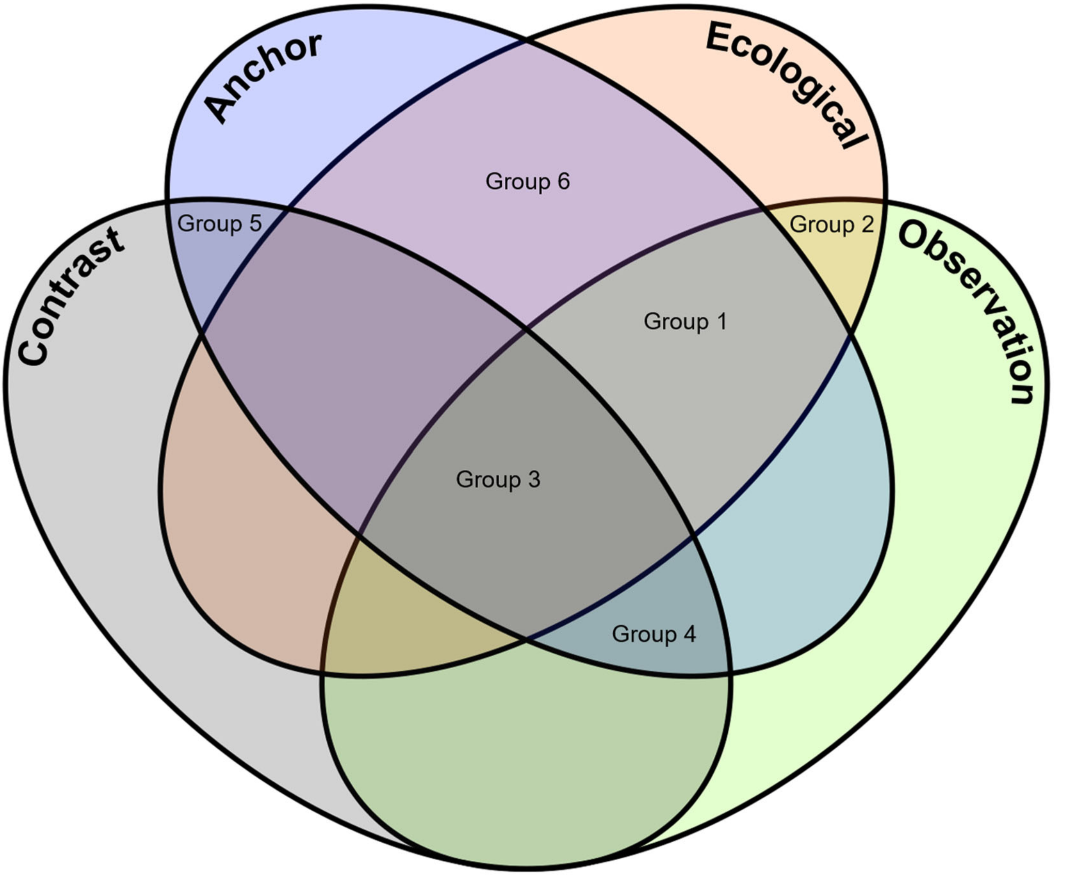

FIGURE 4 Venn diagram of the two Cognitive Bias Subthemes (Contrast Effects, Anchoring) and two Reasoning Subthemes (Ecological Explanation, Observation). This diagram shows overlapping Cognitive Bias and Reasoning strategies students used to explain their choices of scenes following an average of 1° increase in Fahrenheit after 25 years. Each grouping of students (see Figure 3) is indicated by a group number that generally characterizes their arguments as similar to others in their group. The proportion of participants in each group varied (Group 1: 23%, Group 2: 15%, Group 3: 27%, Group 4: 12%, Group 5: 8%, Group 6: 15%).

combinations of Cognitive Biases and Reasoning to defend their chosen Scenes (Figures 4 and 3). Although the argument patterns between the six groups differed more than the patterns within a group, we noticed some variability among students' arguments for their chosen Scene and all other scenes within groups (Figure 3).

Group 1 represents students who used both Ecological Explanations and Observations as well as Anchoring in the defense of their chosen Scene (Figure 4). Group 1 students all chose Scene X (accurate change) for at least one of the chosen Scenes (i.e., two Group 1 participants chose a second incorrect scene as equally possible). In addition, Group 1 students used Contrast Effects, and often Anchoring, to justify scenes they did not choose. Group 2 represents students who relied almost entirely on both Subthemes of Reasoning, Observation and Ecological Explanations, in argument for their accurate chosen Scenes (Figure 4). Group 2 students also used Contrast Effects as explanation for not selecting other scenes. Group 3 was the largest group of accurate predictors. These students all used both Cognitive Biases and Ecological Reasoning, most used both Reasonings to justify their choice of Scene X (accurate change). In addition, Group 3 students all used Contrast Effects in their reasons against the other three scenes they did not select, and many also used Anchoring (Figure 4). Group 4 was the smallest group of accurate predictors, who mostly used Observation and both Biases to justify their chosen Scene X (accurate change)

(Figure 4). Group 4 participants used a mix of Reasoning and Biases to justify scenes they did not select, but all consistently used Contrast Effects to argue against other scenes (Figure 4). Group 5 includes only two students who incorrectly identified Scene W (original scene) as the most likely scene, and each used both Biases for their chosen Scene (Figure 4), and Contrast for Scene W (original scene). Finally, Group 6 represents students with a range of accuracy, but none selected Scene X (accurate change) as their most likely response. These students used Ecological Reasoning and Anchor Bias in their chosen scenes (Figure 4) and a mix of other justifications for scenes they did not select.

6 | DISCUSSION

6.1 | Accuracy in student conceptions

The majority of our biology undergraduate participants from US institutions selected scenes identified by the researchers and experts as the most likely scenes following an average of 1° increase in temperature after 25 years. Despite reports of climate alternative conceptions in other studies (da Rosa, 2022; Fleming et al., 2021), we found that biology college students from our sample predicted accurate outcomes of climate change. Other studies similarly account how students proficiently identify scientific outcomes of climate change in undergraduate science (Holt et al., 2021) and nonscience students (Huxster et al., 2015).

To further support the sophistication of these participants' understanding of the biotic impacts of climate change, we devised the interview protocol such that Scene X (accurate change) was the best response. Although we realized that Scene Y (postforest fire) was a viable choice, that is, a burnt landscape reflecting increased forest fires associated with climate change (Mansoor et al., 2022; Van et al., 2021; Varela et al., 2019), the accurate selection and explanation of Scene Y (post-forest fire), by some participants, showed a deeper understanding of the indirect effects of climate change than we originally expected.

These findings, reflecting that over three-quarters of our participants accurately identified predicted effects of climate change, is encouraging, despite climate literacy alternative conceptions (da Rosa, 2022) and catastrophic or severe thinking (Holt et al., 2021; Wibeck, 2014) reported elsewhere in the literature. Although our sample may be geographically biased (i.e., 17 of our participants were attending institutions located in states with 33% or less of the general population identified as conservative [Pew Research Center, 2022]), which could influence the participants' background on climate change (Khalidi & Ramsey, 2021), we noted no trend in accuracy by state. Additionally, potentially contributing to bias, our survey asked participants their beliefs associated with climate change and all stated that they accept that climate change is occurring and at least partially human-caused.

6.2 | Students' reasoning about their choices

Overall, the most frequent recurring pattern in student Reasoning was their use of both Ecological Explanations and Observations, especially participants who selected Scene X (accurate change). Our careful review of their explanations further determined that these explanations were often accurate, reflecting key biological processes. Holt et al. (2021) also noted the capacity for undergraduate biology students to recognize and relate major ecological processes to climate change. Our respondents leveraged the information provided through their Observations of elements within the scenes, into ecological patterns and processes when providing their arguments for their choices. This Reasoning pattern indicates that undergraduate biology students, at least from our sample in the United States, go one step farther than just describing what they see and use low-level argumentation (Barth-Cohen et al., 2021; Basel et al., 2013). Most of them applied ecological processes and patterns to what they saw (i.e., applying evidence to their argument), which is a key part of successful argumentation and scientific reasoning

(Driver et al., 2000). Interestingly, even students who estimated the inaccurate scenes as the best response, still often use Ecological Explanations and attempt to leverage evidence, even if it is inaccurate. Argumentation can help students develop critical thinking skills required in their professional lives (Gültepe & Kılıç, 2021). The next step appears to be ensuring students can discriminate accurate from inaccurate evidence and this difference is not obscured by oversimplification of scientific evidence and problems (Duncan et al., 2018). Further, climate-focused curricula may benefit from additional focus on the mechanisms of climate change, which may correct inaccurate application of evidence.

6.3 | Students' cognitive biases in their choices

Just under half of our student participants used both Cognitive Biases in their chosen Scene reasoning, roughly one-third used Anchoring alone and only one-seventh used no Cognitive Biases when defending their chosen Scene. Similarly, all participants used at least one Type of Cognitive Bias when describing at least one of the scenes they did not select. This heavy reliance on Cognitive Biases in argumentation illuminates the strong effect heuristics can have on student decision-making, which is similarly observed in other studies (Hoffman et al., 2021). However, this does not imply students are using information illogically, because cognitive biases can be based on rational reasonings (Lieder et al., 2017; Todd & Gigerenzer, 2000) that improve efficiency. Further research is needed to explore the rationality or over-reliance on Anchors and Contrast Effects used by undergraduate biology students when they discuss climate change and build arguments about how it affects ecosystems.

Our student participants would frequently argue that a scene they did not select, often Scene Y (postforest fire) or Z (wasteland), was incorrect because it was "too extreme." This Cognitive Bias shows ecological understanding that the scene held too much change, and these students used this information to quickly exclude options. Alternatively, this Contrast Effect may also reflect extreme aversion which Neumann et al. (2016) reports for consumer behavior. It is important for educators and the media to carefully consider the presentation of climate change-related material to reduce Contrast Effects that perpetuate misinformation (e.g., ecosystem impacts in response to nonclimate effects such as pollution). Furthermore, extreme negative representations of climate change can lead to apathy and avoidance of the issue altogether (Ágoston et al., 2022). On the contrary, presenting implausible, overly extreme outcomes as a contrast to actual outcomes from climate change may downplay the impacts of this pervasive, long-term disturbance. Our study established this contrast, as the most accurate scene was less extreme, and we acknowledge this presentation may have biased participants to choose the accurate scene over more extreme options due to contrast effects rather than climate literacy.

Temperature was the most common anchor used by our participants. Increasing temperature is often a proxy or consequence reported for climate change (IPCC, 2018; NOAA National Centers for Environmental Information, 2021), and is publicized in the media. Again, reporting of these data, including both the numerical value and the unit of measurement, can affect understanding of climate change (Chan, 2018). Previous studies demonstrate that people may misjudge climate change as they anchor on local, short-term temperatures (Joireman et al., 2010). Our study is unique in describing how students use anchoring of numerical value to affect their predictions of climate change effects.

6.4 | Overlap of ecological reasoning and anchoring/contrast effects

Comparing all types of argument patterns in our American biology student sample, we identified six general groups of response patterns (Figures 1 and 2). The largest group, Group 3, used both Subthemes of Reasoning and both Subthemes of Cognitive Biases to argue for their selection of the accurate scene, Scene X (accurate change). Although Cognitive Biases are clearly a useful strategy for our sample of biology undergraduates in thinking about how climate change may affect ecosystems, as it was used at least once by every participant, it is unclear whether these heuristics may be contributing to misunderstandings or alternative conceptions as occurs in evolution education (Bean et al., 2010; Pobiner et al., 2019). Group 2 used both Subthemes of Reasoning but their use of Cognitive Bias was almost strictly limited to their justification for scenes they did not select. Future work exploring strategies used by those in Group 2 may help clarify if their approach is optimal and a better model to guide instruction. With one exception, Groups 5 and 6 all selected inaccurate scenes as their best choice. Interestingly, these groups relied heavily on Cognitive Biases and Ecological Explanations for their chosen Scenes and never used Observations, except when explaining scenes they did not choose. This lack of Observation may be an over-reliance on faulty Ecological Explanations that were not checked against visual evidence presented in the scene itself. All other groups used Observations or Observations coupled with Ecological Explanations to support their chosen, primarily accurate, scenes.

7 | EDUCATIONAL IMPLICATIONS

We found that many biology undergraduate students understand climate change sufficiently to make accurate predictions of how it will affect ecosystems. Most recognize that climate change is a notable disturbance that will alter ecosystems, but also do not claim a catastrophic fate noted in other research (Holt et al., 2021). The present study not only clarifies the accuracy of student conclusions about climate change but describes their thinking about the processes involved and perception of the degree of change. Our findings highlight that even when biology undergraduate students selected inaccurate scenes, most understand that climate change affects ecosystems, but it was their underlying understanding of the biology that was incorrect. However, the overwhelming accuracy and knowledge of climate change detected within our sample does not guarantee climate action or guard against development of climate alternative conceptions (Harrod & Rolland, 2021). Although education alone does not shift students' perspectives on SSIs (Hornsey, 2020), raising educators' awareness of the factors influencing student thinking may allow them to construct curricula in mindful ways (Chen & Xiao, 2021).

In our sample, most students that identified the correct scene used both Observations and Ecological Explanations. This suggests they analyze and assimilate presented information to accommodate into a familiar schema and determine how what they see is related (Duncan et al., 2018) and connected to climate change. However, several of our participants did not use Reasoning in their arguments to explain why they selected a scene (Table 2) and most participants did not use Reasoning when defending Themes they did not select (Table 3). Educators who focus on ecological processes leading to outcomes from climate change may better help their students articulate the effects, present and future, of climate change. We also found that most students in our sample used Cognitive Biases throughout their arguments for scenes they chose and did not choose. This prevalence provides further evidence of how heuristics influences decision-making (Todd & Gigerenzer, 2000). We hope educators will become attuned to recognize when their students use heuristics, perhaps even unknowingly, to explain scientific phenomena and processes. Interventions similar to Schweickart et al. (2021) model how instruction can support students to recognize cognitive biases and leverage them appropriately.

8 | LIMITATIONS

The qualitative nature of our study and purposeful selection of participants within undergraduate biology classes limits the generalizability of these results. Further our sample was drawn from universities in the United States and our findings may not be representative of what other students elsewhere might think or choose. Future research to investigate the trends in student reasoning about climate change in other undergraduate science disciplines, in K-12 systems, or international contexts would further benefit this field. Further, our coding was guided by our codebook and other Themes may have emerged if we had instead used a different approach to coding or a different codebook.

ACKNOWLEDGMENTS

This work was supported by the National Science Foundation (NSF) Improving Undergraduate STEM Education (DUE-1836522). Any opinions, findings, and conclusions or recommendations expressed in this study are those of the authors and do not necessarily reflect the views of the NSF. We thank the 26 interviewees for their participation, Ryan Dunk for conducting all interviews, and Alex Colpitts and Hannah Visoskas for transcription of these interviews. Summers Scholl created the beautiful and accurate illustrations used as Scene prompts in all our interviews.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions. Deidentified, summarized data are available from the authors upon request.

ETHICS STATEMENT

The UNC Institutional Review Board approved this study, and this study conforms to the US Federal Policy for the Protection of Human Subjects.

ORCID

Kaela Clabaugh Howell http://orcid.org/0000-0002-9858-5929

REFERENCES

Ágoston, C., Csaba, B., Nagy, B., Kővàry, Z., Dúll, A., Rácz, J., & Demetrovics, Z. (2022). Identifying types of eco-anxiety, eco-guilt, eco-grief, and eco-coping in a climate-sensitive population: A qualitative study. *International Journal of Environmental Research and Public Health*, *19*(4), 2461.

Barth-Cohen, L. A., Braden, S. K., Young, T. G., & Gailey, S. (2021). Reasoning with evidence while modeling: Successes at the middle school level. *Physical Review. Physics Education Research*, *17*(2), 020106. https://doi.org/10.1103/PhysRevPhysEducRes.17.020106

Basel, N., Harms, U., & Prechtl, H. (2013). Analysis of students' arguments on evolutionary theory. *Journal of Biological Education*, *47*(4), 192–199. https://doi.org/10.1080/00219266.2013.799078

Bean, T. E., Sinatra, G. M., & Schrader, P. G. (2010). Spore: Spawning evolutionary misconceptions. *Journal of Science Education and Technology*, *19*(5), 409–414. https://doi.org/10.1007/s10956-010-9211-1

Berland, L. K., & McNeill, K. L. (2012). For whom is argument and explanation a necessary distinction? A response to Osborne and Patterson: Is argument and explanation a necessary distinction? *Science Education*, *96*(5), 808–813.

Bostrom, A. (2017). Mental models and risk perceptions related to climate change, *Oxford research encyclopedia of climate science*. Oxford University Press. https://doi.org/10.1093/acrefore/9780190228620.013.303

Chan, E. Y. (2018). Climate change is the world's greatest threat – in celsius or fahrenheit? *Journal of Environmental Psychology*, *60*, 21–26. https://doi.org/10.1016/j.jenvp.2018.09.002

Chen, L., & Xiao, S. (2021). Perceptions, challenges and coping strategies of science teachers in teaching socioscientific issues: A systematic review. *Educational Research Review*, *32*, 100377. https://doi.org/10.1016/j.edurev.2020.100377

Christodolou, A., & Grace, M. (2019). Argumentation within societal contexts in chemistry education. In S. Erduran (Ed.), *Argumentation in chemistry education: Research, policy and practice* (pp. 197–222). Royal Society of Chemistry.

Coley, J. D., & Tanner, K. D. (2012). Common origins of diverse misconceptions: Cognitive principles and the development of biology thinking. *CBE—Life Sciences Education*, *11*(3), 209–215. https://doi.org/10.1187/cbe.12-06-0074

Cordero, E. C., Centeno, D., & Todd, A. M. (2020). The role of climate change education on individual lifetime carbon emissions. *PLoS One*, *15*(2), e0206266. https://doi.org/10.1371/journal.pone.0206266

Dorfner, T., Förtsch, C., Germ, M., & Neuhaus, B. J. (2018). Biology instruction using a generic framework of scientific reasoning and argumentation. *Teaching and Teacher Education*, *75*, 232–243. https://doi.org/10.1016/j.tate.2018.07.003

Driver, R., & Easley, J. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. *Studies in Science Education*, *5*(1), 61–84. https://doi.org/10.1080/03057267808559857

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, *84*(3), 287–312. https://doi.org/10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.0.CO;2-A

Duncan, R. G., Chinn, C. A., & Barzilai, S. (2018). Grasp of evidence: Problematizing and expanding the next generation science standards' conceptualization of evidence. *Journal of Research in Science Teaching*, *55*(7), 907–937. https://doi.org/10.1002/tea.21468

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin's argument pattern for studying science discourse. *Science Education*, *88*(6), 915–933. https://doi.org/10.1002/sce.20012

Fleming, W., Hayes, A. L., Crosman, K. M., & Bostrom, A. (2021). Indiscriminate, irrelevant, and sometimes wrong: Causal misconceptions about climate change. *Risk Analysis*, *41*(1), 157–178. https://doi.org/10.1111/risa.13587

Frederick, S. W., & Mochon, D. (2012). A scale distortion theory of anchoring. *Journal of Experimental Psychology: General*, *141*(1), 124–133. https://doi.org/10.1037/a0024006

Gifford, R. (2011). The dragons of inaction: Psychological barriers that limit climate change mitigation and adaptation. *American Psychologist*, *66*(4), 290–302. https://doi.org/10.1037/a0023566

Givi, J., & Galak, J. (2019). The "future is now" bias: Anchoring and (insufficient) adjustment when predicting the future from the present. *Journal of Experimental Social Psychology*, *84*, 103830. https://doi.org/10.1016/j.jesp.2019.103830

Goldberg, M. H., Linden, S., Ballew, M. T., Rosenthal, S. A., & Leiserowitz, A. (2019). The role of anchoring in judgments about expert consensus. *Journal of Applied Social Psychology*, *49*(3), 192–200.

Gülen, S., & Yaman, S. (2019). The effect of integration of STEM disciplines into Toulmin's argumentation model on students' academic achievement, reflective thinking, and psychomotor skills. *Journal of Turkish Science Education*, *16*(2), 216–230.

Gültepe, N., & Kılıç, Z. (2021). The effects of scientific argumentation on high school students' critical thinking skills. *International Journal of Progressive Education*, *17*(6), 183–200. https://doi.org/10.29329/ijpe.2021.382.13

Harring, N., & Jagers, S. C. (2018). Why do people accept environmental policies? The prospects of higher education and changes in norms, beliefs and policy preferences. *Environmental Education Research*, *24*(6), 791–806.

Harris, A. J. L., Por, H. H., & Broomell, S. B. (2017). Anchoring climate change communications. *Climatic Change*, *140*(3–4), 387–398. https://doi.org/10.1007/s10584-016-1859-y

Harrod, S. E., & Rolland, V. (2021). Factors associated with attitudes and knowledge of first-semester college students toward climate change. *BioScience*, *71*(4), 415–425. https://doi.org/10.1093/biosci/biaa151

Heine, S. J., Dar-Nimrod, I., Cheung, B. Y., & Proulx, T. (2017). Essentially biased: Why people are fatalistic about genes. *Advances in Experimental Social Psychology*, *55*, 137–192.

Hoffman, J. K., Bixler, R. P., Treadwell, M. L., Coleman, L. G., McDaniel, T. W., & Kreuter, U. P. (2021). The impact of affective heuristics in decision-making regarding the implementation of prescribed fire on private rangelands in the Southern great plains, USA. *Society & Natural Resources*, *34*(5), 621–638. https://doi.org/10.1080/08941920.2020.1864534

Höijer, B. (2010). Emotional anchoring and objectification in the media reporting on climate change. *Public Understanding of Science*, *19*(6), 717–731. https://doi.org/10.1177/0963662509348863

Holt, E. A., Heim, A. B., Sexton, J., & Hinerman, K. (2021). Undergraduate student conceptions of climate change impacts on animals. *Ecosphere*, *12*(8), e03706.

Hornsey, M. J. (2020). Why facts are not enough: Understanding and managing the motivated rejection of science. *Current Directions in Psychological Science*, *29*(6), 583–591. https://doi.org/10.1177/0963721420969364

Huxster, J. K., Uribe-Zarain, X., & Kempton, W. (2015). Undergraduate understanding of climate change: The influences of college major and environmental group membership on survey knowledge scores. *The Journal of environmental education*, *46*(3), 149–165. https://doi.org/10.1080/00958964.2015.1021661

IPCC, International Panel on Climate Change. (2018). Global Warming of 1.5°C. In V. Masson-Delmotte, P. Zhai, H.-O. Pürtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, & T. Waterfield (Eds.), *An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. Available at: https://www.ipcc.ch/sr15/

IPCC. (2023). Summary for policymakers. In Lee, H., & Romero, J. (Eds.), *Climate change 2023: Synthesis report. A Report of the Intergovernmental Panel on Climate Change. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*.

Jain, G., Nayakankuppam, D., & Gaeth, G. J. (2021). Perceptual anchoring and adjustment. *Journal of Behavioral Decision Making*, *34*(4), 581–592. https://doi.org/10.1002/bdm.2231

Jarrett, L., & Takacs, G. (2020). Secondary students' ideas about scientific concepts underlying climate change. *Environmental Education Research*, *26*(3), 400–420. https://doi.org/10.1080/13504622.2019.1679092

Joireman, J., Barnes Truelove, H., & Duell, B. (2010). Effect of outdoor temperature, heat primes and anchoring on belief in global warming. *Journal of Environmental Psychology*, *30*(4), 358–367. https://doi.org/10.1016/j.jenvp.2010.03.004

Keller, L., Stötter, J., Oberrauch, A., Kuthe, A., Körfgen, A., & Hüfner, K. (2019). Changing climate change education: Exploring moderate constructivist and transdisciplinary approaches through the research-education co-operation kidZ 21. *Gaia-Ecological Perspectives for Science and Society*, *28*(1), 35–43.

Khalidi, R., & Ramsey, J. (2021). A comparison of California and Texas secondary science teachers' perceptions of climate change. *Environmental Education Research*, *27*(5), 669–686. https://doi.org/10.1080/13504622.2020.1838447

Kilinc, A., Demiral, U., & Kartal, T. (2017). Resistance to dialogic discourse in SSI teaching: The effects of an argumentation-based workshop, teaching practicum, and induction on a preservice science teacher. *Journal of Research in Science Teaching*, *54*(6), 764–789. https://doi.org/10.1002/tea.21385

Lederman, N. G., Lederman, J. S., & Zeidler, D. L. (2023). *Handbook of research on science education*. Routledge.

Lieder, F., Griffiths, T. L., M. Huys, Q. J., & Goodman, N. D. (2017). The anchoring bias reflects rational use of cognitive resources. *Psychonomic Bulletin & Review*, *25*(1), 322–349. https://doi.org/10.3758/s13423-017-1286-8

Liu, D., & Wan, F. (2020). What makes proficient writers' essays more persuasive? A Toulmin perspective. *International Journal of TESOL Studies*, *2*(1), 1–13. https://doi.org/10.46451/ijts.2020.06.01

Lorenzoni, I., Nicholson-Cole, S., & Whitmarsh, L. (2007). Barriers perceived to engaging with climate change among the UK public and their policy implications. *Global Environmental Change*, *17*(3), 445–459. https://doi.org/10.1016/j.gloenvcha.2007.01.004

Luo, Y., & Zhao, J. (2021). Attentional and perceptual biases of climate change. *Current Opinion in Behavioral Sciences*, *42*, 22–26. https://doi.org/10.1016/j.cobeha.2021.02.010

Machamer, P., Darden, L., & Craver, C. F. (2000). Thinking about mechanisms. *Philosophy of Science*, *67*(1), 1–25. https://www.jstor.org/stable/188611

Mansoor, S., Farooq, I., Kachroo, M. M., Mahmoud, A. E. D., Fawzy, M., Popescu, S. M., Alyemeni, M. N., Sonne, C., Rinklebe, J., & Ahmad, P. (2022). Elevation in wildfire frequencies with respect to the climate change. *Journal of Environmental Management*, *301*, 113769. https://doi.org/10.1016/j.jenvman.2021.113769

Mason, L., & Santi, M. (1998). Discussing the greenhouse effect: Children's collaborative discourse reasoning and conceptual change. *Environmental Education Research*, *4*(1), 67–85. https://doi.org/10.1080/1350462980040105

Mazutis, D., & Eckardt, A. (2017). Sleepwalking into catastrophe: Cognitive biases and corporate climate change inertia. *California Management Review*, *59*(3), 74–108. https://doi.org/10.1177/0008125617707974

Mercier, H. (2016). The argumentative theory: Predictions and empirical evidence. *Trends in Cognitive Sciences*, *20*(9), 689–700.

Merriam, S. B., & Tisdell, E. J. (2015). *Qualitative research: A guide to design and implementation*. John Wiley & Sons.

Neumann, N., Böckenholt, U., & Sinha, A. (2016). A meta-analysis of extremeness aversion. *Journal of Consumer Psychology*, *26*(2), 193–212. https://doi.org/10.1016/j.jcps.2015.05.005

NOAA National Centers for Environmental Information. State of the climate: Monthly global climate report for 2021. (2021). Retrieved September 6, 2022, from https://www.ncei.noaa.gov/access/monitoring/monthly-report/global/202113/supplemental/page-1

Nurinda, S., Sajidan, S., & Prayitno, B. A. (2018). Effectiveness of problem-based learning module as an instructional tool in improving scientific argumentation skill. *Biosaintifika*, *10*(2), 334–340. https://doi.org/10.15294/biosaintifika.v10i2.12600

O'Sullivan, E., & Schofield, S. (2018). Cognitive bias in clinical medicine. *Journal of the Royal College of Physicians of Edinburgh*, *48*(3), 225–232.

Osborne, J. (2010). Arguing to learn in science: The role of collaborative, critical discourse. *Science*, *328*(5977), 463–466.

Osborne, J. F., & Patterson, A. (2011). Scientific argument and explanation: A necessary distinction? *Science Education*, *95*(4), 627–638.

Palmucci, D. N., & Ferraris, A. (2023). Climate change inaction: Cognitive bias influencing managers' decision making on environmental sustainability choices. The role of empathy and morality with the need of an integrated and comprehensive perspective. *Frontiers in Psychology*, *14*, 1130049.

Pew Research Center, 2022. Political ideology by state. Religious landscape study. Pew Research Center. Available from https://www.pewforum.org/religious-landscape-study/compare/political-ideology/by/state

Pobiner, B., Watson, W. A., Beardsley, P. M., & Bertka, C. M. (2019). Using human examples to teach evolution to high school students: Increasing understanding and decreasing cognitive biases and misconceptions, *Evolution education re-considered* (pp. 185–205). Springer.

QSR International. (2021). NVivo Release 1.5.1. Doncaster, Victoria, Australia. https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home

da Rosa, J. A. (2022). Comparing climate science misconceptions with worldview and cognitive reflection suggests poor understanding and motivated reasoning among undergraduates. *Journal of Geoscience Education*, *70*(4), 501–516. https://doi.org/10.1080/10899995.2021.2006549

Russ, R. S., Scherr, R. E., Hammer, D., & Mikeska, J. (2008). Recognizing mechanistic reasoning in student scientific inquiry: A framework for discourse analysis developed from philosophy of science. *Science Education (Salem, Mass.)*, *92*(3), 499–525. https://doi.org/10.1002/sce.20264

Schweickart, O., Tam, C., & Brown, N. R. (2021). When "bad" is good: How evaluative judgments eliminate the standard anchoring effect. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale*, *75*(1), 56–63. https://doi.org/10.1037/cep0000209

Shah, H., Simeon, J., Fisher, K. Q., & Eddy, S. L. (2022). Talking science: Undergraduates' everyday conversations as acts of boundary spanning that connect science to local communities. *CBE—Life Sciences Education*, *21*(1):ar12. https://doi.org/10.1187/cbe.21-06-0151

Shu, L. L., & Bazerman, M. H. (2010). Cognitive barriers to environmental action: Problems and solutions, *Harvard Business School NOM Unit Working Paper 11046*. Harvard Business School.

Simonson, I. (1989). Choice based on reasons: The case of attraction and compromise effects. *Journal of Consumer Research*, *16*(2), 158–174. https://doi.org/10.1086/209205

Simonson, I., & Tversky, A. (1992). Choice in context: Tradeoff contrast and extremeness aversion. *Journal of Marketing Research*, *29*(3), 281–295. https://doi.org/10.2307/3172740

Skamp, K., Boyes, E., & Stanisstreet, M. (2013). Beliefs and willingness to act about global warming: Where to focus science pedagogy? *Science Education*, *97*(2), 191–217. https://doi.org/10.1002/sce.21050

Soeharto, S., Csapó, B., Sarimanah, E., Dewi, F. I., & Sabri, T. (2019). A review of students' common misconceptions in science and their diagnostic assessment tools. *Journal Pendidikan IPA Indonesia*, *8*(2), 247–266. https://doi.org/10.15294/jpii.v8i2.18649

Stanton, A. (Director). (2008). WALL-E [Motion Picture]. United States: Walt Disney Pictures, Walt Disney Studios Motion Pictures.

Tee, Q. X., Nambiar, M., & Stuckey, S. (2021). Error and cognitive bias in diagnostic radiology. *Journal of Medical Imaging and Radiation Oncology*, *66*(2), 202–207. https://doi.org/10.1111/1754-9485.13320

Todd, P. M., & Gigerenzer, G. (2000). Précis of simple heuristics that make us smart. *Behavioral and Brain Sciences*, *23*(5), 727–741. https://doi.org/10.1017/S0140525X00003447

Tolppanen, S., Claudelin, A., & Kang, J. (2021). Pre-service teachers' knowledge and perceptions of the impact of mitigative climate actions and their willingness to act. *Research in Science Education*, *51*(6), 1629–1649. https://doi.org/10.1007/s11165-020-09921-1

Toulmin, S. (1958). *The uses of argument*. Cambridge University Press.

Trope, Y., & Liberman, N. (2010). Construal-level theory of psychological distance. *Psychological Review*, *117*(2), 440–463.

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases: Biases in judgments reveal some heuristics of thinking under uncertainty. *Science*, *185*(4157), 1124–1131.

United Nations (2015). *Paris agreement*. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement.

Van, T. T. H., Trong, K. H., Hai, A. T. N., & Phan, P. H. V. (2021). Assessment of forest fires risk in U Minh Ha National Park-Vietnam and proposed adaptation measures. *IOP Conference Series: Materials Science and Engineering*, *1092*(1), 012085. https://doi.org/10.1088/1757-899X/1092/1/012085

Varela, V., Vlachogiannis, D., Sfetsos, A., Karozis, S., Politi, N., & Giroud, F. (2019). Projection of forest fire danger due to climate change in the French Mediterranean region. *Sustainability*, *11*(16), 4284. https://doi.org/10.3390/su11164284

Wachholz, S., Artz, N., & Chene, D. (2014). Warming to the idea: University students' knowledge and attitudes about climate change. *International Journal of Sustainability in Higher Education*, *15*(2), 128–141. https://doi.org/10.1108/IJSHE-03-2012-0025

Whitesmith, M. (2020). Experimental research in reducing the risk of cognitive bias in intelligence analysis. *International Journal of Intelligence and CounterIntelligence*, *33*(2), 380–405.

Wibeck, V. (2014). Social representations of climate change in Swedish lay focus groups: Local or distant, gradual or catastrophic? *Public Understanding of Science*, *23*(2), 204–219. https://doi.org/10.1177/0963662512462787

Wu, Y. T. (2013). University students' knowledge structures and informal reasoning on the use of genetically modified foods: Multidimensional analyses. *Research in Science Education*, *43*(5), 1873–1890. https://doi.org/10.1007/s11165-012-9343-9

Zeidler, D. L., & Sadler, T. D. (2023). Exploring and expanding the frontiers of socioscientific issues. In N. G. Lederman, D. L. Zeidler, & J. S. Lederman (Eds.), *Handbook of research on science education* (Vol. 3, pp. 899–929). Routledge.

Zeidler, D. L., Sadler, T. D., Simmons, M. L., & Howes, E. V. (2005). Beyond STS: A research-based framework for socioscientific issues education. *Science Education*, *89*(3), 357–377. https://doi.org/10.1002/sce.20048

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Clabaugh Howell, K., & Holt, E. A. (2023). Student reasonings and cognitive biases in climate change predictions. *Science Education*, 1–21. https://doi.org/10.1002/sce.21826