DISSERTATION

PICTURING CLIMATE CHANGE:

HOW VISUAL LITERACY SHAPES CLIMATE CHANGE LITERACY

Submitted by

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ABSTRACT

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Because climate information is often communicated through visual forms, both in the classroom and in the media, visual literacy (VL) plays a central role in how learners make sense of climate concepts and demonstrate climate change literacy (CCL). This dissertation examines how VL supports CCL across educational contexts and how instructional design can strengthen learners' abilities as both Consumers and Contributors of climate information. In Chapter 2, a systematic review identifies how educational interventions incorporate visual activities to build CCL, yet most emphasize lower-order skills with few opportunities for students to produce visuals or articulate solutions. Chapter 3 introduces the Simple, Serious, Solvable (S3) curricular structure, which is used in subsequent chapters to organize climate content. In Chapter 4, a drawing-to-learn study demonstrates that pre-service and in-service teachers visualize climate change in distinct ways, highlighting opportunities for teacher professional development in both VL and CCL. In Chapter 5, a quantitative VL intervention showed that students with higher VL scores had significantly higher conceptual understanding of climate change and that students intuitively match different image types (e.g., graphs, memes, photos) to different climate topics. Finally, Chapter 6 describes how worldview does not strongly predict conceptual understanding, but that some worldview orientations are associated with higher climate self-efficacy. Collectively, this dissertation advances theory and practice of climate change education by

positioning VL as foundational to CCL and by identifying instructional strategies that more effectively prepare learners to understand, communicate, and act on climate change.

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“Life before death, strength before weakness, journey before destination.”

– Brandon Sanderson

TABLE OF CONTENTS

CHAPTER 1 - INTRODUCTION

Now, more than ever, there is an urgent need for immediate global action to respond to anthropogenic climate change (CC). Despite scientific certainty, the absence of sustained efforts in the United States to mitigate this problem indicates a disconnect with scientific and public perception of CC (Doran & Zimmerman, 2009; Oreskes, 2004). Climate scientists increasingly attribute extreme weather events, like floods, heat waves, and droughts to anthropogenic causes with increased certainty (IPCC 2023). The effects of anthropogenic CC threaten every living system on Earth, including our local and global social systems (IPCC, 2023). While the acceptance of CC has steadily improved in the last decade to over 80% of the American public, only around half of the population thinks that it will affect them, their families, or their communities (Leiserowitz et al., 2025). Additionally, despite the growing evidence of its effects, CC has ranked below other issues like the national debt, terrorism, and immigration as a policy priority for the American public (Pew Research Center, 2023). While this has led to a formidable gap in actions that must be taken to close the "emissions gap" between the changes that are needed to stop the rise in global temperatures and what actions our country is actually taking, many scientists argue that we must first close the "education gap" between the scientific understanding and a CC literate public (Ledley et al., 2017).

Climate Change Literacy

According to the US Global Change Research Program's 2024 guide on Climate Literacy, a climate literate person:

- "Understands the essential principles of Earth's climate system and the options to address human-caused climate change;

- Recognizes credible information about climate change and knows where to find it;
- Communicates about climate change in accurate and effective ways; and
- Can make informed decisions related to climate change."

The concept of literacy is dependent on people being both consumers of information (the readerly part of literacy) as well as contributors to the information landscape (the writerly part of literacy) (Duffy et al., 2019). Climate change education (CCE) is challenged to address both these parts of CCL.

Climate Change Education

Climate change is known as a "wicked" problem in that it is an "ill-defined, ambiguous and associated with strong moral, political and professional issues" (FitzGibbon & Mensah, 2012; Rittel & Webber, 1973). Additionally, conceptualizing CC can be psychologically complex with multiple representations, understandings, and interpretations of the issue (Esbjörn-Hargens, 2010; Hulme, 2009). As students in the "climate change generation" enter university, their perspectives on CC are strong indicators of the influence of their education system and society (Feldman, 2010). Including Millennials and Generation Z (those born between the late 1980s and early 2000) this is the first generation to have lived their entire lives with wide scientific consensus, broad media coverage, and school-specific instruction of CC (Aksit et al., 2018; Ray & Nasedkin, 2020).

These students are more likely to accept that CC is a reality, that CC is caused by human activities, and that they should be concerned about the future impacts of CC (Leiserowitz et al., 2024; Stevenson et al., 2014; Wachholz et al., 2014). While it is expected that this increased exposure and concern may correlate with increased understanding of CC science, there is a growing body of literature demonstrating that university students have a limited grasp of the scientific principles underlying CC (Aksit et al., 2018; Corner et al., 2015; da Rosa, 2022; Wachholz et al., 2014). For example, undergraduate students may hold several common misconceptions about basic principles of climate science (Aubrecht, 2018; Bhattacharya et al., 2021). Misconceptions include thinking pollution is the cause of CC, confusing weather with climate, not identifying carbon dioxide as a greenhouse gas, and believing that ozone depletion is the main driver of global warming (Huxster et al., 2015; Lambert & Bleicher, 2014; Lombardi & Sinatra, 2012; McCuin et al., 2014; A. Versprille et al., 2017; A. N. Versprille & Towns, 2015; Wachholz et al., 2014).

K-12 teachers and science teacher educators have recognized common science misconceptions, and, in response, clearly articulated content expectations in the national The Next Generation Science Standards (NGSS). The goals of the NGSS are to improve both science literacy and systems literacy in K-12 natural (e.g., life, physical, and Earth system science) and social science (e.g., geography) classrooms. The three dimensions of the NGSS (disciplinary core ideas, cross-cutting themes, and scientific practices) allow these literacies to infuse throughout the curriculum (Achieve, 2013). While several states across the country have already adopted the standards, many have done so only recently, like Colorado, which just added them to their academic standards in 2019 (CDE, 2020). In addition to the delay in adapting all curricula to meet the new standards, the COVID-19 pandemic allowed districts to loosen the requirements and were not holding schools accountable for teaching the new material (Scheer et al., 2025).

Although teachers are expected to teach the concepts outlined in the NGSS, including topics of anthropogenic climate change, many may not do so because they do not understand the science or because they do not have an established curriculum (Plutzer et al., 2016; Scheer et al., 2025; Wise, 2010). While the most recent USGCRP report improved the 2009 version with additional considerations of solutions and social characteristics (i.e. social justice), during the 2025 United States presidential administration, this report was removed from government websites (Comms, 2025). The embeddedness of teachers as community members also leads to struggles with the insidious hyper-politicization of CC in the US (Oreskes, 2004; Plutzer et al., 2016). In other words, if teachers alienate community members, it may negatively impact their job security, so they must manage various expectations and perceptions of their students and parents (Scheer et al., 2025; Wise, 2010). Of additional concern is the fact that across the United States, especially in rural areas, teachers have limited opportunities for professional development, and these often do not offer training in the transdisciplinary approaches required to properly engage students with the vast CC information landscape (Barrett et al., 2015; Ledley et al., 2017; Plutzer et al., 2016).

Climate Change in the Media

The ability of the public to develop a nuanced and complete understanding of scientific issues has long been contested due to the influential views often presented to them in the media (Lippman, 1922). As suggested by cultivation theory, people's perceptions of reality are shaped in part by the media environments they inhabit, meaning that repeated exposure to particular narratives, images, and portrayals can influence how individuals come to understand the world around them (Gerbner et al., 1980; Shrum, 2017). Some argue that mass media exploit people's biases by intentionally relaying misleading messages that question the scientific consensus of CC, cast doubt on scientific accuracy, and legitimize alternative explanations (Davidson, 2008). Others have highlighted the ubiquity of CC imagery in the media and how it frames some ways of conceptualizing CC, while marginalizing others (O'Neill et al., 2013). A substantial body of research has demonstrated that these representational choices matter; the ways in which climate change is depicted in the media can shape public beliefs about its causes, urgency, and the kinds of solutions that are deemed necessary or appropriate (Newman et al., 2018; Leiserowitz et al., 2021; Rosenthal, 2022).

As media continue shifting toward increasingly visual forms of communication, audiences now encounter an expanding array of CC imagery across platforms (Mooseder et al., 2023). Some images, like the iconic polar bear stranded on melting ice, have become synonymous with CC, shaping public imagination and reinforcing specific narratives about vulnerability, distance, and crisis in ways that influence how people conceptualize climate change (Bogert & Balgopal, 2025; Harvey et al., 2018).

For young adults especially, social media has emerged as a primary source of climate information, exposing them to a more varied different visual landscape than that presented in traditional news (Highfield & Leaver, 2016; Pew Research Center, 2025). Here, humorous, ironic, or sarcastic formats, such as memes, reaction images, and short-form videos, circulate widely alongside activist-infused imagery, infographics, and user-generated content (Boykoff & Osnes, 2019; O'neill et al., 2013). This range of visuals differs markedly from the graphs, diagrams, and scientific images students encounter in the classroom, yet both domains demand interpretive skill, contextual understanding, and the ability to integrate information across modes. As students navigate these visual environments, their ability to make sense of the information increasingly depends on how they develop and apply their visual literacy skills (Brumberger, 2011). Understanding how learners interpret and apply this diverse visual material is therefore essential for strengthening climate change education and ensuring that students can critically engage with the images shaping their perceptions of the issue.

Visual Literacy

Visual literacy (VL) has been an active area of scholarship since the late 1960s, when early, predigital definitions positioned it alongside other emergent literacies but largely at the margins of higher-education discourse (Debes, 1969). Initial ideas emphasized more passive competencies involved in interpreting still and moving images across photography, film, video, and mass media. VL is framed as the ability to comprehend, recognize manipulation, and appreciate aesthetic qualities of visual communications (Messaris, 1993). It was only in the late 2000s, with the rise of digital technologies, that a more multidimensional definition of VL considered the active application and creation of visuals (Spalter & van Dam, 2008). Today a plethora of definitions of VL abound (Arneson & Offerdahl, 2018; Bombara & Duan, 2024; Schönborn & Anderson, 2006). The Visual Literacy Competency Standards for Higher Education from the Association of College Research Libraries (ACRL) define VL as the ability to find, interpret, evaluate, use, and create visual media. This established a comprehensive framework that includes ethical and legal considerations and emphasizes both students' passive and active roles as knowledge consumers and creators (Hattwig et al., 2011).

In professional scientific communities, the use and creation of visuals is essential, as nearly every scientific discipline relies on visual representations (graphs, diagrams, computer models, chemical structures) to translate abstract ideas and unobservable phenomena into forms that can be perceived and reasoned about (Arslan et al., 2012; Cordero et al., 2008; Gershon et al., 1998). Both empirical and conceptual visuals help bridge the gap between theoretical constructs and the observable world and are integral for modeling hypotheses, identifying meaningful patterns, and communicating ideas within scientific communities and to broader publics (Duan & Bombara, 2022; Rodríguez Estrada & Davis, 2015). Although VL skills are considered fundamental to learning in the sciences, it is rarely explicitly taught in undergraduate and graduate-level science courses. It is often assumed students will acquire these skills on their own as they advance through their coursework, despite little evidence supporting this (R. Arslan & Nalinci, 2014; Avgerinou & Ericson, 1997; Offerdahl et al., 2017). For this reason, VL can be considered a part of the hidden (or implicit) curriculum (Jackson, 1968).

Climate science depends heavily on visual media to convey complex, abstract, and often seemingly invisible processes, from global temperature trends to atmospheric dynamics (Bush et al., 2019; Harold et al., 2016). At the same time, CC images increasingly saturate news and social media, making students' ability to interpret and evaluate these visuals critical for informed engagement (Brumberger, 2019). Concurrently, VL plays an important role in students being able to participate productively as science communicators (Rodríguez Estrada & Davis, 2015). Yet, explicit consideration of VL in published CCE research is sparse. The scarcity of research exploring how VL shapes CC understanding underscores an urgent need for studies that examine the role of VL in developing CCL, which can build on the research on how worldview affects how people perceive images of the environment (Nisbett, 2010).

Considering Worldview

A person's individual values and worldviews can shape how they conceptualize CC information by acting as reference through which new information is compared (Shi et al., 2015). New ideas and visuals they encounter are often integrated into existing belief systems as they negotiate this info (Stern et al., 1995). Worldviews (WV) are "*the inescapable, overarching systems of meaning and meaning-making that inform how humans interpret, enact, and co-create reality*" (De Witt et al., 2016) (Figure 1.1). This can play a role in how people develop shared identities, through which they will consider new ideas and the implications for the cultural values and issues of importance that they share with others (Feldman et al., 2012; Iyengar & Hahn, 2009; Whitmarsh, 2011). For example, (Hamilton, 2011) reported that political leanings had a much stronger influence than education in predicting public concern over CC. Similarly, Kahan et al. (2012) found that people with high numeracy and scientific literacy were not the individuals most concerned about CC. de Rosa (2021) reports that there are WV differences in the misconceptions students hold.

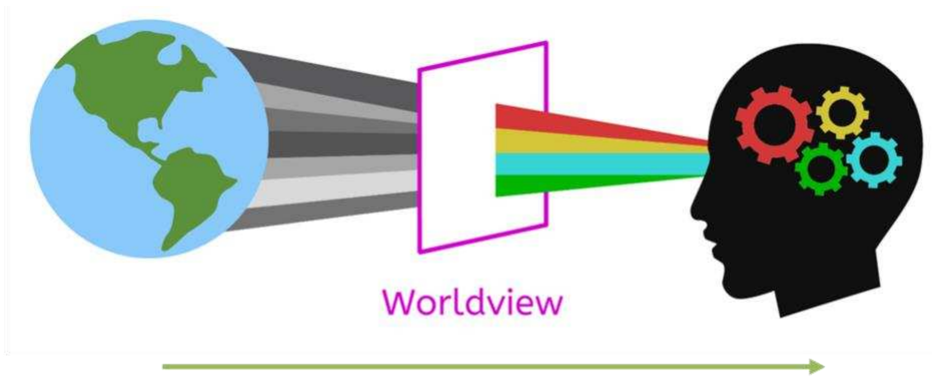

Figure 1.1 Worldview is depicted using the purple box, which represents the lens through which all new information is processed. This leads to individual meaning making, as represented by the colored gears inside the silhouette.

Considering that students frequently encounter various forms of CC information (e.g. CC images in the media and the classroom), the role of WV in how they make meaning of these is relevant. Studies have argued that because adolescents and young adults are still developing their WV (Vollebergh et al., 2001), climate education can have a significant impact on their CC concern and literacy (Stevenson et al., 2014). Aksit et al. (2018) posited that undergraduates may be diverging from adults because they have had different exposure to CC in their education systems and in the media. Additionally, because interpretation of visual content is culturally situated and symbols can be interpreted differently across groups, developing both VL and CCL requires attention to the cultural, affective, and WV factors that guide students' interpretations and shape their engagement with climate change (Shi et al., 2015; Lee et al., 2020).

Dissertation Organization

Chapter 2 - *In Sight, Out of Mind: A systematic review of visual literacy and climate change literacy in education interventions*

I begin with a Systematic Literature Review in Chapter 2 that provides background on VL and CCL and investigated how VL was being incorporated to achieve CCL competencies in formal CCE contexts. After evaluating over 300 articles, I was able to outline some of the successful strategies and themes that emerged from the analysis between these constructs. During this study I was able to better understand the practical application of VL skills and developed a hierarchical model of these skills inspired by how they aligned on Bloom's taxonomical levels. This also led to the development of a similar CCL competencies hierarchy based on the USGCRP 2024 definition of CC and observations made during analysis.

Chapter 3 – *From Science to Solutions: Teaching Climate Change as Simple, Serious, and Solvable*

Since CC can be taught in many ways, this curriculum paper was written to lay the foundation for the Simple, Serious, Solvable model that was used to structure CC content in all my subsequent studies. Here we discuss the content that goes into each S3 unit as well as the associated assessment materials. It was taking Dr. Denning's class and first being exposed to this model that inspired me to pursue research in CCE.

Published in: *Journal of College Science Teaching*

Chapter 4 - *How science teachers visualize climate change through drawing-to-learn activities*

Chapter 4 investigates how in-service and pre-service teachers are conceptualizing CC before and after going through an S3 lesson. Through a drawing-to-learn activity that had participants take on the role of Contributors of both CC information and VL, we elicited the factors of CC that were most salient to them and made inferences as to how this might impact their teaching and the resources that teacher educators can further provide.

Chapter 5 - *The Role of Visual Literacy in Improving Climate Change Literacy*

This research provides a quantitative assessment of how students' VL level influences their CCL. Through the analysis of a series of VL interventions, I quantified student VL using a created rubric. Then, using responses from an adapted version of the Climate Change in the American Mind survey (Leiserowitz et al., 2013), scores on a CC Knowledge Assessment (Aksit et al., 2018), and class HW assignments, I was able to measure all the CCL competencies. Additionally, I analyzed patterns in the types of images that students interacted with. Through a series of statistical analyses, I discuss how student VL scores impact CCL.

Chapter 6 – *What in the worldview? Research brief on how worldview relates to student VL and CCL*

In this research brief, I discuss ongoing research on the influence of worldview and demographic factors (student political orientation major, program level, and course structure) on VL and CCL. Using the Integrative Worldview Framework (De Witt et al., 2016) and the VL scores and CCL constructs from Chapter 5, I conduct a series of hierarchical regression models to measure these relationships. I discuss implications for future research.

Chapter 7 – *General Discussion*

This discussion highlights my main findings and considers them in the context of the current science and education system. I provide a consideration of how our education and communications systems can be improved through the incorporation of VL to develop CCL. Directions for future research are also discussed.

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CHAPTER 2 - IN SIGHT, OUT OF MIND: A SYSTEMATIC REVIEW OF VISUAL LITERACY AND CLIMATE CHANGE LITERACY IN EDUCATION INTERVENTIONS

ABSTRACT

To respond to the increasingly urgent effects of climate change (CC), educators need to develop students' holistic climate change literacy (CCL). Recent changes in the USGCRP Climate Literacy Guide emphasize not only building understanding of the mechanisms, impacts, and solutions of CC, but also developing confidence and skills in evaluating information, communicating, and making informed decisions. As educators increasingly use visual images to teach CC, examining students' visual literacy (VL) in developing their climate change literacy (CCL) is timely. However, there have been few studies looking at the relationship between CCL and VL in K-12 settings, necessitating this systematic review of CC education literature to identify how VL can be leveraged to achieve CCL. Through large database searches, 58 relevant articles were identified in CC education. Thematic analysis revealed that five emergent themes illustrate how VL has been implemented to develop holistic CCL. These themes include Seeing & Experiencing, Seeing the Unseen, Visualizing Thinking, Communicating Like a Scientist, and Seeing and Being the Change. Findings from this study can guide educators who wish to leverage VL to build CCL.

INTRODUCTION

As the effects of anthropogenic global climate change (CC) become increasingly evident, so too does the need to have an engaged public ready to respond to environmental and economic impacts of CC. Despite scientific certainty, the absence of sustained efforts in the United States (US) to mitigate CC indicates a disconnect between public perception and understanding of the urgency of CC (Doran & Zimmerman, 2009; Oreskes, 2004). Developing a knowledgeable and motivated population is crucial to ensuring that communities are prepared to mitigate and prevent the impacts of CC. Youth hold the greatest potential for impact as they are the generation that will experience the most significant overlap with the projected effects of CC and already display increased worry and concern about these issues relative to most Americans (DeCamp, 2024; Leiserowitz et al., 2023; Stevenson et al., 2014; Wachholz et al., 2014). However, despite having grown up hearing about the issue throughout their lives, youth often exhibit low climate literacy and harbor persistent misconceptions (Cordero et al., 2008; Corner et al., 2015; Wachholz et al., 2014). To promote pro-environmental behaviors, K-12 graduates require opportunities to build their CC knowledge and competencies (Allen & Crowley, 2017).

Academic standards in the US have largely focused on developing knowledge and understanding of CC mechanisms and impacts (Chang & Pascua, 2015). This is emphasized by the previous US Global Change Research Program (USGCRP, 2009) Essential Principles of Climate Literacy, which prioritized scientific facts about the Earth's climate system and human impacts but hardly mentioned solutions. Additionally, academic standards often ignore other features of what it means to be a 'climate literate person', which includes the ability to communicate about CC, evaluate CC information, and take informed and responsible actions to respond to CC (Dupigny-Giroux & Cole, 2018). To move from this more "derived" climate literacy that focuses on the consumption and comprehension of information, towards a more "fundamental" climate literacy, where students are prepared to consider information and act in pro-environmental ways, requires an expansion of the knowledge and skills that are currently presented and developed in the classroom (Busch & Román, 2017).

Climate science concepts are often presented to students along with complex visualizations. Due to the abstract and intricate nature of climate science concepts, students often struggle to fully comprehend them without the aid of instructional materials that enable the visualization of these complex ideas (Arslan et al., 2012; Cordero et al., 2008). Integrating data visualizations, such as graphs, diagrams, simulations, and interactive visualizations, has become an effective approach in climate change education (CCE) (Bush et al., 2019; Harold et al., 2016). In part, this is because media communications about CC are primarily visual in nature, particularly for the types of media with which youth are engaging (i.e. social media) (Andersson & Olson, 2014; Wang et al., 2018). Some studies suggest that social media serve as primary source of climate-related information for many adolescents, significantly impacting their awareness and understanding of CC issues. Thus, to develop robust climate change literacy (CCL), students also need to be visually literate. Visual literacy (VL) for scientific fields has been defined in many ways (Offerdahl et al., 2017; Schönborn & Anderson, 2006; Trumbo, 1999), but broadly encompasses the ability to find, use, interpret, critically analyze, and create visual images, processes that involve both the decoding and encoding of visual imagery (Ausburn & Ausburn, 1978; M. D. Avgerinou & Pettersson, 2011). The role of VL in developing CCL has yet to be reviewed.

The development of VL is tied closely to the development of semiotics (i.e., an understanding of the symbols and representations that are used in a field of study) (Bopry, 1994). In the field of biochemistry, Offerdahl et al., 2017 develop a description of VL that draws on this need to develop fluency in the disciplinary discourse for learning to occur (Airey & Linder, 2009; Offerdahl et al., 2017). When considering the classroom context, if this discourse is not developed or taught, students must rely on their own worldview, interpretations, and prior knowledge when decoding visuals (Dupigny-Giroux & Cole, 2018). The meaning that is created from a visual image relies on both bottom-up processing that draws on the salient visual characteristics of an image (colors, shapes, and sizes of elements), as well as top-down processing that is driven by viewer expectations, prior knowledge, and cultural contexts (Harold et al., 2016; Latour, 1986). If the image does not match these, this can lead to misconceptions or incomplete understandings of the topic (Seglem & Witte, 2009). Popular media images about climate change have been found to frame some ways of conceptualizing CC, while marginalizing others, which may determine the salience of these perspectives for students (O'neill et al., 2013). For example, common imagery of melting ice caps or endangered species like polar bears can evoke feelings of fear, helplessness, and psychological distancing which may lead students to disengage from the topic rather than fostering a constructive understanding of climate change science and impacts (Feldman et al., 2017; Leviston et al., 2014).

When considering the development of CCL, it is crucial to understand how an individual's perspectives can act as an opportunity to fully make meaning of CC information (Azevedo & Marques, 2017; Dupigny-Giroux & Cole, 2018; Wang et al., 2018). For the public, these personal factors have been found to be more influential than knowledge in developing CC risk perceptions (Kahan et al., 2012). However, because adolescents have a certain "plasticity" in their perspectives, knowledge development has been found to have a bigger effect on risk perception for this demographic (Aksit et al., 2018; Vollebergh et al., 2001). Furthermore, given the highly politicized nature of CC in the US, educators must consider the dual role of developing knowledge while addressing student personal factors (Stevenson et al., 2014; Zummo et al., 2020).

This study aims to systematically review the existing literature of CCE intervention studies to determine the relationship between VL and CCL. To understand this relationship, we have developed the following questions to scaffold the information and structure this review:

1) What visual literacy skills are climate change education interventions incorporating?

2) What climate change literacy competencies are these visual literacy skills developing?

METHODS

A systematic literature review was conducted using a comprehensive, large database search strategy to identify relevant peer-reviewed studies using methods that are replicable. Systematic review was the chosen method because it allows for a rigorous, transparent, and replicable synthesis of the available evidence on a topic while avoiding cherry picking (Gough et al., 2012). Inspired by the systematic reviews conducted by (Monroe et al., 2019) and (Bhattacharya et al., 2021), this study builds on CCE research.

Literature Search and Review

The literature search was conducted using the academic search engine EBSCOhost, which provides access to 101 databases from [state] University's library subscription. These databases included American Search Ultimate and Premier ERIC, PsycINFO, GreenFILE, and Environment Complete. Google Scholar was used to supplement the EBSCO search using the same search terms. Additionally, backward searches were conducted from relevant key reviews of Monroe et al., 201 and Bhattacharya, 2020 (Webster & Watson, 2002).

The selection of search terms aimed to gather as many applicable studies as possible while considering the feasibility of this review, based on available time and resources. The key search terms are shown in Figure 2.1. These were entered into the search engines using the bolded Boolean operators, and for EBSCOhost, it was set to examine title, abstract, subject, keywords, and author. We limited the results to peer-reviewed studies published in English and used 2009 as the earliest year of publication. 2009 was chosen because it was the last year that the USGCRP published their climate literacy report and this year saw a large increase in CCE research studies published (Rousell & Cutter-Mackenzie-Knowles, 2020); USGCRP, 2009). This resulted in 569 total citation records collected.

‘climate change’ **OR** ‘global warming’
AND
‘climate change literacy’ **OR** ‘climate literacy’ **OR** ‘climate change education’ **OR** ‘climate education’ **OR** ‘environmental education’ **OR** ‘education for sustainability’ **OR** ‘education for sustainable development’ **OR** ‘conservation education’ **OR** ‘sustainability education’ **OR** ‘ecology education’ **OR** ‘energy education’ **OR** ‘adult education’ **OR** ‘community education’ **OR** ‘formal education’

Figure 2.1. Search Terms. In the box above, the search terms are listed with the included Boolean operators in bolded letters.

A decision tree was created to determine which studies to include (Figure 2.2). The inclusion criteria aimed to look at the field of CCE broadly and focused on whether the studies had measured interventions. We limited the review to primary, peer-reviewed research studies published in the US to have uniformity in the inherent and context-specific Western perspectives that would be represented by the students in the studies. We kept the studies to those in formal education settings (institutionalized, intentional, and planned by an education provider; UNESCO, 2012) at the secondary (grades 6-12), post-secondary (undergraduate and graduate) levels, and educator professional development (PD) contexts.

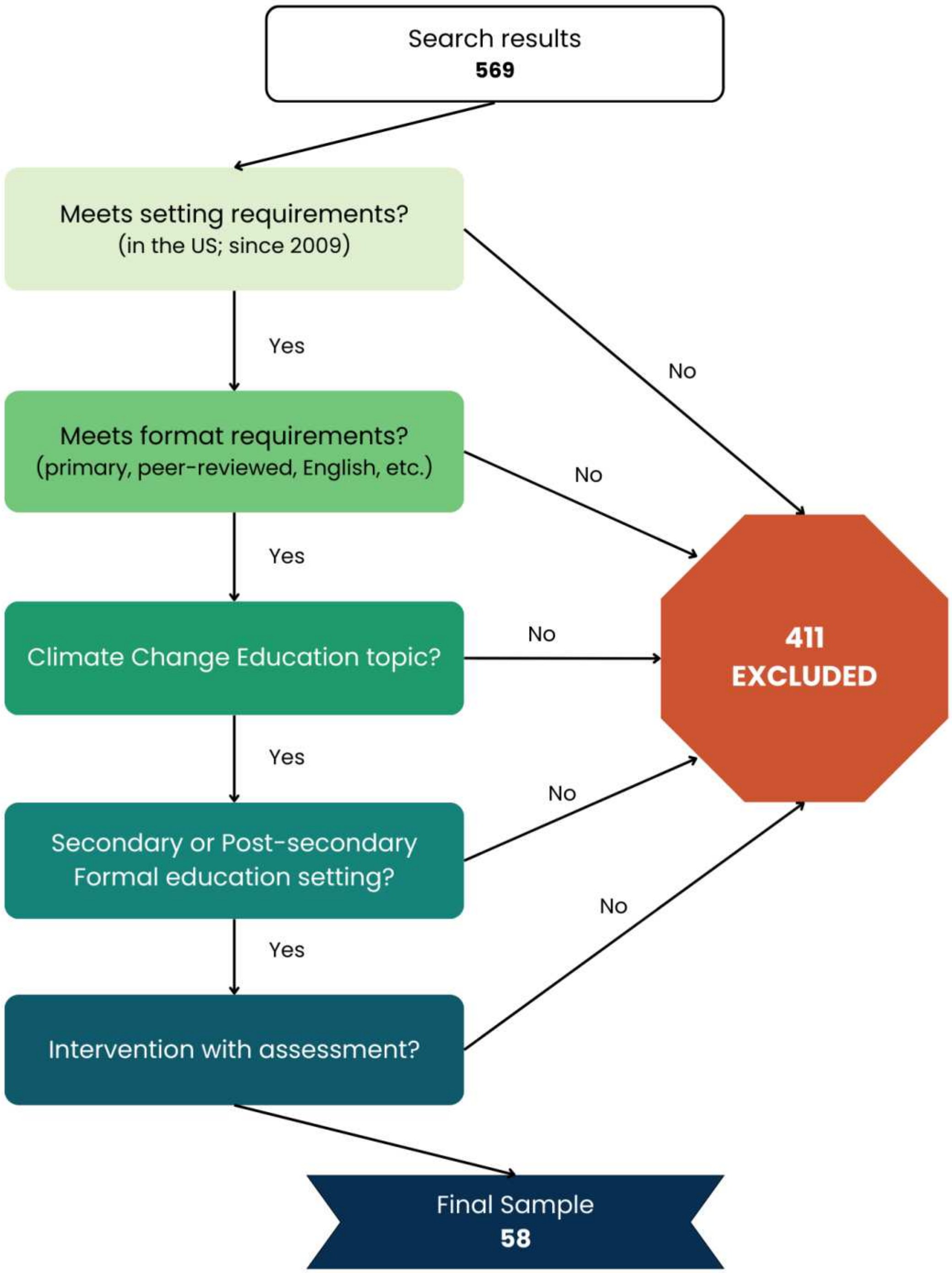

Figure 2.2. Decision Tree. Selection criteria and the total number of excluded papers are shown.

Using these criteria and the decision tree, the first round of review involved examining the title, abstract, and the methods sections. After the first two steps filtered out several of the studies, we imported the remaining 265 into Rayyan (Ouzzani et al., 2016), a systematic literature review organization system, for further analysis. This step resulted in 411 citations being excluded, and a final remaining sample of 58 studies. Information from these studies was exported from Rayyan and added to an Excel spreadsheet for further information tracking during analysis. Additionally, the PDF files of these studies were uploaded into MAXQDA 2024 (VERBI Software, 2024) coding software for analysis.

Analysis

Each study was read in entirety, enabling us to identify pertinent information to record in a spreadsheet, including study population, type of intervention, and a short summary of the key focus and findings related to our research questions. The papers were inductively and deductively coded (Corbin & Strauss, 2014) to determine themes related to the research questions. Because VL was a central concept, we began coding and analysis using this construct. Then, examining VL papers, we searched for themes related to CCL using a developed definition. The coding process and analysis was conducted iteratively, with multiple rounds of review at each stage to refine the codes and themes. Details of the codes and themes are found in the following sections.

Limitations

The exclusion criteria ensure that there will be several potential sources of relevant information that were not included. For example, including only studies published in English and set in the U.S. means that results are only relevant to these contexts. Additionally, this review excluded any gray literature (conference articles, dissertations/theses, and reports) in which there might be important contributions to this topic. By concentrating on the studies whose interventions were measured, we left out potentially informative studies that did not evaluate their interventions.

The search terms themselves were also limiting in that relevant research that did not use these terms would be excluded. This is also exacerbated by the fact that I chose to look specifically at the literature in the realm of CCE and did not look at other fields that may have been employing visual literacy interventions.

RESULTS

Demographics

There was a total of n=58 studies that comprised the data set. Of these, n=24 studied post-secondary (undergraduate and/or graduate) students, n=19 studied secondary (middle school and/or high school) students, and n=15 studied teachers or a combination of teachers and students (Figure 2.3). Since all the studies were conducted in the US, middle school students referred to students in grades 6-8, high school students referred to students in grades 9-12, undergraduate students referred to university or college students, and graduate students referred to Masters and PhD students. Teachers included in-service K-12 educators as well as university teaching faculty.

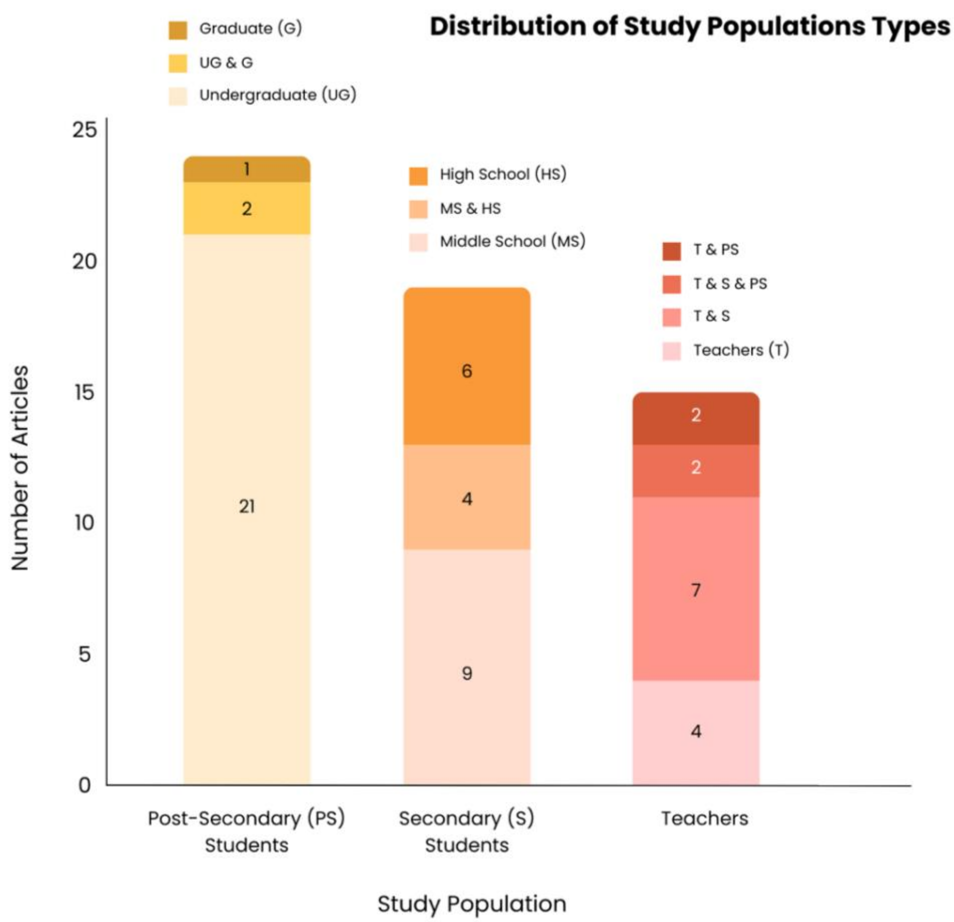

Figure 2.3. Distribution of Study Population Types. These three stacked bar graphs show the study populations in the data set. The leftmost yellow bar shows the distribution of Post-Secondary (PS) students (n=23), which includes Undergraduate (UG) (n=21), Graduate (G) (n=1), and UG and G (n=2) students. The middle orange bar shows the distribution of Secondary (S) students (n=19), including counts for the articles that studied Middle School (MS) (n=9), High School (HS) (n=6), and MS and HS (n=4) students. The rightmost red bar shows the distribution of articles that studied Teachers (T) (n=4), T and S students (n=7), T and S and PS students (n=2), and T and PS students (n=2).

The articles measured several types of interventions. These included an entire degree program (n=1), whole courses (n=18), limited units or short modules within a course (n=22), PD sessions or workshops (n=8), and individual activities (n=8). Several of these interventions also had activities specified within other contexts; this included whole courses (n=15), the limited units (n=8), and the PD units (n=4). There was also a subset of interventions that incorporated a limited curricular unit, PD, and activities (n=7). See Figure 2.4 for the distribution of the intervention types.

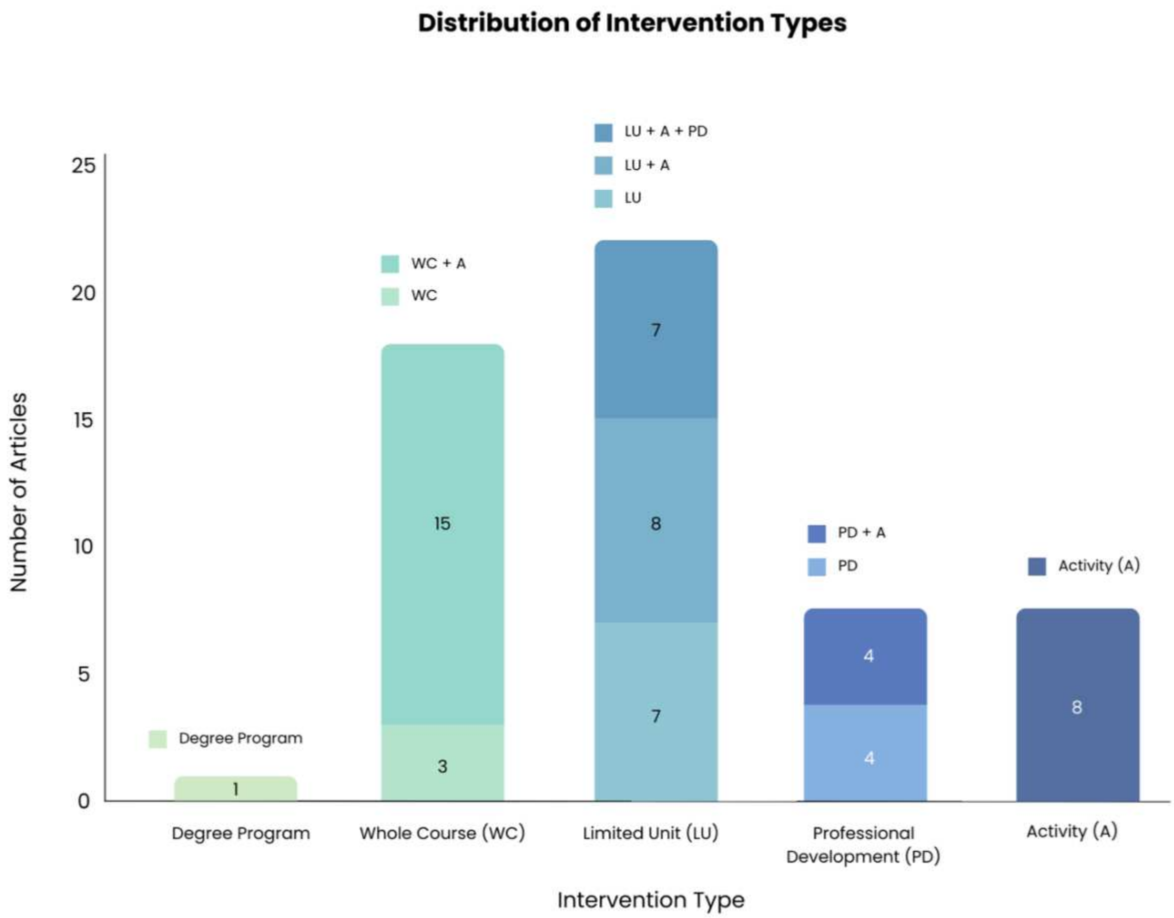

Figure 2.4. Distribution of Intervention Types. These stacked bars show the intervention types within the data set. From left to right: An entire degree program (n=1); Whole Courses (WC) (n=18) separated further by those that also included an Activity (WC + A) (n=15); Limited Units (LU) (n=22), split by those that also included Activities (LU + A) (n=8), and those that had an A and a Professional Development (PD) component (LU + A + PD) (n=7); PD interventions (n=8), divided by those that also included an A (PD + A) (n=4); and finally, the interventions that only measured an Activity (n=8).

Of the 58 articles in the data set, 44 incorporated a visual literacy skill (VLS). Within these, 38 had a climate change literacy (CCL) competency associated with the VLS (Figure 2.5). The details of these articles are further elaborated in the appropriate sections.

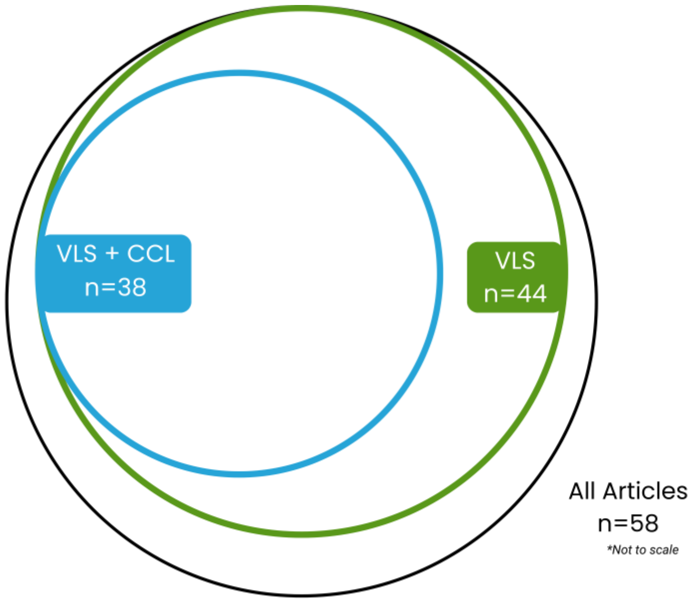

Figure 2.5. Venn Diagram of the VLS and CCL Articles. The circles depicted in this nested Venn Diagram are not to scale. The entire data set is represented by the black circle (n=58). Within the black circle is a green circle, which represents the articles that had a VLS component included (n=44). Within this green circle, there is a blue circle representing the articles that had both a VLS and CCL competency (n=38).

The articles in the data set used a range of measurements and instructional approaches related to CC and environmental education. The specifics of the intervention outcomes are beyond the scope of this study, and much of this information has been reported elsewhere (Monroe et al., 2019). Here, we considered which VLS and CCL competencies were targeted in the instructional interventions. Our intentions are to describe a model of the relationship between these literacies and example strategies that are successful.

Visual Literacy

Most (n = 44) articles mentioned a visual component in their instructional intervention. However, there was only a single instance of an explicit "visual literacy" integration in the interventions (Krejci et al., 2020). Therefore, the others were classified and analyzed by considering the implicit, implied intention of the incorporation of visual elements. The extent of incorporation of visual images into the interventions or assessments differed significantly. From a casual mention of including videos in course content (Aksit et al., 2018; Arya & Maul, 2016; DeWaters et al., 2014), to detailed descriptions of hands-on visualization activities (Ramamurthy et al., 2014; Zangori et al., 2017), there was a wide range of ways that the studies described the need for or develop VLS. This required us to carefully analyze the context in which the visual component was embedded in the interventions to identify the specific VLS relevant for each paper.

Informed by the Association of College & Research Libraries definition of VL and inspired by (Arneson & Offerdahl, 2018) Visualizing Bloom's Tool (VBT), the skills found within the studies were grouped into 7 types: See & Experience, Recognize, Interpret, Analyze, Evaluate, Find, Use, and Create. Additionally, the three major categories that emerged were related to the roles that the learners took as they participated in the interventions: 1) Passive Consumer, 2) Active Consumer, and 3) Contributor. These categories were based on the ACRL consideration of a visually literate individual as "both a critical consumer of visual media and a competent contributor to a body of shared knowledge and culture" (ALA, 2011). Like VBT, the skills within each of these larger themes were sorted into a hierarchical structure that represented low to high-order levels of engagement and cognition (Arneson & Offerdahl, 2018) (Figure 2.6).

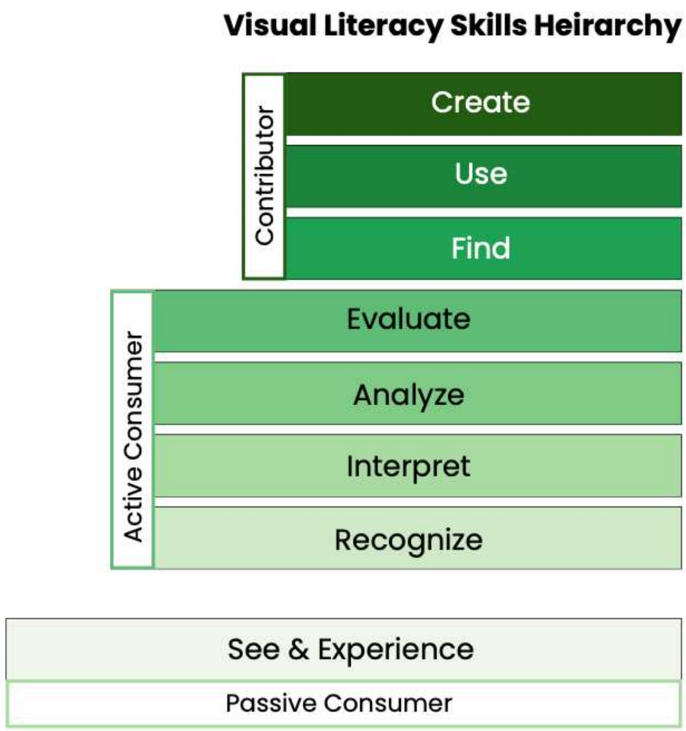

Figure 2.6. The Visual Literacy Skills Hierarchy. There are three main categories which relate to the roles students are taking as they engage with visual material, and each has associated skills within that are ordered from low-level engagement skills on the bottom of the hierarchy to the higher-order skills on top. The progression of skills is emphasized using darker green color saturation for higher-order skills. The widths of the boxes relate to the fundamental nature of the roles and how they are built upon for the higher-order roles and skills. The categories and skills are 1) Passive Consumer: See and Experience; 2) Active Consumer: Recognize, Interpret, Analyze, and Evaluate; and 3) Contributor: Find, Use, and Create.

Passive Consumer (n=4)

This emergent category is not one strictly related to VLS because it represents an inactive engagement of visual processing, hence the term “passive.” This category can be considered foundational to the skills hierarchy because it represents situations where the act of engaging with visual content is important, but there is no conscious cognition being measured. Rather, these represent the unconscious perceptions and feelings students employ when seeing or experiencing visual images without building on or using a skill that would qualify in the VLS hierarchy. Hence, in the Figure 2.6 hierarchy, this category is at the bottom and separate from the others but is still foundational. The studies that qualified in this category were those that only had this code and no other VLS included. In this data set, these included instances when students watched a movie or a presentation and their reactions were measured, but there was no further cognitive engagement integrated (Bondi et al., 2021; Flora et al., 2014; McNeal, Spry, et al., 2014). Additionally, these included engaging visually with a location or context while outside of the classroom, usually through travel related to an educational experience (Landon et al., 2019; Stapleton, 2019).

Active Consumer (n=31)

Students take on the role of Active Consumer when the engagement with visual material requires conscious and effortful cognitive processing. At the lowest level, the Recognize (n=11) VLS are instances when students drew on their memory and identified the components of a visual and/or recalled information. Examples include identifying components of a scientific diagram (Breslyn et al., 2017; McNeal, Libarkin, et al., 2014), graph (Bush et al., 2019; Ellwein et al., 2014; Holthuis et al., 2014; Krejci et al., 2020), or image (Liu et al., 2015), as well as from course slides and videos (Bofferding & Kloser, 2015; Hestness et al., 2019; McNeal, Spry, et al., 2014).

Students moved beyond recall and recognition to developing understanding of the information being conveyed as they Interpret (n=18) visual images. This included answering conceptual questions about CC videos (Aksit et al., 2018; Bitting & Merricks, 2025; Hestness et al., 2019; Lambert & Bleicher, 2014), diagrams (Breslyn et al., 2017; Drewes et al., 2018), models (Pallant & Lee, 2015; Powers et al., 2021), online games (Cook et al., 2023; Nussbaum et al., 2015), graphs (Krejci et al., 2020; Nam & Ito, 2011), and images (Lindgren et al., 2021). In addition, interpretation skills are required when students cited evidence from a visual image (e.g. graph) as evidence for a claim (Arya & Maul, 2016; Ellwein et al., 2014; Holthuis et al., 2014).

When asked to Analyze (n=15) a visual image, students were expected to identify the relationship between concepts represented to draw conclusions beyond what was shown. This included identifying patterns and trends among several graphs, diagrams, or models (Bitting & Merricks, 2025; Bodzin & Fu, 2014; Krejci et al., 2020; Lambert & Bleicher, 2014; Nussbaum et al., 2015; Powers et al., 2021; Ramamurthy et al., 2014; Visintainer & Linn, 2015). In addition to finding connections across visual images, students generated new research questions by reviewing graphs, models, or images for experimentation (Ellwein et al., 2014; Lindgren et al., 2021; Pallant & Lee, 2015; Varma & Linn, 2012), as well as from, videos or diagrams to find personal or local connections (Clary & Wandersee, 2012; Leichenko et al., 2022).

At the highest level of Active Consumer, students Evaluate (n=7) the effectiveness of a visual image in supporting a claim, along with the reliability of information. This included finding reliable sources for visual information (Bitting & Merricks, 2025; Rooney-Varga et al., 2014), determining if videos or visual images were reputable (Clary & Wandersee, 2012; Hestness et al., 2019), and determining the types of misinformation represented in an image (Cook et al., 2023). Students also evaluated the visual creation of their classmates through peer review activities (Nam & Ito, 2011). In addition, when creating models, students were asked to evaluate the effectiveness as they developed further content understanding (Zangori et al., 2017).

Contributor (n=21)

As Contributors, students engage in the highest level of cognitive activity as they move beyond thinking about the visual image to applying and producing them. In some studies, students were asked to Find (n=3) appropriate visual images for a given context. After students analyzed several graphs and charts, they were tasked with searching for additional sources that supported the conclusions they drew from their analyses to help synthesize their ideas (Bitting & Merricks, 2025). Similarly, when conducting a project requiring climate-friendly navigation, students had to find appropriate maps to visualize their chosen route (DeWaters et al., 2014). During a creative project, students were required to find images to use as inspiration for their work (Stafford & Brain, 2022). The evaluation of existing visual images requires students to understand the context and Use (n=7) the images in appropriate ways. For example, when developing presentations or other informational materials (e.g. brochures, posters, PowerPoint, videos), students were asked to include or apply relevant images communicate a topic, which was often supported with written text (Bitting & Merricks, 2025; Burkholder et al., 2017; DeWaters et al., 2014; Madden & Dell'Angelo, 2016; Nam & Ito, 2011; Shea et al., 2016; Zangori et al., 2017).

At the highest level of the hierarchy, students develop new materials through the Creation (n=19) of visual images. This level requires students to combine and synthesize the other skills and build on them as they generate something novel. Most often, this took the form of synthesizing data to construct models, graphs, and/or maps (Bush et al., 2019; Drewes et al., 2018; Ellwein et al., 2014; Hallar et al., 2011; Lambert & Bleicher, 2014; Monroe et al., 2019; Ramamurthy et al., 2014; Shea et al., 2016; Teed & Franco, 2014; Zangori et al., 2017). Other examples include visualizing their conceptions or mental models through drawings (Hestness et al., 2019; Shepardson et al., 2011; Zangori et al., 2017), virtual tools (Nussbaum et al., 2015), photographs (Madden & Dell'Angelo, 2016), and constructing new visual materials (e.g. infographics, art, videos) for the purposes of communicating about CC (Bitting & Merricks, 2025; Nam & Ito, 2011; Rooney-Varga et al., 2014; Siegner & Stapert, 2020; Stafford & Brain, 2022).

While students were often asked to take multiple roles within an intervention, they are reported here as individual tasks allowing us to develop a more granular view of what each activity entailed and what VLS students were building. This skill hierarchy was used as a basis to then consider which aspects of CCL they were contributing to.

Climate Change Literacy and Visual Literacy

To answer our second research question, we sought to define climate change literacy. The recently updated USGCRP 2024 Climate Literacy and their new, expanded definition of a climate–literate person was the basis for which I analyzed the interventions and the context for the VLS. According to the USGCRP (emphasis added), a climate-literate person:

- ***Understands*** the essential principles of Earth's climate system and the options to address human-caused climate change;
- ***Recognizes*** credible information about climate change and knows where to find it;
- ***Communicates*** about climate change in accurate and effective ways; and

  Can make informed ***decisions*** related to climate change.

Using the Essential Principle outlined in the guide and associated details, I summarized them into 6 Climate Change Literacy Competencies (Figure 2.7) that include: Understand the Science, Understand the Impacts, Understand the Solutions, Evaluate, Communicate, and Decisions. These were also organized into a hierarchy that reflected that of the VLS and included the larger categories of Consumer and Contributor. The role of Consumer represents the development of the readerly part of climate literacy (derived CCL), where students are taking in information about CC, whereas the role of Contributor represents the writerly aspects of CCL that prepares students with the skills to take action in response to what they have learned (fundamental CCL) (Duffy et al., 2019).

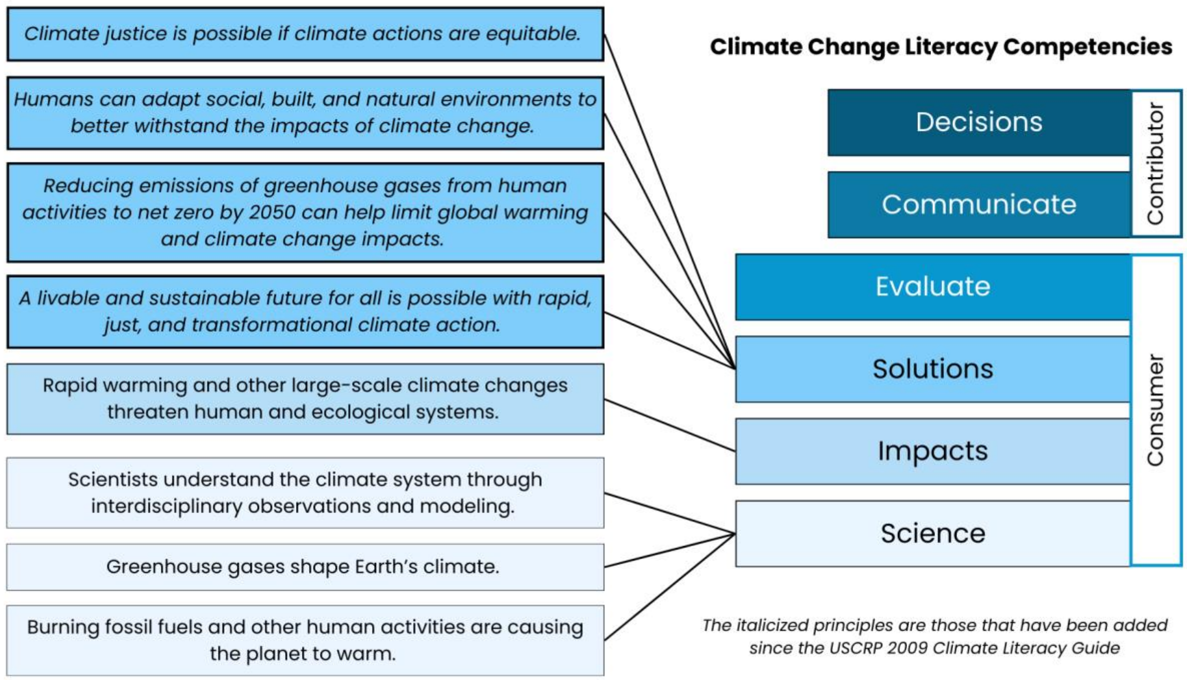

Figure 2.7. Climate Change Literacy Competencies derived from the USGCRP 2024 Climate Literacy Guide Essential Principles. These competencies include Understand the Science, Understand the Impacts, Understand the Solutions, Evaluate, Communicate, and Decisions. The names of the competencies were summaries of the CC areas they are addressing and derived from the description of "a climate-literate person" in the Guide. The term "Evaluate" was used instead of "Recognize" to align better with the "Evaluate" VLS it was associated with and avoid confounding these meanings. On the left-most boxes are the Essential Principles aligned with each of the Understand categories. In italics are the Essential Principles that were new to the 2024 guide since the last 2009 iteration.

These CCL Competencies were used to deductively analyze the VLS within each of the articles. There were instances where an article had a VLS that was applied to more than one CCL competency, but they are reported here separately for each article. For example, if an intervention prompted students to create an infographic that expressed the local impacts of CC on a community, followed by the students sharing this infographic with local community members, this was categorized as Create because it was co-coded as both Understands Impacts and Communicates. Additionally, as described within each section below, several VLS were also used in tandem for a single instance of a CCL competency. As such, the counts in the heat map (Figure 2.8) represent the number of articles included a relationship between a particular VLS and a corresponding CCL competency, but the squares are not necessarily independent of each other.

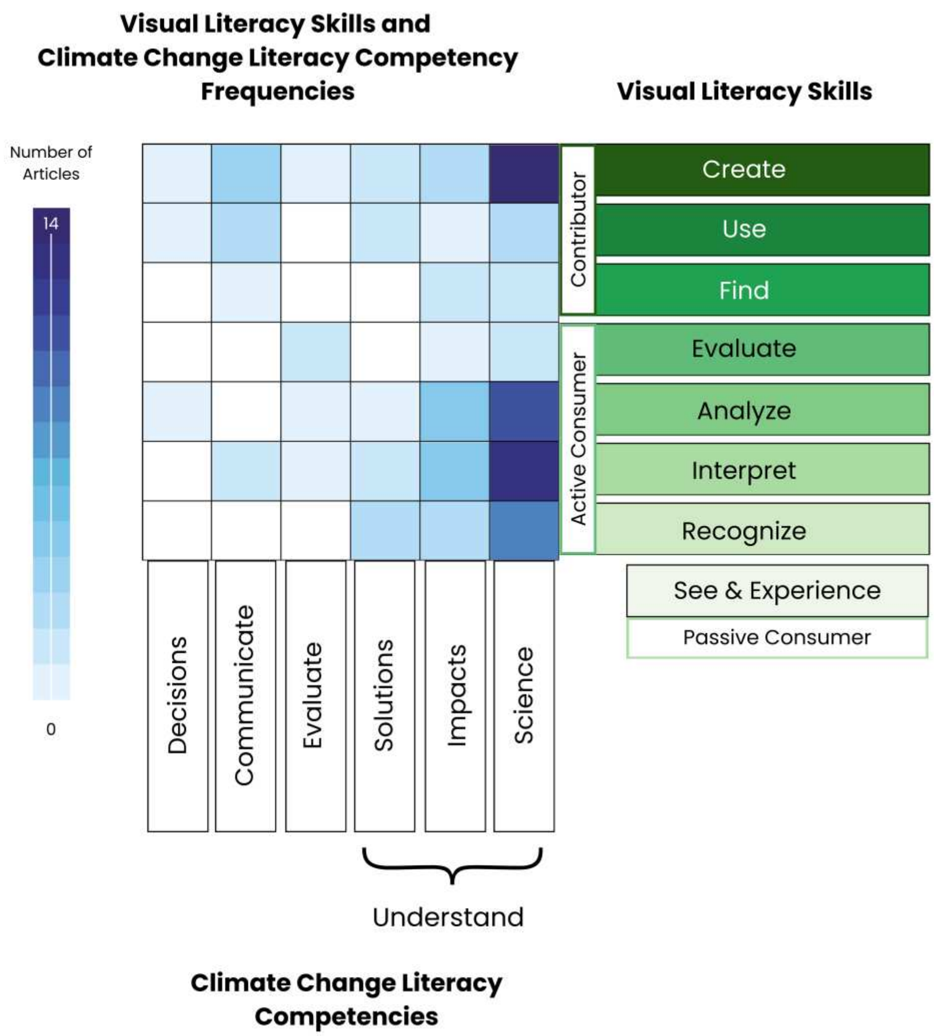

Figure 2.8. Frequency Heat Map of VLS and CCL. (Right) The VLS hierarchy with a green gradient. (Left) The frequency of articles at the overlap of the VLS and CCL competencies represented by a blue gradient. Dark blue represents a higher frequency (maximum of 14) with subsequent lighter blue colors representing a decrease in frequency to white representing 0 articles.

Understand the Science (n=30)

Some studies drew on lower-level CCL competencies, like recalling (Recognize) facts of greenhouse gases and energy balance learned from a slide presentation (Bofferding & Kloser, 2015), Interpreting videos on the "science of CC" (Aksit et al., 2018; Hestness et al., 2019) ,or Using videos and animations to communicate fundamental concepts related to carbon dioxide and rising temperatures (Shea et al., 2016). Additionally, students were Recognizing, Interpreting, and Analyzing various graphs and maps to build skills in working with these visuals and developing their understanding of the various physical and environmental mechanisms of CC (Krejci et al., 2020).

Other studies aimed to develop student understanding of CC mechanisms and build on their perceptions. This included Creating drawings of climate processes (the carbon cycle, (Monroe & Oxarart, 2019); greenhouse effect, (Shepardson et al., 2011)) or personal connections to CC (Hestness et al., 2019), while Evaluating and iteratively building on these conceptions of CC processes (Nussbaum et al., 2015; Zangori et al., 2017). It also included Creating photos of CC science concepts that connected to what they learned in class (Madden & Dell'Angelo, 2016) and using Photo Elicitation to allow students to Recognize components of a CC image and share their understanding (Liu et al., 2015). This included Recognizing components of and Interpreting graphics used in CC scientific articles (Holthuis et al., 2014; Nam & Ito, 2011) and Using images to create a poster on topics related to the relationship between humans, climate, and the environment (Nam & Ito, 2011). Through more advanced tools and technologies, many of the studies aimed to get students involved with climate science data. For example, students worked with modeling programs to Create and Recognize factors of (Bush et al., 2019), Interpret (Lambert & Bleicher, 2014; Pallant & Lee, 2015), and Analyze (McNeal, Libarkin, et al., 2014;

Powers et al., 2021; Visintainer & Linn, 2015) graphs and visualizations of geographic Earth systems and processes.

Students Created graphs of relationships of collected data of atmospheric variables (temperature, altitude, particle conc.), used Excel to organize data (Hallar et al., 2011), and examined Earth-system processes over time (Drewes et al., 2018; Teed & Franco, 2014). Students used interactive data visualization tools to Recognize, Interpret, Analyze, and Create graphs on aspects related to the biological interactions of CC (Ellwein et al., 2014), Analyze the relationships between CO2 and temperature, and the relationship between paleoclimate and insolation (Ramamurthy et al., 2014). These interactive tools were also used to conduct virtual experiments and Interpret (Drewes et al., 2018; Varma & Linn, 2012), Analyze (Bodzin & Fu, 2014; Varma & Linn, 2012), Recognize (Bodzin & Fu, 2014) graphical and geospatial aspects of fundamental climate processes, and Find map evidence for calculations GHG emissions using similar tools (DeWaters et al., 2014).

Most of the CCL competencies represented in all the studies involved the Understanding of Science (n=29) (see Figure 2.7) Of these, students were most often asked to Create or Interpret visual material, but there was representation of all the VLS types for this CCL competency. This speaks to how fundamental visualizations are in science teaching and learning about the mechanisms of CC (Schuster et al., 2024). Students were most dynamically taking the role of VL Active Consumer, with several studies asking students to Recognize (n=10), Analyze (n=12), Interpret (n=14), and Evaluate (n=2) visual material related to Understanding the Science of Climate Change. As VL Contributors, students were mainly asked to Create (n=14) materials (e.g. drawings, graphs, models) related to Understanding the mechanisms of CC Science, and much less often Find (n=2), and Use (n=1).

Understand the Impacts (n=13)

The interventions addressed CC impacts at different spatial scales and incorporated various VLS. At the smallest spatial scale, students were asked to Interpret information from the media and Create drawings to represent how they believed CC would impact them personally (Hestness et al., 2019). Similarly, students developed graphic organizers (Create; (Shea et al., 2016)) or Analyzed simulations (Nussbaum et al., 2015) depicting local CC impacts. Moving up in scale, students Created models to explore the impacts of CC on a specific species (Zangori et al., 2017). (Bitting & Merricks, 2025) helped students understand broader human impacts around the world by Interpreting videos, Analyzing graphs and charts, and Evaluating the reliability of different sources. To understand impacts on ecosystems, students Interpreted information from graphs (Arya & Maul, 2016; Holthuis et al., 2014) or Analyzed trends across images (Lindgren et al., 2021). At the regional level, they recalled information from lectures on CC impacts in the southeastern U.S. and discussed these with peers (Recognize; McNeal et al., 2014b). At the largest global scale, students Interpreted information from documentaries and graphs (Lambert & Bleicher, 2014), Analyzed trends across multiple models (Holthuis et al., 2014; Powers et al., 2021) and interactive visualizations (Bodzin & Fu, 2014), or Finding information using digital tools like Google Earth (DeWaters et al., 2014).

The Understanding of Impacts mostly incorporated VLS that had students as Active Consumers Analyzing (n=5) or Interpreting (n=5) visuals, but all the VLS were represented as students were also employing skills in Recognizing (n=2), Evaluating (n=1), Finding (n=2), and Using (n=1) visuals (Figure 2.7). Looking at the scales at which these impacts were considered, as discussed above, it becomes evident that the more personally/locally relevant considerations of Impacts required students to take the role of Contributors. This suggests that drawing on higher-order VLS could provide opportunities to engage students by helping them see the content as personally relevant.

Understand Solutions (n=10)

The solutions discussed in papers primarily mentioned mitigation and adaptation strategies. These required students to Recognize types of solutions, such as mitigation, adaptation, renewable energies, and geoengineering, in lecture slides (McNeal, Spry, et al., 2014) or videos (Hestness et al., 2019). They Used this information in visual communications like infographics and videos (Bitting & Merricks, 2025). From a slide-based lecture, students had to Recognize different types of mitigation strategies, including fuel efficiency, transportation conservation, building efficiency, alternative energy sources, and efficient electricity production, while completing a recall worksheet (Bofferding & Kloser, 2015). In a role-playing activity, students presented as scientific advisors and Used graphs to suggest mitigation and adaptation strategies to political delegates (DeWaters et al., 2014). They were also asked to Analyze climate model projections and consider interventions to mitigate or adapt to the impacts (Powers et al., 2021). Similarly, in an online game, students were tasked with Interpreting information as they considered household and community conservation activities (Nussbaum et al., 2015). To develop scientific argumentation, students had to cite graphical data to justify claims about mitigation strategies (Interpret; (Holthuis et al., 2014)). Additionally, they Created public service announcements (PSAs) to communicate local solutions to their communities (Rooney-Varga et al., 2014; Stafford & Brain, 2022).

The Understanding of Solutions was underrepresented in the use of visual images amongst the interventions, especially when compared to the other Understanding CCL competencies (Figure 2.7). Students only employed a single VLS at a time, and most often were asked to Recognize (n=3), but also Interpret (n=2), Analyze (n=1), Use (n=2) or Create (n=2) visual images.

Evaluate (n = 3)

There were a few instances where VL was used for evaluative purposes, but the VLS that were associated were Evaluating (n=2), Creating (n=1), Analyzing (n=1), and Interpreting (n=1). In (Clary & Wandersee, 2012), through mandatory discussion participation, students Analyzed and Evaluated videos and news clips to prompt discussions about CC. This activity required students to reference personal experiences and local environmental issues in their arguments. Discussions involved considering the sources of information and providing several pieces of evidence to develop a position, resulting in a significant increase in students citing peer-reviewed articles by the end of the graduate course. Using strategies of humor and gamification, the Cranky Uncle game engaged students in Interpreting information focused on strategies for addressing climate misinformation (Cook et al., 2023). In developing a public service announcement (PSA) for CC communication, students received intentional instruction in Evaluating visual materials they consumed to understand how the visual images they created might affect audiences (Rooney-Varga et al., 2014).

Given the widespread concern of mis/disinformation about CC and how this might affect students, the low representation of this CCL competency (Figure 2.7) is unexpected. Particularly since this is a CCL skill that overlaps directly with a VLS, this presents an opportunity to leverage and develop these skills together. However, it may be that whie teachers help students to develop CCL skills in Evaluation, they are less likely to help students evaluate visual materials.

Communicate (n=8)

Communication using VLS took on two main forms: creating materials and presenting content. For example, students collaboratively Created posters using relevant CC visuals and scientific evidence on a chosen topic related to climate and human interactions, which they then presented to their peers and Evaluated for effectiveness (Nam & Ito, 2011). At other times they Created infographics, brochures, and short videos advocating for clean water within their communities, receiving collaborative feedback from community members (Bitting & Merricks, 2025). In a role-playing activity, students took the role of a science advisor, writing policy memos Using graphs as evidence to inform their political delegates about the anthropogenic causes of CC and predicting temperature changes for their "country." After Interpreting a news article, students Created personal "Climojis" (climate emojis) to communicate their emotions related to CC visually (Siegner & Stapert, 2020).

Presentations were given to both community members and classmates. Students participated in a communications colloquium, where they Interpreted videos and slide presentations on argumentation in CC media to prepare for communicating with skeptical audiences (Lambert & Bleicher, 2014). Similarly, students engaged closely with local community members to Create presentations on CC aimed at motivating audience members to take local actions (Burkholder et al., 2017). Through the engaged development of PSAs, students employed various skills, including Finding appropriate visuals and Creating material in the form of videos or visual posters (Rooney-Varga et al., 2014; Stafford & Brain, 2022).

Several of these studies are represented in the Understanding section of CC as skills in Understanding can be considered as pre-requisites for Communicating, and the VL activities were closely aligned. As expected, most of the interventions contributing to the CCL competency of Communicating required students to take the role of Contributor (Figure 2.7). As students communicated about CC, they were Creating (n=4), Using (n=3), and Finding (n=1) appropriate visual elements, and sometimes Interpreting materials to help them do so (n=2).

Decisions (n=3)

This measure was the most difficult to find because it required considering the direct impacts of a VLS on behavioral intentions. This meant that we only coded this when there was a clear connection between a stated VL component and reported behavioral intentions or perceptions. For example, students engaged in a community project where they Used (n=1) visuals to create a PowerPoint presentation for adult audiences to inform them of and encouraging them to make carbon-reduction changes, which was found to lead to long-term behavioral changes for the students (Burkholder et al., 2017).

To prepare students to participate in an engaged project where they were considering individual CC actions, they were presented with a conceptual model in a diagram. Students Analyzed (n=1) the model image and considered each of the components in relation to actions they would take for their project (Leichenko et al., 2022). This process of forming a plan around a visualized model led to sustained behavioral changes and awareness of individual actions the students felt they could sustain beyond the class project.

Creating (n=1) a PSA aimed at promoting clear air in their communities encouraged students to engage with peers, teachers, and family members, often leading to broader discussions about air pollution and changed behaviors, such as reduced idling (Stafford & Brain, 2022). Parents generally welcomed their teens' influence and requests to adopt clean air actions. The active, public, effortful, and freely chosen nature of the PSA task appeared to foster a commitment to clean air behaviors among students and their families.

Overall, the interventions drew on a variety of VLS to develop understanding of CC science, impacts, and, to a lesser extent, solutions. However, there was limited evidence of the use of VLS for higher-level CCL competencies of Evaluating, Communicating, and Decision making. Most commonly, the higher-order VLS were associated with the higher-order CCL competencies as can be seen from the darker clustering at the top ends of the heat map (Figure 2.7). The Understanding CCL competencies were more often associated with students taking on the role of Active Consumer; while for Evaluating, Communicating, and Decision-making, students more often took the role of Contributor.

DISCUSSION

This systematic review of 58 studies suggests that VLS are crucial to the development of holistic CCL. The ubiquity of visual images found throughout the studies suggests that CCE is not possible without some degree of VL integration. This study focused less on what visuals were being used, but rather on how they were being used to better understand the VLS students are expected to leverage or develop. While the use of relevant visuals has long been tied to effective science teaching (McGrath & Brown, 2005; McTigue & Flowers, 2011), consideration of VL and the skills required to interact with these scientific visuals, particularly for CC, is a relatively new and under-explored area of research (Krejci et al., 2020; McTigue & Flowers, 2011; Offerdahl et al., 2017). Only one study, Krejci et al., 2020, explicitly mentioned VL, even though most of the studies included a visual component.

Previous studies have found that science instruction does not often integrate VLS in standard curriculum but assumes that students will “pick it up” along the way (M. Avgerinou & Ericson, 1997; Vermeersch & Vandenbroucke, 2015). A complex and abstract concept like CC that draws on discipline-specific visual images and requires students have ample opportunities to develop disciplinary literacies. The oversight of such may perpetuate climate change misunderstandings (Airey & Linder, 2009; Offerdahl et al., 2017). One study (Breslyn et al., 2017), for example, found that when students were asked to Interpret an image of the greenhouse effect, they more frequently referenced the misconception that "CO2 was removed from the atmosphere by escaping into space" than when the image was not present. While the researchers were not sure why the image might have been leading to these explanations, it suggests that without appropriate VLS development, misconceptions can develop and persist.

The VLS hierarchy developed here drew on the roles the students took during instructional interventions and grouped them into Passive Consumer, Active Consumer, and Contributor. These reflect Seels (1994)'s constructs of visual thinking, visual learning, and visual communication. Our VLS hierarchy provides educators with tangible ways to scaffold and build skills in the CC classroom. In general, we considered CCL in holistic ways and drew heavily on the expanded description of climate literacy by the USGCRP Climate Literacy Guide 2024. This description now emphasizes the understanding of not only the essential principles of climate science and the impacts of CC, but also the understanding of solutions to CC including mitigation, adaptation, and climate justice principles. The previous emphasis on only the understanding of science and impacts, while not considering solutions, is reflected in the interventions analyzed in this study.

Most of the studies incorporated the VLS to improve student understanding of climate science and impacts but rarely coupled these with knowledge or skills in the solutions-oriented areas of mitigation, adaptation, and justice. A growing body of literature has emphasized that climate literacy can be impeded by "faulty models" or an absence of the social, political, and economic systems that are intertwined with the issue of CC and crucial to solutions understandings (Shwom et al., 2017). When these systems are not considered, CCL cannot truly be achieved (Duffy et al., 2019).

The emphasis on the understanding of CC was categorized here as Consumer CCL, where students processed information. Like the descriptions of “readerly” or “derived” climate literacy described in other studies (Busch & Román, 2017; Duffy et al., 2019). This focus on Consumer CCL was mirrored by a focus on Active Consumer VLS, where these lower-level skills were most often used for developing CC understanding. This is not to minimize, however, the several studies that did leverage Contributor VLS, particularly the Create VLS, to achieve Consumer CCL. We note that the USGCRP perspective on climate literacy recognizes the significance of knowledge about climate but extends beyond that. As with other literacies, including VL, the concept of "literacy" encompasses not only skills in comprehension but also the critical capacity to assess new information and act on that information and knowledge in responsible ways (Norris & Phillips, 2003). Therefore, literacy denotes not just the ability to read and process content, but also to Contribute: to act upon, extend, and recompose information. This more advanced level of CCL has been characterized elsewhere as being “fundamental” or as a “writerly” form of climate literacy where students' understanding of the causes and consequences of CC are further coupled with the ability to utilize and build upon that knowledge (Busch & Román, 2017; Duffy et al., 2019; Zeidler & Newton, 2017). Most studies that fell into this Contributor CCL category leveraged Contributor VLS, emphasizing the reciprocal relationship between developing these higher-level VLS and higher-dimensional CCL.

When looking for successful strategies at the intersection of VL and CCL, this study developed a model with 5 main themes (Figure 2.9). The model aims to elucidate these relationships and draw on the studies that exemplified them. While these themes that represent strategies to leverage VL are not fully inclusive of the ways that visuals can be used to achieve CCL, we hope to inform educators of the opportunities to do so and simultaneously build the literature on the relationship between these concepts in the realm of CCE.

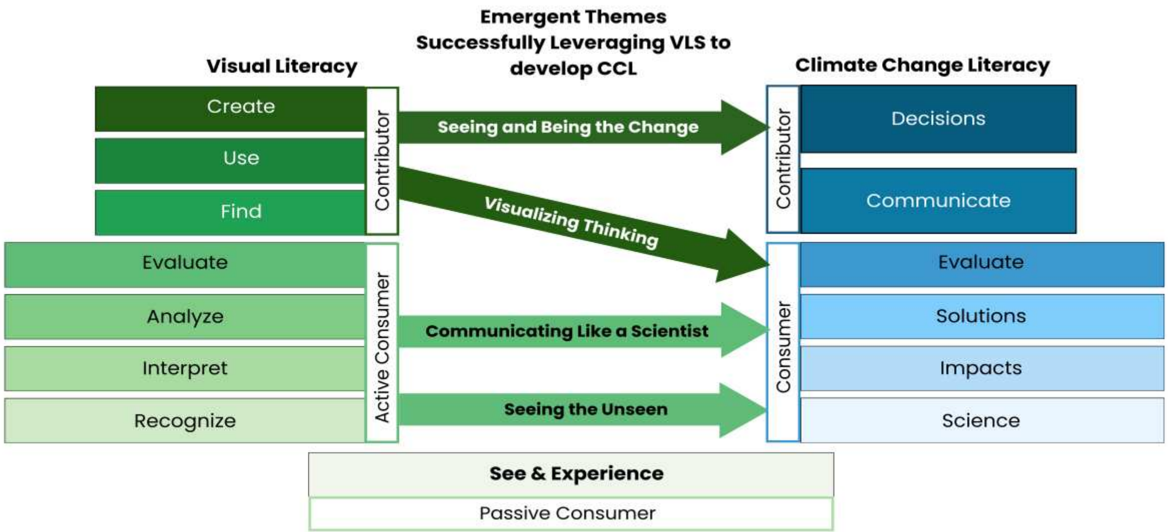

Figure 2.9. Emergent Themes of Successfully Leveraging VLS to develop CCL. This model shows the themes that emerged from the successful examples integrating VL to meet CCL. On the left is the VLS hierarchy in green and on the right is the CCL Competencies hierarchy in blue. In the center are the arrows that represent the themes, each of these is colored to match the VL roles that are being taken. At the base of the image is the theme of See & Experience that is foundational and encompasses the role of Passive Consumer but not expressly developing CCL. The next arrow above in the medium green represents the theme of Seeing the Unseen, where students are taking the role of VL Active Consumer to be a CCL Consumer. The medium green arrow of Communicating Like a Scientist also represents situations with these same roles. The Visualizing Thinking arrow is in the darker green representing students in the role of VL Contributor and pointing to them as CCL Consumers. Finally, the Seeing and Being the Change arrow, also in dark green, represents situations where students are CL Contributors and CCL Contributors.

In the context of CCE, incorporating student perspectives using visual and experiential opportunities can develop a sense of engagement with the issue that can prime students to develop their CCL. The theme of See & Experience exemplified this engagement of student perspective and VL that can be considered a precursor to learning and developing CCL competencies. The studies that fell into this theme provided opportunities for students to engage visually with CC topics, but did not quite venture into developing the CCL (e.g. watching movies or presentations, study abroad), thus it is depicted as foundational in the model Engaging and developing emotional connections through visual and experiential means could create a personal relevance and appreciation of the impacts of CC, which could then motivate the development of the more academic understanding and analytical skills that are at the core of CCL (Bentz, 2020; le Roux, 2014).

The fundamental science behind climate phenomena is inherently abstract and complex (Arslan et al., 2012). The large-scale mechanisms that make up the climate system are impossible to observe directly and are dependent on visual aids in order to be studied and taught (Harold et al., 2016; Hawkins & Stark, 2016; Sharma, 2012). When students are given opportunities to not only develop a mental picture of these complex systems but also manipulate and visually explore the concepts and mechanisms behind them, it enhances learning (Bobek & Tversky, 2016; Eilam & Poyas, 2010; Quillin & Thomas, 2015). Several of the articles used visual images to make the "unseen, seen" for students. The articles represented by this theme of Seeing the Unseen effectively drew on different forms of VL to help students develop an understanding of CC through engagement with visualizations. Embodying the VL role of Active Consumers, students engaged in interactive data visualizations (Bush et al., 2019; Visintainer & Linn, 2015), virtual experimentation (Varma & Marcia, 2012; Powers et al., 2021), and local data exploration (Ellwein et al., 2014; Nussbaum et al., 2015), which allowed them to build on prior knowledge to improve their CC knowledge and increase their confidence and self-efficacy in addressing climate issues. These activities not only enhanced understanding of climate science, but also helped students develop skills in data literacy, visualization of local impacts, and practical strategies for environmental conservation.

The studies within the theme of Communicating Like a Scientist emphasized a need to develop skills in embodying the perspectives of scientists and using scientific argumentation and have provided opportunities for students to draw on VLS to do so. Argumentation fosters scientific literacy by promoting an understanding of scientific practices and the importance of evidence in supporting claims (Cavagnetto, 2010). Scientific argumentation is a powerful tool for addressing complex socio-scientific issues like CC, as it helps students critically analyze information and develop well-reasoned positions (Lambert & Bleicher, 2014). Additionally, role-playing exercises can facilitate a deeper understanding of CC by enabling students to explore the implications of scientific data and policy decisions from different angles (Belova et al., 2015). This experiential learning fosters empathy through negotiating with their own perspectives and enhances students' ability to engage in informed discussions about CC (Freire et al., 2016). Having students engage as VLS Active Consumers, researchers emphasized the importance of students not only developing CC knowledge but also understanding the process of scientific inquiry through engagement in argumentation and claims-evidence-reasoning practices (Holthuis et al., 2014; Rooney-Varga et al., 2014) using visuals. By applying visual data sources and collaborating in discussions or role-play scenarios, students adopted scientific vocabulary and reasoning styles, enhancing their knowledge, self-efficacy, and affective engagement with climate issues. These approaches, including role-playing as science advisers (DeWaters et al., 2014) or time-traveling scientists (Teed & Franco, 2014), allowed students to embody scientific roles, analyze complex data, and communicate their findings, leading to improved comprehension and confidence in their scientific skills.

Activities that allow students to be metacognitive and consider their own conceptions in relation to new information can be beneficial for learning (Zummo et al., 2020). The theme of Visualizing Thinking represents successful examples of the ability of visual literacy activities to help students make connections between science content, their own perspectives, and global environmental issues. As an educational tool, the process of creating mental models has been shown to provide both learners and educators understand students' scientific conceptions, while also eliciting factors like values, emotions, and attitudes (Mcginnis & Hestness, 2017). Primarily taking the role of VLS Contributors, through interactive methods including environmental modeling (Lindgren et al., 2021; Shepardson et al., 2011), photojournaling (Madden & Dell'Angelo, 2016), and reflective drawing (Monroe et al., 2016; Hestness et al., 2019), students developed deeper understanding of the connections between humans and the environment in the context of CC , thus building competencies as CCL Consumers. These activities allowed them to build on prior knowledge while enhancing nature-related attitudes, environmental concern, and understanding of climate science concepts. Reflective photo journaling and model-building activities also facilitated connections between climate content and students' personal experiences, promoting self-reflection and contextualization of their learning and emotions regarding climate issues.

When activities range beyond the bounds of the classroom to incorporate local and meaning full projects, students can not only better connect with the issues, but they also become agents of change in their communities (Ruffell & Mayberry, 2019). Through the engaged creation of communications materials students gained greater awareness and understanding of local impacts of CC, showed shifts in their values and attitudes, and developed critical thinking and problem-solving skills while fostering a sense of social responsibility (Hunt et al., 2011).

The articles within this theme of Seeing and Being the Change embodied the development of CCL from that of Consumer to Contributor through their roles as VL Contributors. Through community-engaged projects, PSA production, and educational outreach, students actively communicated CC information, tailored messages to specific audiences, and developed pro-environmental goals, which fostered their climate literacy, confidence, and motivation to act. These activities not only increased students' awareness and commitment to environmental justice but also promoted long-lasting improvements in interdisciplinary skills, self-efficacy, and pro-environmental behaviors, with impacts extending into their community.

We have presented here several examples of interventions that have been effective in building student CCL using VL. However, successful implementation requires effortful teaching practices. VL requires structured educational approaches to cultivate these skills effectively (M. D. Avgerinou & Pettersson, 2011; Seglem & Witte, 2009). One of the main takeaways from the one study that had explicit VL was the need for intentional and sustained instruction for students to develop their VLS (Krejci et al., 2020). This study employed the Novice's Information Visualization Sensemaking (NOVIS) model. The NOVIS model involves sequential steps beginning with identifying textual and non-textual objects within a visualization, exploring the visualization to find trends, and projecting data beyond the visuals. Even with the class time devoted to developing these skills, the study found students still struggled in the construction and interpretation of visual data, underscoring that developing VLS requires sustained and explicit instruction and practice. This is further emphasized by the most successful examples of VLS prioritizing instruction as part of the intervention strategy (e.g. Bitting & Merricks, 2024; Rooney-Varga et al., 2014; Nam & Ito, 2011; Hestness et al., 2014). This intentional instruction, however, cannot happen instantaneously as educators need effective PD opportunities to help them implement VL practices (Özsoy & Saribas, 2021). The articles in this study that developed PD for teaching CC had recommendations and findings that also translate well to developing VLS practices. These PDs included incorporation of Pedagogical Content Knowledge (Li et al., 2021; Holthius et al., 2014; Shea et al., 2016), measured impacts through further student studies (Teed & Franco, 2014, Ramamamurthy et al., 2014; Lindgren et al., 2021), and planning that involves various stakeholders (DeCamp, 2024; Drewes et al., 2018; Shea et al., 2016).

CONCLUSION

In summary, the reviewed literature provides important insights into how VL can be leveraged to enhance students' holistic CCL. The relationship between VL and CCL, however, needs to be more explicitly developed and investigated. While this study sought to determine the trends, future research should seek to explicitly measure how VL impacts student Consumer and Contributor CCL, as well as how student perspectives influence their VL development. Additionally, the relationship between VL and student misconceptions about CCL could be explored. Given the impact of media on students' conceptions of CC, a VL study that incorporates common media visuals as well as those seen in the classroom could provide a richer understanding of student VL and the potentially mediating impacts of their worldview. Finally, measuring teacher development and VL could be a further avenue of exploration that could help the development of future training and PD. As the field of VL expands and is incorporated into CCE, so too do the opportunities for developing holistic CCL.

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CHAPTER 3[1] - FROM SCIENCE TO SOLUTIONS: TEACHING CLIMATE CHANGE AS SIMPLE, SERIOUS, AND SOLVABLE

ABSTRACT

Climate change is a critical global challenge that necessitates climate literacy among college graduates. This paper presents a comprehensive curricular model for teaching climate change in higher education, organized into three units: Simple, Serious, and Solvable (S3). The Simple unit covers the fundamental science linking carbon emissions to climate warming through hands-on activities and simulations. The Serious unit emphasizes the diverse impacts of climate change across sectors like agriculture, water, health, and infrastructure, evaluating associated costs and ethical considerations. Students explore temperature projections, cascading effects, and environmental justice. The Solvable unit introduces mitigation and adaptation strategies, including renewable energy, energy efficiency, and sustainable practices. Interactive "toy models" incorporated throughout the course allow data manipulation to illustrate components of complex climate models and foster the development of quantitative skills. Writing assignments like climate fiction stories enable students to synthesize learning and articulate values. Overall, the interdisciplinary S3 model aims to build climate literacy through active learning, empowering students as informed stakeholders in confronting this global challenge.

INTRODUCTION

College graduates need to be climate change literate. Climate change has profound and far-reaching consequences across environmental, societal, and economic realms, making climate

[1] Diaz-Clark, E., Balgopal, M. M., & Denning, A. S. (2025). From Science to Solutions: Teaching Climate Change as Simple, Serious, and Solvable. *Journal of College Science Teaching*, 1-6.

change education in higher education crucial (Henderson et al., 2017). Helping university students understand climate change science, impacts, and solutions is imperative for cultivating a generation ready to confront this critical global challenge. They should be able to comprehend, communicate, and make informed decisions about climate-related issues. Only then can they critically evaluate climate information, engage in constructive dialogue, and contribute to effective solutions (Monroe et al., 2019).

Yet, gaps and obstacles continue to exist when integrating climate change studies into university curricula. Many instructors perceive challenges such as limited time, lack of relevant pedagogical resources, and uncertainty about effective integration strategies (Henderson et al., 2017). This underscores the need for comprehensive curricular models and instructional support to teach this interdisciplinary topic (Plutzer et al., 2016). Siloed approaches risk failing to provide students with the nuanced appreciation of complexities needed to address challenges posed by climate change. Climate change literate students recognize how social, economic, and ethical dimensions relate to biophysical systems. Students need critical thinking skills to evaluate and implement potential solutions (Monroe et al., 2019). Solution-oriented pedagogical approaches empower students to explore, analyze, and contribute to mitigation and adaptation strategies, fostering a proactive mindset and climate change literacy. However, educators must also recognize the emotional and psychological dimensions of the issue. The potential for eco-anxiety and climate grief among students necessitates the incorporation of strategies to promote resilience and hope (Wibeck, 2014). By acknowledging and addressing these emotional aspects, educators can foster a supportive environment that motivates students to take constructive action as they develop climate literacy.

Although there are climate change courses across US institutions, we describe a model that is grounded in science, invites students to integrate values, and ends with a message of empowerment and engagement. This climate change curricular model is organized in three units: Simple, Serious, and Solvable. The S3 model is designed to be comprehensive, interdisciplinary, and solutions oriented, while engaging students in active learning. The use of active learning strategies, data manipulation, and solicitation of student values and perspectives is effective in enhancing student engagement and understanding of climate change concepts.

Course Objectives

The overarching learning objectives align with each of the Ss:

1) Explain fundamental mechanisms linking carbon combustion to climate warming and describe how they are quantified.
2) Calculate and interpret climate change damages, costs, and evaluate benefits of mitigation.
3) Evaluate strategies for avoiding unnecessary damages using clean energy, including balancing supply and demand and addressing inequities.

THE S3 APPROACH

The curriculum begins with the simple science behind climate change before describing the seriousness of the impacts (Table 1). It ends with the sense of hope needed to assess and find solutions.

Table 3.1. Course Outline with Units and Associated Modules and Topics.

Unit	Module	Topic
Simple		
	1	Simple, Serious, Solvable Overview
	2	Energy and Radiation
	3	How Climate Works
	4	Forcing, Feedback, and Sensitivity
	5	Climate Change of the Past
Serious		
	6	Observed Climate Change and Impacts
	7	Climate Modeling
	8	Future Climate Change and Impacts
	9	Fate of Fossil CO2
Solvable		
	10	Carbon Economics
	11	Social Cost of Carbon
	12	Climate Change Policy
	13	Deep Decarbonization
	14	Cleaning Up the Mess
	15	Where Do We Go from Here?

Simple: Presenting the Science

To be climate literate students must be able to explain the fundamental mechanisms linking carbon combustion to climate warming and describe how these processes are quantified (Monroe et al., 2019). Students should be able to describe the greenhouse effect, the role of burning carbon in increasing atmospheric greenhouse gas concentrations, and the resulting impacts on the Earth's energy balance and climate system. This unit emphasizes that the fundamental science behind the greenhouse effect and climate change has been well-understood for over a century, with scientists recognizing the potential for human activities to alter the Earth's heat balance even before the invention of the light bulb.

In this section, the instructor introduces the principle of conservation of energy, expressed through the concept of: "Heat in minus heat out equals change of heat." Students explore this principle through hands-on activities and simulations, visualizing the flow of energy into and out of systems, how atmospheric molecules operate, and how imbalances lead to changes in temperature. The instructor must make a key distinction: while weather involves the lateral movement of heat within the atmosphere, climate change is driven by changes in the Earth's overall heat balance. An important concept here is that the only way to alter the Earth's heat content is through changes in the radiation it absorbs or emits. The atmosphere is selectively transparent, allowing visible sunlight to pass through while trapping a portion of the outgoing IR radiation – a phenomenon known as the greenhouse effect.

Next, the instructor should introduce the specific gases responsible for the greenhouse effect. Through interactive toy models, students investigate that while nitrogen and oxygen make up 99% of the atmosphere, they do not interact with IR radiation. Instead, it is the remaining 1% of gases, particularly carbon dioxide (CO2) and water vapor (H2O), that play a crucial role in trapping heat. Students learn how to calculate that every doubling of CO2 concentration adds approximately 4 W/m2 of radiative forcing – equivalent to the heat output of night light bulbs covering the world with a spacing of one meter apart. Students conclude how this seemingly small change can have significant impacts on the Earth's temperature over time.

Serious: Assessing Impacts and Costs

The S3 model emphasizes the importance of students enumerating the diverse and far-reaching impacts of climate change and evaluates the associated costs and benefits of mitigation efforts. Climate change poses significant risks to various sectors, including agriculture, water resources, human health, ecosystems, and infrastructure (IPCC, 2014). It is important for students to acknowledge the severity and scope of these impacts. Hence, our goal is for students to develop a sense of urgency needed to address this global challenge.

We underscore that without concerted action, global temperatures by the end of this century could rise as much as they did over the course of 100 centuries following the end of the last ice age. These abstract temperature projections are made tangible through relatable examples in the United States. For instance, students calculate how a doubling of atmospheric CO2 concentrations could lead to a global average temperature increase of approximately 3°C (5.4°F). However, this global average masks significant regional variations, with central regions of the United States potentially experiencing temperature increases of up to 6°C (10.8°F) – akin to the difference between the climates of Denver, CO and Albuquerque, NM. We also draw parallels to familiar elevational gradients in our state.

Through electronic discussion boards students share their understanding of the forecasting models (SSPs) and the implications on cascading impacts of such temperature changes, including increased risks of drought, wildfires, flooding, and mass displacement of people across various regions. This allows the opportunity for students to share authentic and personal examples that illustrate the far-reaching consequences of climate change on water resources, agriculture, ecosystems, and human communities to be included in class and online discussions.

The Serious unit emphasizes the long-lasting nature of climate change. Every ton of coal, barrel of oil, or cubic foot of natural gas burned releases carbon dioxide into the atmosphere, much of which will persist for millennia, contributing to ongoing warming. We challenge students to consider if the world's remaining fossil fuel reserves, if fully exploited, are sufficient to warm the Earth to catastrophic and potentially irreversible levels. Through a different set of toy models, students identify the need for a rapid and comprehensive transition away from carbon-based energy sources within a single generation.

Climate change is an interdisciplinary issue that affects all people. It is important for instructors to provide time for students to consider the potential benefits of mitigating greenhouse gas emissions and adapting to climate change (National Research Council, 2011). Therefore, we highlight the disproportionate burden of climate impacts on frontline communities invoking the importance of environmental justice. Students analyze and discuss the ethical dimensions of climate change, drawing connections to their own values and experiences through both class discussions and through a written assignment, described in detail below.

Solvable: Exploring Solutions and Strategies

Students need to imagine a hopeful future. In this unit, students learn about strategies for avoiding unnecessary climate damage through the adoption of clean energy solutions. We introduce various mitigation and adaptation approaches, including renewable energy technologies, energy efficiency measures, sustainable land-use practices, and climate-resilient infrastructure (IPCC, 2014). Our primary message is to stop setting carbon on fire. Two key components of the solution are (1) to live well with less energy and (2) to make energy without combustion. To illustrate how this may be done, students explore the Kaya Identity (Kaya & Yokobori, 1997), an equation that equates global CO2 emissions (F) to the relationship between population (P), economic activity, the per capita economic activity (G/P), the energy intensity (E/G), and the carbon intensity of energy consumption (F/E).

Kaya Identity:

$$F = P\,x\,\frac{G}{P}\,x\,\frac{E}{G}\,x\,\frac{F}{E}$$

Students conclude that given severe energy poverty and underconsumption among billions of low-income people, the only equitable pathways target the energy intensity of income (E/G) and the carbon intensity of energy (F/E) to lead to emissions reductions. A key focus is on energy efficiency as a critical solution pathway. Many energy efficiency measures not only reduce emissions but also save money over their lifetime, effectively costing "negative dollars." We encourage students to consider how these savings can be reinvested to offset the capital costs of other mitigation strategies, creating a virtuous cycle of emissions reductions and cost savings. This is an opportunity for students from various majors to bring their knowledge and creativity to class discussions.

We highlight the abundance and affordability of low-cost renewable energy sources, such as wind, solar, hydroelectric, and geothermal power as crucial components of a sustainable energy future. However, students also grapple with the challenges of intermittency and the need for effective energy storage and transmission solutions. We share case studies and interactive simulations, allowing students to again play with data on various energy storage technologies, including batteries and other emerging solutions, through toy models. Through data manipulation with toy models, students evaluate the trade-offs and considerations associated with each of these technologies.

For students to better understand the overall costs of transitioning to a low-carbon economy, estimated to be around 1% of global GDP, we present analogies. For example, this investment is comparable to the annual budget of the United States Department of Defense and only slightly higher than the cost of purchasing new cell phones each year. Through a hopeful and forward-looking approach that draws on the successes of equivalent investments in US history (e.g., interstate highways, wireless communications infrastructure), students consider these high financial costs and how they might be outweighed by the societal benefits. We highlight the long-term cost savings of renewable energy sources compared to fossil fuels, once the initial capital investments have been made. The transition to clean energy presents an opportunity for every generation to contribute to a sustainable future.

Students articulate potential futures given their own values, and the content they are exposed to in the class, through various writing activities. Other than short essay responses and discussion posts, students submit a future fiction story (Keys & Keys 2022). In their stories, students consider the need to balance energy supply and demand, while addressing issues of equity and environmental justice in the transition to a low-carbon economy. Students are asked to reflect on their own values, beliefs, and experiences related to climate change as they write about individual lifestyle choices to community-based initiatives and policy advocacy.

In this unit, we aim to foster a sense of optimism and agency, emphasizing that while the challenge of climate change is daunting, it is solvable with the right combination of technological solutions, policy interventions, and collective will. We hope to empower students with the knowledge and skills to become active participants in driving this transition, recognizing that "we can and, therefore, we must do this."

RESOURCES

Open-access text and short videos

The primary resource for this curriculum is an open-access textbook structured around the Simple, Serious, and Solvable (S3) framework written by Dr. Denning. This textbook is a comprehensive guide that is organized around the three units. We also provide more than 40 short (5-10 minute) videos that accompany the text in a lively and engaging way.

Engaging with Data

To enhance students' quantitative skills and data literacy, students analyze and interpret authentic climate data (Kjelvik & Schultheis, 2019). Dr. Denning created a set of "toy models," which are simplified representations of complex climate modeling systems (Figure 3.1). These models allow students to explore the relationships between various factors, such as greenhouse gas emissions, temperature changes, and climate impacts, in a controlled and interactive environment using real, locally relevant data. The toy models present the data in a piece-wise fashion allowing students to make sense of individual parts of larger climate modeling systems. We have found that students benefit from manipulating models because they often have not had the chance to do so in other courses.

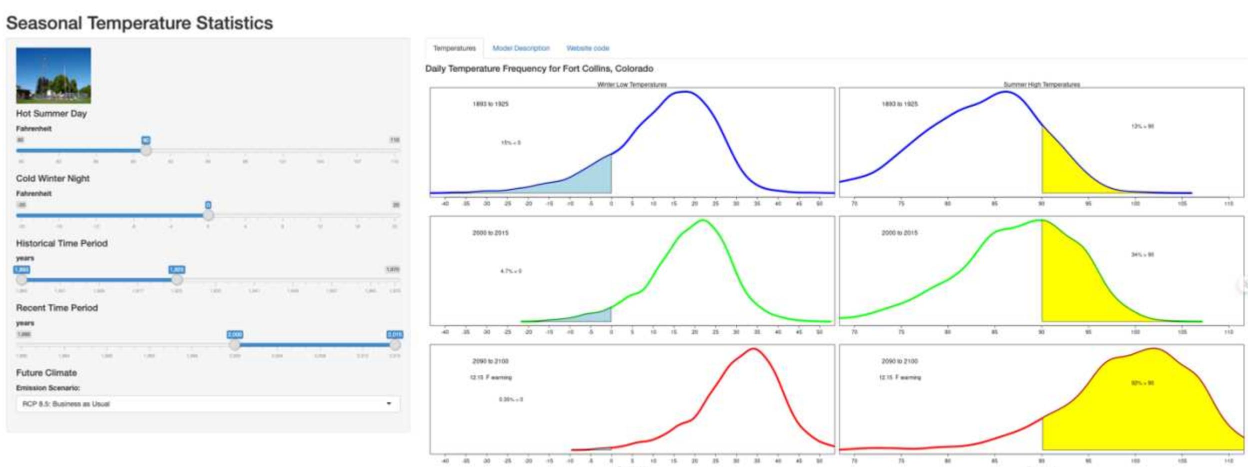

Figure 3.1. Example of a toy model used in the Serious module comparing daily high and low temperature data in two different time periods in the past (from real observations) with projections for the future using the various emissions scenarios.

By identifying patterns and trends, students can make connections between how data are generated and how scientists and policy makers make decisions about climate change.

Writing Assignments

Writing can be an effective way for students to not only practice their communication skills, but to review their content knowledge (Balgopal & Wallace, 2009). One example is the use of future fiction as a medium to imagine and describe a future world impacted by climate change. Through these writing assignments, students can synthesize their knowledge of climate change science, impacts, and solutions and apply it to a hypothetical scenario. They can explore the potential consequences of different climate trajectories, the challenges faced by societies, and the innovative solutions that may be required to address these challenges. They can also articulate how climate change can impact both social and biophysical systems. While we do not provide explicit instruction on how to write stories, this assignment allows students to express their values, beliefs, and perspectives in a narrative and more personal format (Shahn & Costello, 2000). Our hope is that through narrative writing, students feel more compelled to be engaged in climate change action (Woodley et al., 2022).

SUMMARY

The S3 model is for instructors who want to foster climate literacy, critical thinking, and a sense of empowerment among their students, preparing them to become active participants in mitigating and adapting to climate change. Students explore concepts through toy models, small group discussions, and creative writing. The model is intended for a range of students who bring their own disciplinary and personal knowledge to the classroom. Our hope is that other college instructors will use this approach and modify it for their own context. We offered the class in a large lecture-based format, but we imagine that others may integrate recitation or laboratories sections where active learning exercises can increase students' opportunities to make sense of the concepts.

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CHAPTER 4 - HOW SCIENCE TEACHERS VISUALIZE CLIMATE CHANGE THROUGH DRAWING-TO-LEARN ACTIVITIES

ABSTRACT

There is a critical need for public engagement to both prevent and mitigate the impacts of climate change. K-12 teachers are essential mediators, who can help students understand, relate to, and respond to the climate crisis. Teachers have varying understandings of climate science, the severity of climate change, and the potential for solutions to mitigate and prevent environmental impacts. We describe a drawing-to-learn (DTL) activity that allows both science education researchers and teachers to examine the mental models that teachers have about the causes and consequences of climate change. We found that while in-service science teachers focus on the solutions to climate change, pre-service science teachers focus on the scientific mechanisms that lead to climate change. We argue that science teacher educators should consider DTL activities as an intervention that prompts teachers across professional stages to consider both the science and solutions for climate change.

INTRODUCTION

Climate change (CC) is a global threat, with wide-ranging consequences for ecological systems, human health, and societal infrastructure (Calvin et al., 2023). As the effects of climate change intensify, so too does the need for informed public engagement and action to both prevent and mitigate the impacts (IPCC, 2023). While the acceptance of the anthropogenic causes of CC has steadily improved in the last decade to around 60% of the American public, only about half of the population thinks that it will affect them, their families, or their communities (Leiserowitz et al., 2024). Additionally, despite the growing evidence of its effects, CC has consistently ranked below other issues like the recent four-decade high inflation, COVID-19 pandemic, and healthcare costs as a policy priority for the American public (Pew Research Center, 2022). The role of humans as drivers, casualties, and responders to this threat highlights the complexity of the issue and the need to consider the interconnectedness of social and ecological systems.

Increasing climate literacy has long been recognized as a critical pathway to empower people to address environmental challenges spurred by global climate change (USGCRP, 2024). According to the US Global Change Research Program's 2024 guide on Climate Literacy, climate literate individuals understand how the climate system works, how humans influence it, and how it affects people and the Earth, and can integrate scientific, social, cultural, and justice perspectives to make informed decisions and take effective action. For youth, this means that they need opportunities to develop knowledge, critical thinking skills, and sense of agency needed to navigate and address the challenges of a changing climate (Janney et al., 2024). Because K-12 teachers are essential mediators, who can teach lessons that create space for students to understand, relate to, and respond to the climate crisis, climate educators must meet teachers' needs (Ahmed et al., 2021; Shepardson et al., 2012) In fact, Shepardson and colleagues (2012) called for K-12 educators and administrators to prioritize endeavors to increase students' climate literacy.

Making meaning of climate change

How individuals mentally organize and make sense of a phenomenon can be indicative of future behaviour, including teaching decisions and pedagogical emphasis (Fan et al., 2023). Climate change is known as a "wicked" problem in that it is an "ill-defined, ambiguous and associated with strong moral, political and professional issues" (FitzGibbon & Mensah, 2012; Ritchey, 2011; Rittel & Webber, 1973). Additionally, conceptualizing CC can be psychologically complex with multiple representations, understandings, and interpretations of the issue (Esbjörn-Hargens, 2010; Hulme, 2009). For this reason, it is important to explore the mental models and assumptions that teachers hold about climate change at different stages in their career.

Drawings, as visual representations of internal thought processes (i.e. mental models), provide a unique window into how people understand and conceptualize scientific phenomena, like climate change (Chang et al., 2020; Author, 2021). Moreover, drawings potentially reveal underlying beliefs, attitudes, and knowledge gaps that may not be easily evaluated in traditional assessments (Alerby, 2000; Lin, 2022). In science education studies, drawings have been used effectively to assess students' and teachers' understanding of scientific concepts, reveal misconceptions, and promote deeper learning through visual representation and reflection (Moseley et al., 2010). For example, the Draw-a-Scientist Test exemplifies the power of visual elicitation methods in educational research, revealing students' perceptions and biases related to science and scientists through their drawings (Chambers, 1983). Mosely and colleagues (2010) used drawings to assess pre-service teachers' conceptions of the environment through their "draw-an-environment-test and rubric (DAET-R)." They found that 60% of the pre-service teachers in their study did not consider humans to be a part of the environment and concluded that many of the mental models consisted of only the built environment where the participants lived rather than an integrated conception of humans and nature together. In a similar study using the DAET-R methods, 463 pre-service Turkish teachers' mental models of the environment were assessed through drawings, revealing that 70% did not include humans or abiotic variables in their drawings (Ahi et al., 2017). These findings are noteworthy because mental models indicate how teachers are likely to frame and teach climate change and other environmental issues

(O'Neill & Smith, 2014). Thus, how teachers conceptualize human environmental interactions can be an indicator of their underlying beliefs, and what they likely will prioritize when teaching climate change.

Drawing, however, is not merely a representational activity but also a sense-making one. Like writing, it allows participants to actively construct and negotiate their understanding of complex concepts, like climate change. It allows them to see what they know and to reorganize, reconceptualize, or reframe what they believe and understand (Bereiter & Scardamalia, 1987). This process also reveals gaps in their own knowledge that might otherwise remain implicit. Writing-to-learn research has demonstrated that generating external representations through written language supports deeper conceptual processing, integration of new information, and heightened metacognitive awareness (Emig, 1977; Klein, 1999). Writing requires that learners transform information into their own words, creating opportunities to articulate, revise, and refine understanding.

Building on this tradition, drawing-to-learn (DTL) research has demonstrated that constructing visual representations functions in much the same way, serving as a form of "visual writing" that can deepen conceptual engagement (Ainsworth et al., 2011; Van Meter & Garner, 2005). The creation of drawings allows learners to externalize mental models, make explicit connections between concepts, and identify inconsistencies in their reasoning (Fiorella & Kuhlmann, 2020; Prain & Tytler, 2012). Moreover, drawing has unique affordances for representing abstract, systemic, and relational phenomena, such as climate change, that are not easily captured in text alone. (Prain & Tytler, 2012) In this way, drawing serves not only as a diagnostic tool for educators seeking to understand the drawers' conceptual frameworks but also as a generative strategy for drawers themselves to reorganize and expand their own sense-making (Al-Balushi & Ambusaidi, 2017; Mcginnis & Hestness, 2017).

Teachers' climate literacy

How teachers think and what they think about climate change impacts both the adoption and the effectiveness of climate change education strategies in the classroom (Oversby, 2015). Teachers' personal beliefs, knowledge, and attitudes strongly shape how they approach climate instruction, from how they emphasize scientific consensus to how they frame the causes and consequences of climate change (Authors et al., 2025; Wise, 2010). For example, teachers who perceive climate change as scientifically uncertain or politically controversial are more likely to present "both sides" of the issue, which can inadvertently reinforce misconceptions among students (Plutzer et al., 2016). Conversely, teachers with higher levels of climate literacy and greater confidence in their content knowledge tend to adopt inquiry-based pedagogies and integrate climate change across disciplines, resulting in deeper student engagement and understanding (Boon, 2009; Lambert & Bleicher, 2013a). Additionally, whether teachers teach climate change from a systems perspective will indicate whether they present content as a socio-scientific issue that integrates both social and natural systems (de Sousa et al., 2019). This highlights how teacher cognition and beliefs are not peripheral, but central, to the uptake and success of climate change instruction. Therefore, assessing teachers' conceptions of climate change is crucial, so scientists and science teacher educators can identify what types of support they need to increase their own students' climate literacy.

Not surprising, pre-service and in-service teachers differ in their pedagogical knowledge. Studies of pre-service teachers suggest that while many acknowledge the significance of climate change, they frequently uncertainty about the degree of scientific consensus and relatively low levels of confidence in their ability to teach the subject (Boon, 2016; Lambert & Bleicher, 2013b). In contrast, instructional approaches used by in-service teachers are shaped not only by their knowledge but also by contextual factors, such as community norms, political pressures, and personal beliefs. These influences often result in the presentation of climate change as a controversial issue or in its omission from the curriculum altogether (Herman et al., 2017; Plutzer et al., 2016; Wise, 2010). Investigating climate knowledge of both pre-service and in-service teachers can inform how to design effective professional development and teacher preparation programs (Hestness et al., 2014). However, few studies use the same intervention to study both pre-service and in-service teacher perspectives of CC. By doing so, science teacher educators are better positioned to support teachers in CC education. In this study, we asked: *How do teachers at different professional stages visualize climate change?*

METHODS

To answer this research question, we used a mixed-methods design (Creswell & Clark, 2017) to investigate how science teachers at different career stages conceptualize climate change through a DTL activity. We analyzed participant-generated drawings and annotations using both deductive coding based on an adapted framework and inductive content analysis. Semiotic qualitative analysis guided the interpretation of participant drawings, treating them as visual texts that convey meaning through signs, symbols, and compositional choices (Kress & Van Leeuwen, 2020). This approach recognizes that drawings do not merely represent literal objects or concepts but encode layers of meaning that operate on both denotative and connotative levels (Barnham, 2019; Chandler, 2017; Saussure et al., 2020). Importantly, the interpretation of visual symbols is not universal but culturally bound. The significance of specific images used depends on shared cultural frameworks and interpretive repertoires that shape how viewers assign meaning (Latour, 1986). For this reason, annotations of drawings helped us interpret the intentions of the symbols that teachers drew.

By identifying the ways teachers use visual signs, such as symbols, metaphors, and spatial organization, semiotic analysis illuminates the deeper conceptual and affective dimensions of their climate change representations. To complement these qualitative findings, a Chi-square test of independence was run to assess differences in theme occurrence between pre-service and in-service teacher groups. By combining interpretive visual analysis with statistical comparison, our goal was to comprehensively describe how educators represent and conceptualize climate change concepts.

Participants

We recruited two populations of science educators: pre-service (PS) teachers and in-service (IS) teachers The pre-service teacher group (n=12) were recruited from an undergraduate science methods course in Fall 2021 (n=6) and Spring 2025 (n=6) at a large university in the mountain west region of the US. The in-service teacher group (n=10) was recruited from a professional development workshop at a national science teacher conference held in Spring 2024. Data from only consenting participants were analyzed in this study.

Intervention: Drawing Activity

We used writing-to-learn (WTL) interventions to introduce IS and PS teachers to climate change during workshops. WTL interventions are designed to help individuals articulate and organize their ideas (Bereiter & Scardamalia, 1987). Often, WTL approaches can help learners revise their conceptions or reconcile confusing ideas (Author et al., 2012). K-12 teachers have long used multimodal assignments, combining writing and drawing, to support student learning of science (Wilson & Bradbury, 2016), though this approach has been less commonly studied in secondary science classrooms (Tytler et al., 2020). Studies have shown that concept mapping, a form of DTL, can reveal learners' prior knowledge, increase knowledge retention, and elicit conceptual change (Nesbit & Adesope, 2006; Rebich & Gautier, 2005). Nature journaling has similarly provided a multimodal way for students to integrate writing and drawing while observing real phenomena and furthering their connections to the environment, while improving learning (Tsevreni, 2021).

Writing tools, such as the writing tool Role-Audience-Format-Topic (RAFT), have been implemented to provide learners opportunities to explore issues from multiple perspectives and to strengthen critical thinking (Groenke & Puckett, 2006; Senn et al., 2013). RAFT encourages writers to adopt a role beyond their own, address an audience other than the teacher, and communicate using formats that differ from conventional academic assignments (Anggraini & Usman, 2017). These strategies are particularly valuable in science lessons about socioscientific issues because they position learners to negotiate meaning, integrate disciplinary knowledge with personal viewpoints, and communicate ideas in authentic ways. Because socioscientific issues are complex, multi-dimensional topics for which people draw on various types of knowledge, learning how to consider evidence from different perspectives can help students think more deeply about decision-making (Author et al., 2017; Sadler et al., 2007).

The activity completed during the study was integrated into a presentation on climate change centered around a Simple, Serious, Solvable (S3) model of CC teaching (Author et al., 2025). The S3 model compartmentalizes CC lessons into three distinct sequential components that build on one another. The Simple unit introduces the fundamental science of climate change, including the greenhouse effect and the role of carbon dioxide in global warming, and summarizes energy absorption and radiation in the Earth system. The Serious unit addresses the wide-ranging impacts of climate change on sectors such as agriculture, water resources, health, and infrastructure, highlighting projected temperature changes, cascading effects, environmental justice considerations, and associated economic and ethical dimensions. The Solvable unit emphasizes actionable mitigation and adaptation strategies, including renewable energy, energy efficiency, and sustainable practices, exploring solutions to reduce greenhouse gas emissions and enhance resilience.

Before the S3 workshops, participants were asked to pick a CC topic of relevance to them and draw an image representing this topic using markers and colored pencils. This exercise prompted participants to identify the following before writing or drawing: Role, Audience, Format, Audience (RAFT) (Fisher & Frey, 2014). The participants were randomly assigned to a role (Atmospheric Science professor, weather channel journalist, high school teacher, or science policy maker), audience (university students, media consumers, high school students, or community members), and format (infographic, graph, scientific diagram, meme, conceptualized photograph, or drawing) by picking cards. Given these RAF, the students were then allowed to pick their own CC Topic before creating their drawing. The RAFT activity was assigned to allow thinking about CC from different perspectives and from a variety of viewpoints.

At the end of each S3 section, participants reflected on their drawing. We asked them to use different colored pens (blue for simple, red for serious, and green for solvable) to circle the parts that represented each of these themes, and/or make comments as to where in the image they would add these elements.

Data Collection

The pre-service teacher part of this study took place within an undergraduate teacher preparation course, “Secondary Science and Technology Education.” This course is designed for undergraduate science majors pursuing a teaching license in secondary science. The course was taught by a retired science teacher who had 25 years of experience as a middle school Earth system science teacher in the local school district. At the time of the course, he was a teacher-in-residence at the university where the course was taught. While this 3-credit course runs an entire semester, meeting twice a week for an hour and forty minutes, the data for this study were collected over a week's time during two different semesters when the class was taught. Data from the in-service teacher workshop occurred during a 2-hour workshop at a national science teacher conference attended by teachers who work across the United States. The workshop was co-led by both authors and a third collaborator, a retired professor of Atmospheric Sciences (see Authors et al., 2025). Consenting participants either handed in hard copies of their drawings or uploaded a photo of their drawing using an online form.

Data Analysis

To understand how teachers at different stages conceptualized CC topics and the signs and symbols they used to represent their conceptions and perceptions, we analyzed the drawings both deductively and inductively. An adapted codebook from (Rebich-Hespanha et al., 2015) was used to conduct a deductive thematic analysis on the drawings. While Rebich-Hespanha's codebook was developed to identify image themes in US CC news imagery, once organized to represent the S3 themes, the comprehensive descriptive nature of the adapted codebook was deemed appropriate for evaluating the content of the drawings in alignment with the goals of this study. An inductive content analysis was then conducted to identify patterns related to the S3 themes in the drawings from the IS and PS teachers. Following the content analysis, we ran a chi-square test of independence using R Statistical Software (R Core Team, 2025) to determine the significance of the difference in occurrence of the S3 themes across the drawings from both participant populations. To ensure consistency in coding, inter-rater reliability was completed by the first author and the science methods instructor using a random subset of 25% of the drawings, which were reiteratively coded until 95% agreement was reached followed by discussion to clarify codes. Subsequently, all data were coded with the revised codebook. Additionally, expert debriefing was conducted regularly between the co-authors.

FINDINGS

Comparing across teaching stages

Pre-service and in-service teachers draw differently about S3 topics, based on our content analysis. A chi-square test of independence revealed a significant difference in the distribution of climate change themes (Simple, Serious, and Solvable) between in-service and pre-service teachers, χ^2 (2, N = 96) = 16.49, p = .00026 (Figure 4.1). Examination of standardized residuals indicated that in-service teachers were significantly more likely to include representations of CC as Solvable and significantly less likely to include representations of Simple, while pre-service teachers were more likely to include Simple and less likely to include Solvable. No meaningful differences were observed for the occurrence of Serious themes.

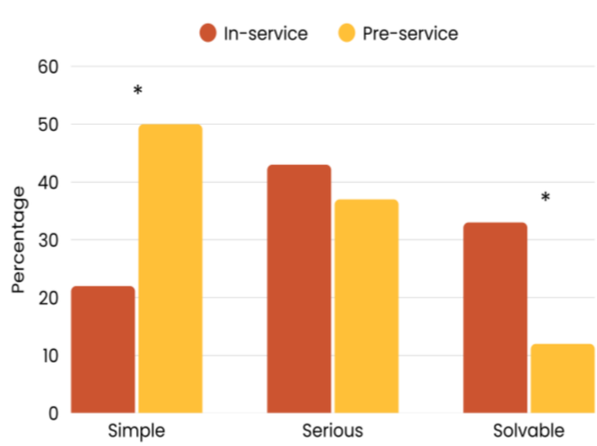

Figure 4.1. Column Chart of the Distribution of Climate Change Themes by Teacher Group. Column chart depicting the occurrence of Simple, Serious, and Solvable themes between in-service (orange) and pre-service (yellow) teachers. A chi-square test of independence was conducted [χ^2(2, N = 130) = 16.49, p = .00026]. *Indicates standardized residual |r| > 2.

Depicting the drivers of climate change

The PS teachers depicted a greater relative number of Simple themes in their drawings. The most common depictions of this theme were around greenhouse gases (GHGs) and of anthropogenic forms of contributions to atmospheric concentrations. The mechanistic connections between humans and their contributions did not, however, depict people and, instead, featured infrastructure and technology (i.e., power plant smokestacks). The greenhouse effect was commonly represented using the common graphic of the sun and the earth from space with rays of light passing between them represented by arrows (Figure 4.2). While the in-service teachers also referenced GHGs (chemical symbols and terms like "CO2") and their connection to rising temperatures in similar systemic diagrams, their drawings included more in-depth components of the embedded social system (Figure 4.3). Through the inclusion of certain visual components (e.g., a menu/grocery store and golfing), the in-service teachers drew humans as the drivers of emissions and as individuals whose decisions had consequences.

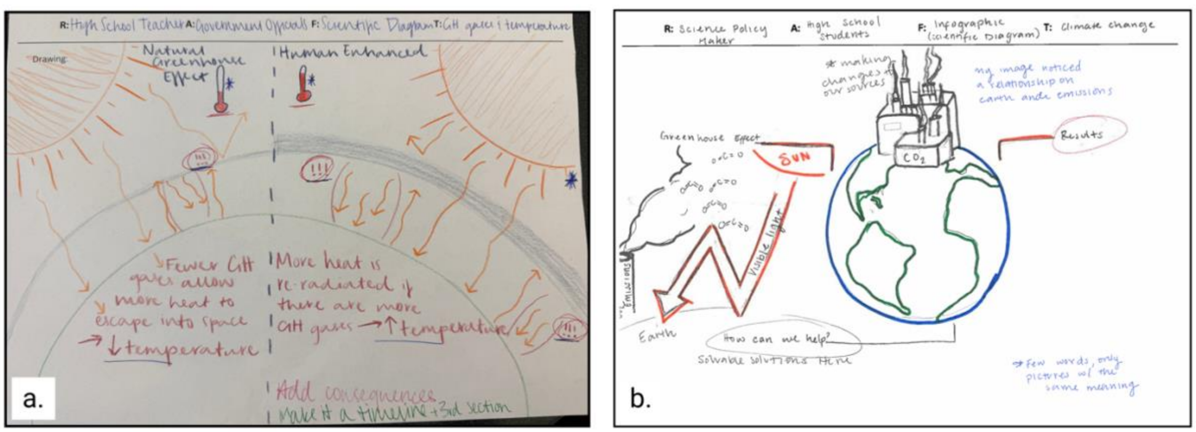

Figure 4.2. Preservice Teacher Drawings of Simple Climate Change Topics

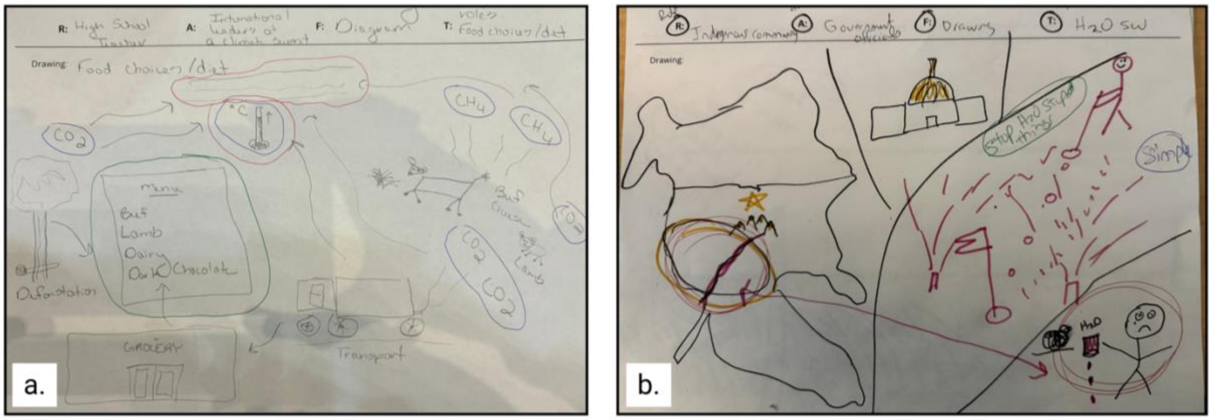

Figure 4.3. In-service Teacher Drawings of Simple Climate Change Topics

Showing the impacts

Both participant groups drew a range of CC-related impacts, particularly extreme weather concerns, including fire, drought, and sea level rise. However, how these were shown differed between the groups. The IS teachers more often showed these weather phenomena with the added context of the effects they have on people and communities. For example, Figures 4.4a and 3b portray similar topics of drought in the United States using a map in their assigned Format of “drawing.” While the PS teacher image includes just the map of rainfall and drought (Figure 4.4a), the IS teacher image uses the crying stick figure (representing a sad person) to illustrate the impact that the lack of water has on humans (Figure 4.3b).

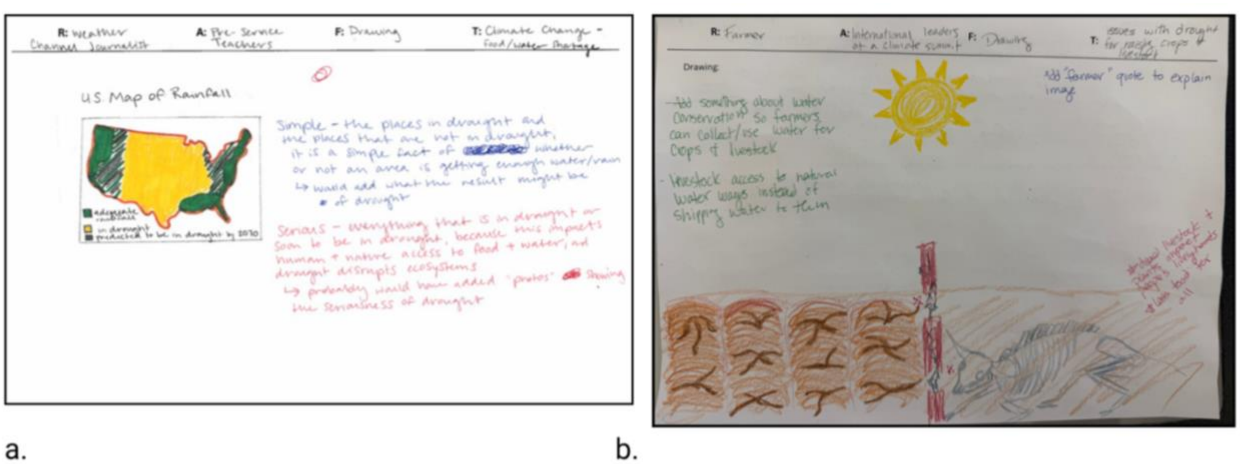

Figure 4.4. Pre-service Teacher Drawings of Serious Climate Change Topics

In the context of the Format of meme/comic, both teachers presented sea level rise and included people. While the PS teacher drew the people as storytellers, there was no clear visual connection to how they were affected by this environmental change. On the other hand, the IS teacher image illustrated prom attendees "under the sea" (Figure 4.5a and b). Here, the drawing portrayed people as not only drivers of climate change through their decisions, as shown before, but also as the ones being affected. Hence, people were perceived by this teacher as both the perpetrators and the casualties of CC.

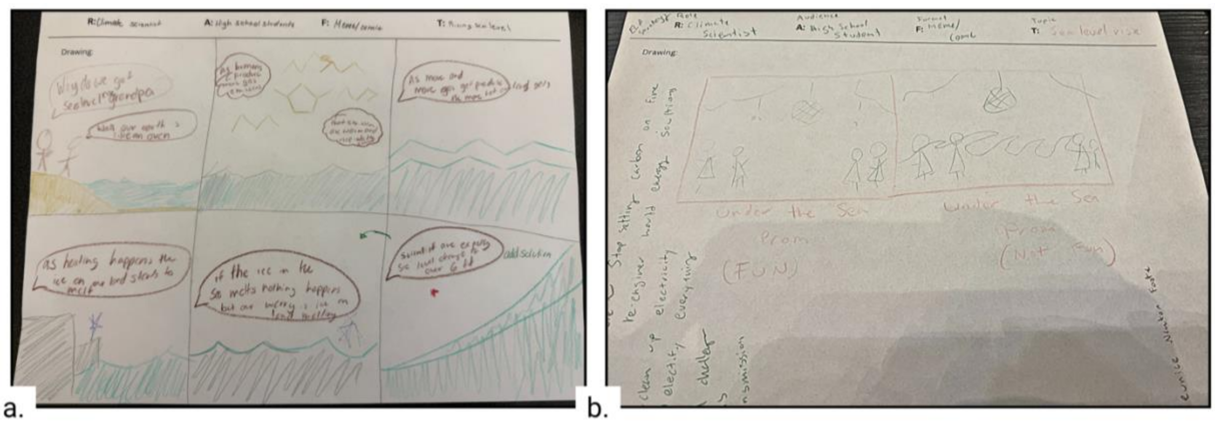

Figure 4.5. Drawings of Sea-Level Rise by a Pre-service and an In-service Teacher given the same RAF

The financial costs of CC were recorded by both groups of teachers as a Serious component. In Figure 4.6 we see a PS (a) and IS (b), who had the same RAF, and chose very similar depictions. Their graphs both showed a CC impact (drought and soil shrinking), and they included an illustration of a public forum with a group of people talking to a politician. In both images, the group of people are expressing their concerns over rising food/water costs and their livelihoods. Figure 4.4b shows drought connected to loss of crops and livestock, which the PS described as impacting "livelihoods."

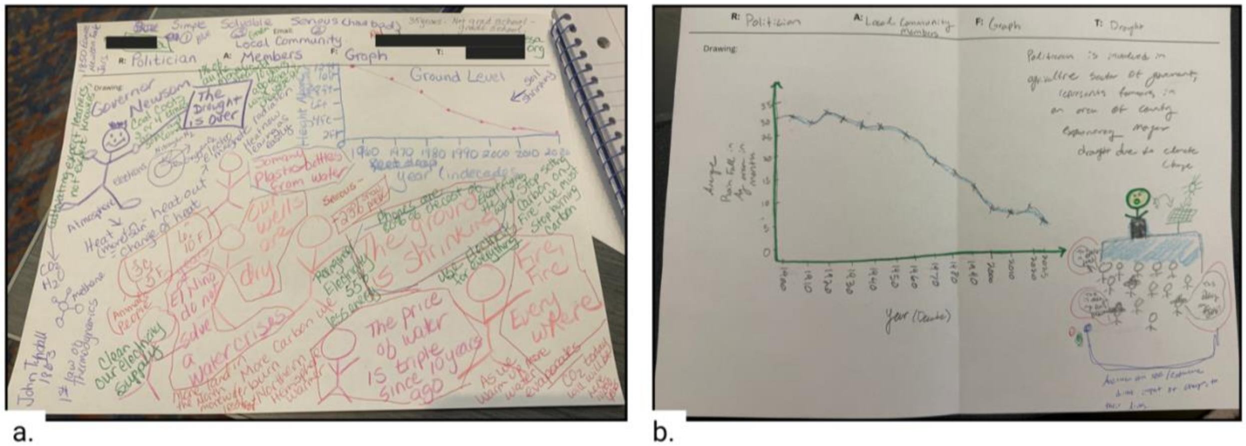

Figure 4.6. Drawings of Graphs and Political Processes comparing Pre-service and In-service Teachers given the same RAF

Visualizing solutions

The IS teachers were much more likely to include Solvable aspects in their drawings. They often depicted renewable energy sources as central components of the drawings, whereas the pre-service teachers typically added them in at the later stages of the activity (Figure 4.7; Figure 4.6b). Some of the IS teacher images also illustrated some potential financial benefits and profits from proposed solutions. For example, the figure in Figure 4.7a implies that while windmills look expensive, wind is free and does not need to be bought.

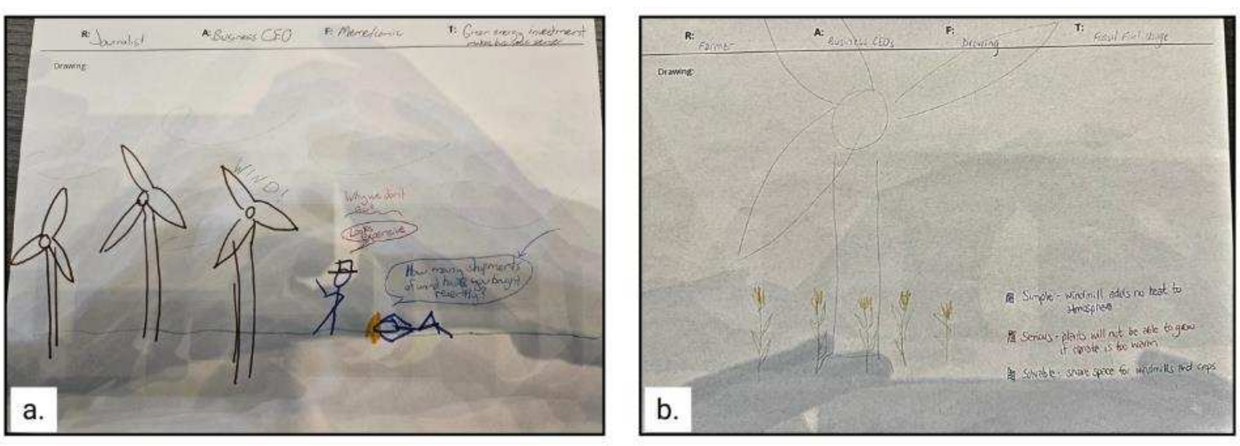

Figure 4.7. In-Service Teachers Drawings of Climate Change as Solvable

Both teacher groups portrayed in their drawings that scientists are integral to identifying climate change solutions. In meme format, both groups highlighted the disconnect between "scientists" and societal change (Figure 4.8). However, the implied responsibility is depicted differently in each group. For the PS teachers, it is "society" that is preventing scientists from "caring for the environment," whereas the IS teachers' drawings indicated that scientists need to work with policymakers to find climate solutions. Hence, while both participant groups' drawings included accountability, they focused on different societal roles who they implied should bear the responsibility.

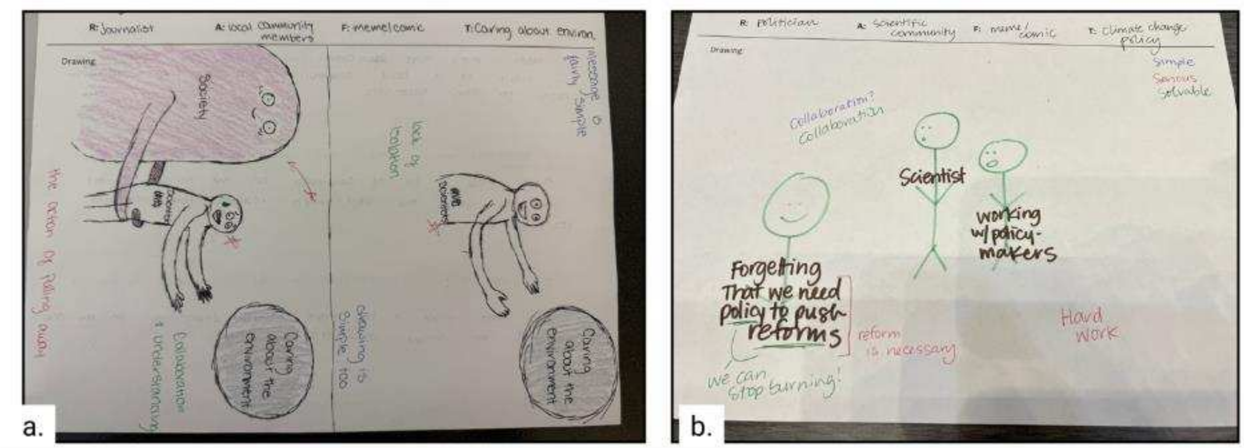

Figure 4.8. Pre-service and In-service Teacher Drawings Portraying Scientists

Some drawings focused on how different community members perceive the impacts of climate change in opposing ways. For example, Figure 4.6a emphasizes a disconnect between the public and its political figure, where "Governor X" is claiming that the "drought is over" while smiling, but the other stick figures are still complaining about the effects of this drought.

DISCUSSION

Drawing-to-learn (DTL) can be understood as a type of writing-to-learn (WTL). These approaches require learners to externalize and organize ideas, often using multiple representations, which strengthens their ability to make meaning from complex concepts (Ainsworth, 2008; Klein, 1999). While WTL often relies on sequential text-based explanation, DTL allows learners to represent multiple processes, actors, and relationships at the same time. To illustrate the greenhouse effect, for example, a written explanation might list sequential steps in energy transfer, but a drawing requires learners to depict interactions (e.g. sunlight, Earth, atmosphere, arrows) that exist simultaneously in space. This visual flexibility requires engaging prior knowledge about a topic and encourages systemic reasoning, an essential skill for understanding climate change (Ainsworth & Scheiter, 2021; Rau, 2017). Here, we found that science teachers at different professional stages (pre-service and in-service) focused on different aspects of climate change (i.e., that it is simple and solvable), while sharing some attributes (i.e., that is serious) during professional development DTL activity. We argue that the DTL activity allows both science teacher educators and science teachers themselves to visualize the teachers' mental models of CC.

The Role-Audience-Format-Topic (RAFT) strategy employed in this activity, extending beyond its traditional use in language arts class writing assignments, provided a structured framework that helped participants focus on content conveyed in their drawings (Fisher & Frey, 2014). The varied RAFTs encouraged teachers to consider climate change from multiple perspectives, eliciting a more holistic and nuanced representation of their understanding (Anggraini & Usman, 2017). Research has shown that RAFT can enhance students' organization skills, content knowledge and creative thinking, and critical thinking (Alshehri, 2025; Senn et al., 2013; Sisalima & Sánchez, 2023). Our findings extend this work by demonstrating how RAFT, when paired with DTL, prompts both cognitive and affective engagement. The random assignment of roles, audience, and format also allowed teachers to consider different perspectives as they reflected on their perceptions of CC. Teachers used the RAFT model to generate drawings that ranged from systemic diagrams to humorous memes. Furthermore, we could use these to compare mental models of our two different participant populations. The pre-service and in-service teachers demonstrated notable differences in how they conceptualized climate change and represented human perspectives. PS teachers emphasized more Simple themes, such as greenhouse gases and global mechanisms, whereas IS teachers included more Solvable aspects, like renewable energy solutions, alongside systemic and local impacts. These patterns reflect the influence of prior knowledge and teaching experience. Learners with limited practical experience often focus on surface-level features rather than integrated, systemic relationships, which aligns with PS teachers' emphasis on more abstract greenhouse gas diagrams (Rau, 2017). In contrast, IS teachers' inclusion of both technical and social elements suggests that richer prior knowledge enables more complex, integrated representations of climate systems (S. Ainsworth, 2008). This is supported by (Jeong et al., 2021) that found that while structured interventions improve PS teachers' climate change awareness, these gains often remain theoretical, with limited connections to local or human-scale impacts, consistent with the observed PS focus on global mechanisms.

PS teachers frequently depicted humans in abstract ways, often as storytellers or indirect contributors, whereas IS teachers portrayed humans as both drivers of climate change and as affected individuals, integrating local community impacts and societal interactions. For example, IS drawings showed people shopping or playing golf as contributors to emissions while also illustrating consequences such as drought effects on families. Socio-scientific perspective-taking supports such nuanced representations; learners who adopt multiple viewpoints develop a more holistic understanding of complex societal issues (Newton & Zeidler, 2020). Moreover, integrating social dimensions into climate education strengthens awareness of human and community impacts (Shwom et al., 2017). IS teachers' drawings reflected both findings by simultaneously representing scientific mechanisms and the human-scale impacts of climate change.

The differences in the content of the drawings also reflect a varied level of psychological distancing, emphasized by global versus local contexts between the teacher groups. PS teachers often focused on the Earth from space or abstract atmospheric models, emphasizing global mechanisms while omitting human perspectives. This approach aligns with research showing that climate change perceived as distant can feel less personally relevant (Leiserowitz et al., 2024). IS teachers, however, incorporated human elements such as crying figures and community interactions with policymakers, suggesting greater affective engagement alongside cognitive understanding. Teachers with classroom experience are more likely to incorporate human impacts and societal relevance into their teaching, consistent with IS teachers' inclusion of humans as both drivers and victims of climate change (Herman et al., 2017). These findings suggest that IS teachers are better able to integrate social and environmental perspectives, which could promote a more holistic climate literacy (McCaffrey & Buhr, 2008).

These differences in perspectives reveal an opportunity for teacher educators to consider how to better prepare teachers to develop a more holistic climate change understanding through coursework, experiential opportunities, and professional development (Shwom et al., 2017). PS teachers may benefit from opportunities to connect theoretical climate change knowledge with human-centered impacts and solutions to help make the issue meaningful and relevant for their future students (Beach, 2023). IS teachers may benefit from support in maintaining a content-focused grounding of the global scale causes and impacts to ensure that their students understand the primary scientific mechanisms that lead to or that are a consequence of CC, in addition to local impacts and solutions (Liu et al., 2015; Raj & Amin, 2024).

By grounding climate change education in scientific mechanisms, while also making connections to the multi-scale impacts, science teachers can emphasize not only individual scale solutions, but collective community responses that address the issue globally as well. Professional development and education preparation that specifically addresses self-efficacy and pedagogical content knowledge provides many benefits for teachers, especially for pre-service teachers who do not have previous experience with teaching about climate change (Li et al., 2021). Teachers equipped in this way are better positioned to foster climate literacy in their students, as what teachers know and believe directly affects classroom learning (Herman et al., 2017; Hestness et al., 2014; McCaffrey & Buhr, 2008).

In this study, we used drawings as both an instructional intervention and an assessment of mental models. Drawings can be a powerful tool to understand the underlying beliefs and perceptions that teachers have towards climate change. Our DTL activity provided insight into teachers' implicit mental models. In this study, the drawings revealed not only what teachers knew but also how they viewed climate change in relation to people and society. For example, images like smokestacks, crying figures, and political processes communicated the teachers' perspectives of both the scientific and social dimensions of the issue and which they chose to emphasize. Creating a drawing requires learners to make deliberate choices about symbols, spatial relationships, and emphasis, all of which reveal how they conceptualize a topic (Fernandes et al., 2018; Goffman, 1949; Tytler & Hubber, 2016). We encourage science teacher educators to explore the use of DTL in environmental education professional development workshops. Not only do drawings and associated text provide data that can be analyzed; it demonstrates, for teachers, an instructional approach that they can use with their own students.

A limitation of this study is that we did not interview PS or IS teachers about their drawings to make sure our interpretations aligned with their intentions. This is important because symbols are culturally embedded, and we may have coded some images or symbols in ways other than what the participant intended (Goffman, 1949). This drawing activity only provided a glimpse into the perspectives of the teachers, and further research with interviews and deeper participant engagement is needed to understand how these understandings manifest in their teaching practices, and how to best support teachers in developing a holistic view of climate change for their students. It is critical that teachers are prepared to help students build both intellectual and emotional resources to help build resilience in the face of the climate crisis. Through understanding their own perspectives and conceptions, teachers can be poised to build these skills in their own students (Christensen et al., 2023).

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CHAPTER 5 - THE ROLE OF VISUAL LITERACY IN IMPROVING CLIMATE CHANGE LITERACY

INTRODUCTION

Climate change (CC) is the most pressing environmental and social issue with impacts on local, national and global systems already being felt and predicted to worsen in coming years (IPCC 2023 Calvin et al., 2023; NCA5 Crimmins et al., 2023). This has been reflected in the substantial increase in coverage of CC in both social media and mass media, with a nearly 300% increase in news stories since 2012 (Bolstad & Victor, 2024; Storani et al., 2025). As students in the "climate change generation" (those born between the late 1980s and early 2000s) enter university, their perspectives on CC are strong indicators of the influence of both news media and the education system These generations, also referred to as Millennials and Gen Z, are the first to have lived their entire lives with wide scientific consensus, broad media coverage, and classroom instruction of CC (Aksit et al., 2018; Ray & Nasedkin, 2020).

Young adults are particularly well positioned to make an impact on CC. They will experience the most extensive overlap with future CC effects, already show higher levels of concern about CC compared to the broader American population and are increasingly immersed in different and newer forms of media than previous generations (DeCamp, 2024; Leiserowitz et al., 2023; Stevenson et al., 2014; Wachholz et al., 2014). New media formats include Instagram, TikTok, X (formerly Twitter), and LinkedIn. However, despite hearing, potentially discussing, and learning about the topic throughout their lives, young adults continue to demonstrate low climate literacy and persistent misconceptions (Cordero et al., 2008; Corner et al., 2015; Wachholz et al., 2014).

Developing climate change literacy (CCL) requires not only a strong content knowledge base, but also the ability to critically analyze and interpret climate information (USGCRP, 2024). These abilities are essential for preparing students to communicate and make informed decisions, essentially moving from being CC consumers to CC contributors (see Chapter 2). CC literate individuals: *Understand the Science, Understand the Impacts, Understand the Solutions, Evaluate Information, Communicate about CC, and Make Informed Decisions (USGCRP, 2004).* Because many climate science concepts are abstract and highly complex, students often have difficulty grasping them unless instructional materials include images to help make these ideas visible and concrete (Arslan et al., 2012; Cordero et al., 2008).

Students are encountering more visuals in the classroom, as well as through media (Andersson & Olson, 2014; Mooseder et al., 2023a; Wang et al., 2018), particularly in social media, which, for many young adults, is their primary source of CC information (Newman et al., 2025). Images serve as platforms for news and everyday information, helping them to make meaning of complex topics (Pearce et al., 2019). The wide range of visuals that young adults consume also provides an opportunity to discover perspectives beyond the highly technical aspects of CC that they typically learn in a science class (Schäfer, 2020; Wozniak, 2020). For example, humorous images, like CC memes, have become powerful forms of socio-political expression of opinions and emotions (Boykoff & Osnes, 2019; Ross & Rivers, 2019). Shifts in the media landscape have created new opportunities for learning but have also increased potential exposure to mis- and dis- information. Some studies have found increasing trends of young people's engagement with unreliable sources compared to reliable ones on social media (Lee et al., 2024; Storani et al., 2025). With the influx of visual CC information, students need to be visually literate to develop their CCL.

Visual literacy (VL) in the sciences has been defined (Arneson & Offerdahl, 2018a; Schönborn & Anderson, 2006) and broadly encompasses the ability to *find, use, interpret, critically analyze, and create visual images,* processes that involve students taking the role of both consumers, and contributors of visual information (Ausburn & Ausburn, 1978). While this definition was developed for life sciences, the same VL skills are critical to developing fluency in the scientific "language" of CC, which has its own norms of communicating (Airey & Linder, 2009). However, despite its clear relevance, the role of VL in supporting the development of CCL has not been thoroughly examined (see Chapter 2). Here, we asked: *How does visual literacy contribute to university students' climate change literacy?*

METHODS

To answer the research question, we employed a mixed-methods design integrating qualitative analysis of VL interventions with quantitative measures of climate knowledge, classroom artifacts (performance on homework assignments (HW) and exams), and survey measures.

Context

This study was conducted in two classes, an undergraduate version (100-level) and a graduate version (500-level), both taught by the same instructor (a professor of atmospheric sciences) in Fall 2023 at a large university in the mountain west region of the US. The 100-level course was offered as an elective for undergraduates. While the 500-level course was part of the curriculum for some graduate programs at the university, many of the students enrolled in it as a supplemental course, not required by their program. Both courses allowed enrollment to be either online or in-person. These courses were centered around a Simple, Serious, Solvable (S3) curricular model described elsewhere (Diaz-Clark et al., 2025). The S3 model presents CC education in three distinct units, with each subsequent section building on the other. The Simple unit focuses on the physical and chemical mechanisms that drive CC, the Serious unit highlights the human-caused drivers of CC and consequences of these actions, and the Solvable unit prompts students to evaluate the ways that people can mitigate consequences and prevent future CC. Both courses were 15 weeks long with each unit taking approximately 5 weeks.

Participants

Together, the courses had a total of 106 students, 102 of which (50 undergraduate and 52 graduate) consented to participate in the study. Undergraduate students (UG) were those enrolled as degree-seeking students for their bachelor's degree. Graduate students (G) included Master's, PhD, and graduate certificate seeking students. We organized student majors and degrees by their disciplinary relevance into Science (Sci) (62; 61%), which included degrees in natural, physical, health and engineering, and Non-Science (NSci) (40; 39%), which included liberal arts, humanities, social science degrees. We recognize that the process of science includes both natural and social sciences but use these terms for ease of reference. When looking at the distribution of format, 70 (69%) were enrolled in an in-person (IP) section, whereas 32 (31%) were enrolled in an online (O) section. 37 (36%) identified as Male, 62 (61%) as Female, and 3 (3%) preferred not to identify their gender. Representative of the mountain west region and university demographics, most students identified as White (80; 78%), with small numbers of Asian (8; 8%), Black or African American (4; 4%), and Other (10; 10%). An additional variable we considered was student political orientation (PO), due to the politicized nature of CC in the US. Most students identified as Democrats

(43; 44%), followed by Independent (28; 29%), and then Republican (8; 8%), with (19; 19%) identifying as Other or No Party.

Data Collection

To address our research questions, qualitative and quantitative data was gathered (approved under IRB protocol no. 4235) that could inform our variables of interest: Climate Change Literacy and Visual Literacy. These included classroom artifacts, as well as survey responses, a knowledge assessment, and responses on targeted interventions (Figure 5.1).

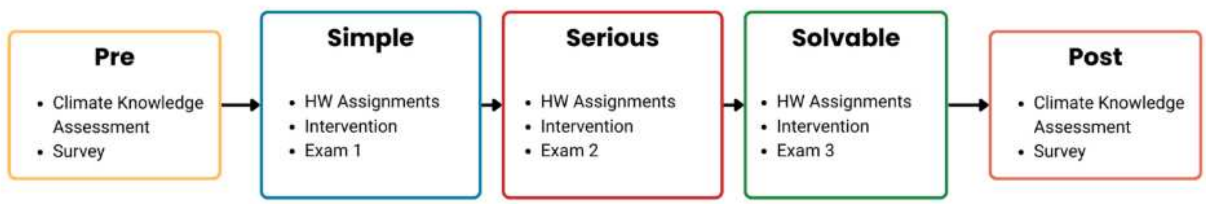

Figure 5.1. Data Collection Structure

Classroom Artifacts

While the CC course contained many different measures of performance, we chose assessments that allowed us to calculate students' CCL. These included exam grades and an average "HW score" for each unit, which also assessed using student performance on HW that required the use of toy models (Diaz-Clark et al., 2025).

Knowledge Assessment (KA)

To determine changes in students' CC knowledge, we used a pre/post knowledge assessment, The Climate Knowledge Assessment (Aksit et al. 2018). The KA instrument consists of 21 multiple-choice questions designed to assess students' content knowledge of climate-related science. Most of the questions assess the content covered during the Simple unit. The questions are either single response or multiple response and are scored using an all or nothing approach where no partial points are given. The responses were analyzed and compared as a raw score out of 21 possible points.

Visual Literacy (VL) Intervention

To measure student VL, we designed a classroom intervention for students to evaluate different types of popular CC scientific and media images. These interventions were administered at the end of each S3 unit. The three CC image types were: 1) a scientific graph or diagram, 2) a photograph, and 3) a meme or comic. From these three, they chose one and then completed a short writing activity explaining the image and its relevance to the unit. The images were selected from online news and social media. Additionally, each intervention asked students to find or create their own image that they thought best represented the units' content. Images and writing prompts can be found in Appendix 5.1.

Perceptions Survey

A pre/post survey was given to gain a better understanding of preconceived ideas about CC (beliefs, risk perception, policy support, and communication behavior; Leiserowitz et al., 2021), as well as indicators of media use and engagement with CC info outside of the classroom. We used the Climate Change in the American Mind survey conducted by the Yale Program on Climate Change Communication (YPCCC) and the George Mason University Center for Climate Change Communication (Mason 4C). These groups have been conducting their survey on the American public since 2008 and have carefully tracked the changing viewpoints and beliefs of the public over time. For our survey, however, we changed the use of "global warming" to "climate change" in all the questions. This was to better reflect the expectations and common verbiage of the students being evaluated. While the questions cover beliefs, emotional responses, risk perceptions, engagement, social perceptions, possible impacts, and communications of CC, we chose a subset of the questions to analyze in this study that were aligned with our research question.

Data Analysis

Climate Change Literacy (CCL)

CCL was evaluated based on the CCL Competencies hierarchy found in Chapter 2 (Figure 5.2.). CCL Competencies were determined using the USGCRP's definition of climate literacy and were organized using Bloom's taxonomy of cognition (Bloom et al., 1956). The hierarchy is designed the progressive roles that students take, from CCL *Consumer* to CCL *Contributor*. Here we use "Understanding" to represent the understanding of the Science, Impacts, and Solutions of CC and is represented by the various class and knowledge assessment performance metrics. According to Bloom et al. (1956) understanding is best assessed by the ability to transfer and explain content in a new context.

"Evaluate" represents considering the relevance and trustworthiness information about CC. For our study, we use Likert responses from the survey that centered on CC media consumption:

About how often do you hear about climate change in the mass media (TV, movies, radio, newspapers/news, websites/ magazines, etc.)?

About how often do you hear about climate change in social media/new media (Facebook, LinkedIn, Twitter, TikTok, YouTube, Podcasts, etc.)?

For "Communicate", we assessed the frequency with which students may have heard and discussed CC:

How often do you discuss climate change with your family and friends?

About how often do you hear people you know (your family, friends, co-workers, etc.) talk about climate change?

Finally, for the "Decision" competency, we examined student self-efficacy in acting on CC. Perceived self-efficacy refers to individuals' beliefs about their capability to perform tasks and is a key determinant of intention and subsequent behavior, varying by level, generality, and strength (Bandura, 1997). In this study, self-efficacy is defined as individuals' belief in their ability and confidence to take CC action (Huang, 2016).

Please indicate how strongly you agree or disagree with the following statement:

- *"It's already too late to do anything about climate change"*
- *"The actions of a single individual won't make any difference in climate change"*
- *"I feel a personal sense of responsibility to help reduce climate change"*

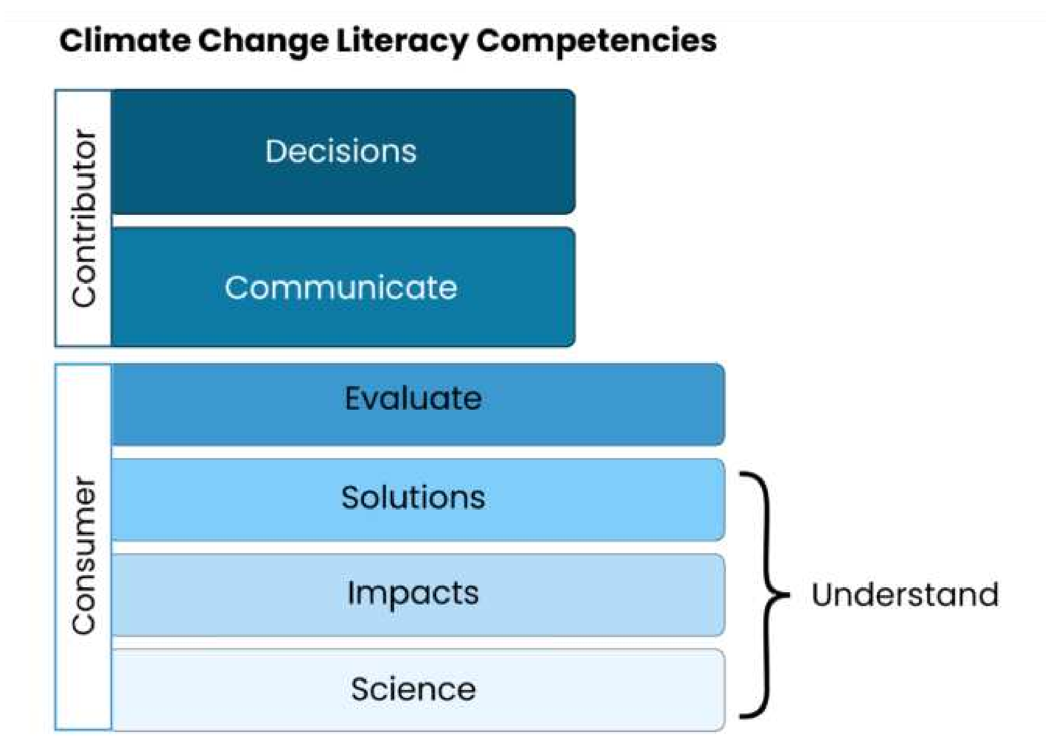

Figure 5.2. Climate Change Literacy Competencies Hierarchy. Derived from the USGCRP 2024 Climate Literacy Guide Essential Principles, these competencies include Understand the Science, Understand the Impacts, Understand the Solutions, Evaluate, Communicate, and Decisions. The

names of the competencies were summaries of the CC areas they are addressing and derived from the description of "a climate-literate person" in the Guide.

To analyze students' CCL Understanding we first examined group differences in performance across HW, exams, and KA. Because many of these variables exhibited non-normal distributions, non-parametric tests were used when appropriate. Differences in HW and exam scores across demographic groups (program level, course format, academic major, and political orientation) were evaluated using Wilcoxon rank-sum tests for two-level predictors and Kruskal–Wallis tests for multi-level predictors. When omnibus tests were significant, pairwise Wilcoxon tests with false discovery rate (FDR) correction were conducted. These procedures allowed detection of demographic performance differences across the Simple, Serious, and Solvable units.

Pre–post learning gains on the KA were evaluated using a Wilcoxon signed-rank test. Additional analyses assessed whether demographic groups differed in KA performance for pre-test and post-test using rank-based group comparisons with Holm- or FDR-adjusted post hoc tests. These analyses established the demographic predictors associated with instructional outcomes prior to examining relationships among constructs.

Visual Literacy (VL)

VL was assessed using a multi-item scoring codebook applied to students' responses on the VL intervention. The structured codebook was based on the VL Skills Hierarchy found in Chapter 2 (Figure 5.3). Informed by the Association of College & Research Libraries definition of VL and inspired by Arneson & Offerdahl, 2018 Visualizing Bloom's Tool (VBT), the skills in the hierarchy are grouped into 6 levels: Recognize, Interpret, Analyze, Evaluate, Find, Use, and Create. With the lower-level Bloom's cognitive skills at the foundation and encompassed by the role of "Consumer" and the higher-level skills at the top where students take the role of "Contributor." The full codebook can be found in Appendix 5.2.

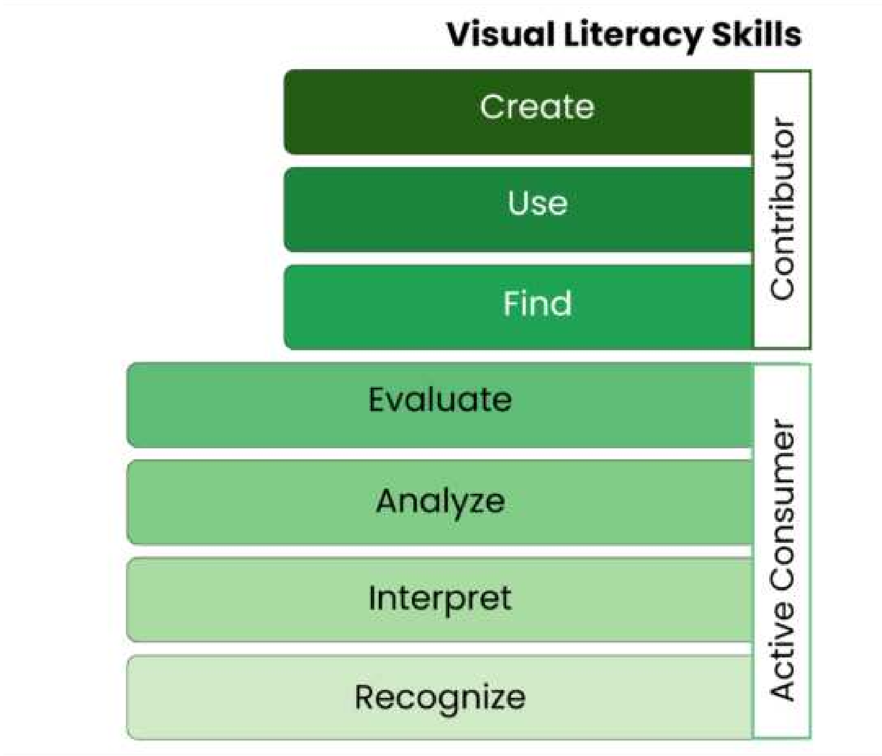

Figure 5.3. The Visual Literacy Skills Hierarchy. There are the main categories which relate to the roles students are taking as they engage with visual material, and each has associated skills within that are ordered from low-level engagement skills on the bottom of the hierarchy to the higher-order skills on top (Bloom et al., 1956). The progression of skills is emphasized using darker green color saturation for higher-order skills. The widths of the boxes relate to the fundamental nature of the roles and how they are built upon for the higher-order roles and skills. The categories and skills are 1) Passive Consumer: See and Experience; 2) Active Consumer: Recognize, Interpret, Analyze, and Evaluate; and 3) Contributor: Find, Use, and Create.

Coding involved transforming the written qualitative responses on the VL intervention to a numeric score. Inter-rater reliability was completed between the first author and an outside coder. A subset of intervention responses was iteratively coded until a high agreement was met. Cohen's Kappa (κ) values across the six rubric codes ranged from 0.87 to 0.92 ($M = 0.89$, $SD = 0.02$), indicating almost-perfect agreement between raters (Landis & Koch, 1977). The student codebook score yielded a continuous VL score per S3 unit.

To calculate overall VL proficiency, a composite VL_Score was created by adding the three VL scores together. Group differences in VL performance across demographic categories were evaluated using Wilcoxon rank-sum and Kruskal–Wallis tests, depending on the number of levels in each demographic variable. Because none of the omnibus tests were significant, no pairwise comparisons were conducted. To examine whether VL varied across instructional units, a Friedman test was conducted on students' Simple, Serious, and Solvable VL scores, followed by Holm-corrected Wilcoxon signed-rank tests to identify specific unit-level differences.

To examine how students interacted with images, we looked at the types of images students were *Selecting* and *Submitting* in the VL Intervention. Separate multinomial mixed-effects logistic regressions were conducted to examine whether the image types that students selected and submitted (Graph/Diagram, Photo, Meme/Comic, or Other) varied across the three course units (Simple, Serious, Solvable). Student ID was included as a random intercept to account for repeated measures across units. Graph/Diagram was set as the reference image category, and the Simple unit served as the reference instructional condition.

To investigate how VL levels related to the CCL competencies, we used two complementary analytic approaches. First, students were categorized into High VL and Low VL groups using a median split, and then, we conducted a series of Wilcoxon rank-sum tests with nonparametric effect sizes to compare CCL outcomes between groups. Using the continuous VL_Score, we ran Spearman rank-order correlations between VL and each CCL competency. To control for multiple comparisons, False Discovery Rate (FDR) corrections using the Benjamini–Hochberg procedure were applied within each analytic set. Correlations were computed using pairwise complete observations for each outcome variable. All analyses were conducted in R (version 4.5.2).

RESULTS

Climate Change Literacy

Understanding

For CCL Understanding, we examined classroom artifacts for performance between the S3 units and for overall learning performance we used student scores on the knowledge assessment. Students demonstrated significant gains in climate-change knowledge from pre- to post-assessment (Wilcoxon signed-rank test, $V = 8.46$, $p < .001$, $n = 80$) (Figure 5.4).

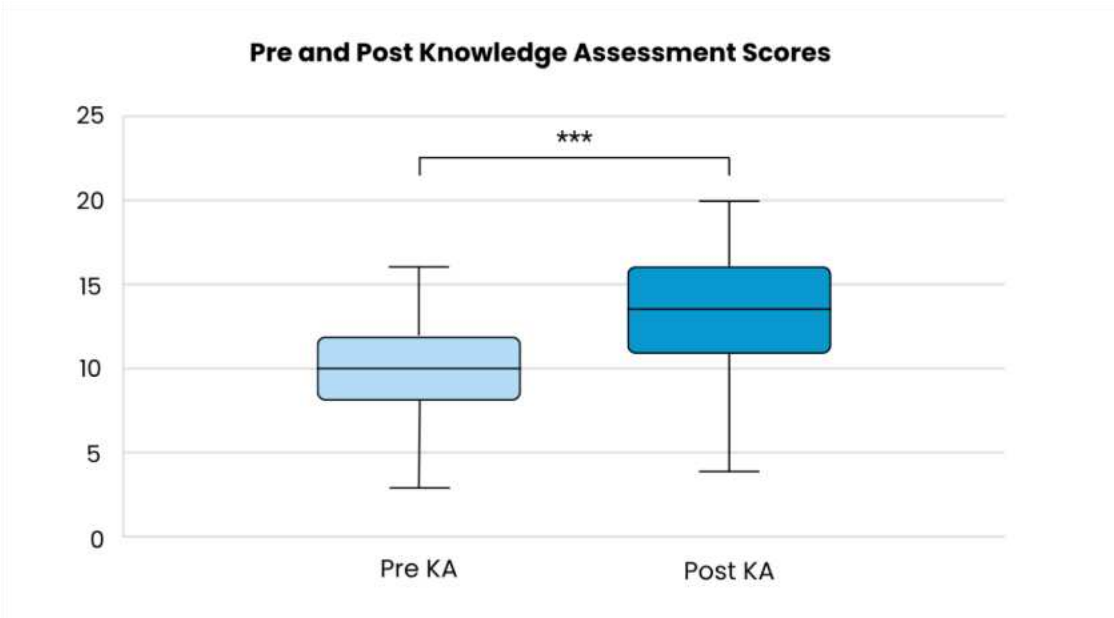

Figure 5.4. Pre- and post-course Knowledge Assessment (KA) scores. Boxplots show the distribution of students' KA scores before (pre) and after (post) completing the course. Students demonstrated a significant increase in knowledge from pre to post, as confirmed by a paired t-test, $t(79) = 8.46$, ***$p < .001$. Boxes represent the interquartile range (IQR), horizontal lines indicate medians, whiskers extend to 1.5× IQR.

Demographic analyses of KA scores showed that most groups began the course with comparable baseline knowledge, with no significant differences by program or major (both p_adj > .15), although in-person students scored higher than online students at pre-test (p_adj = .019; Table X). After instruction, significant differences emerged:

Graduate (G) students outperformed Undergraduate (UG) (p_adj = .0148), In-person (IP) students outperformed Online (O) students (p_adj = .0046), and Science (Sci) majors outperformed Non-science (NonSci) majors (p_adj = .0184). Political orientation (PO) also predicted post-instruction knowledge, with students identifying as Republican scoring significantly lower than those identifying as Democrat (p_adj = .001), Independent (p_adj = .031), and Other (p_adj = .002), while no differences were found among the non-Republican groups. Together, these findings indicate that some demographic factors influenced post-, but not pre-climate knowledge outcomes (Table 5.1).

Table 5.1. CCL Understanding Outcomes by Demographic Predictor

CCL Understanding Outcomes by Demographic Predictor

Significant Differences and Direction of Effects

		Program (UG vs G)	**Format (O vs IP)**	**Major (Sci vs NSci)**	**PO (4 groups)**
		Wilcoxon rank-sum			Kruskal–Wallis
HW	Simple	G > UG***	IP > O***	ns	ns
	Serious	G > UG***	IP > O*	ns	ns
	Solvable	G > UG***	IP > O***	ns	ns
Exam	Simple	G > UG***	IP > O	ns	ns
	Serious	ns	ns	ns	ns
	Solvable	G > UG***	IP > O***	ns	ns
KA	Pre	ns	IP > O*	ns	ns
	Post	G > UG*	IP > O*	Sci > NSci*	Republican < Dem, Ind, Other*

Abbreviations: UG = Undergraduate; G = Graduate; IP = In-person; O = Online; Sci = Science; NSci = Non-Science; PO = Political Orientation, HW = Homework Assignments, KA = Knowledge Assessment

Significance codes: * p < .05; ** p < .01; *** p < .001; ns = not significant

HW scores showed the clearest pattern: G students consistently outperformed UG on Simple, Serious, and Solvable HW, with all comparisons highly significant after FDR correction ($p\_adj < .001$). Course format differences followed a similar pattern, with IP students outperforming O students on all three HW units ($p\_adj \approx .010$). Exam performance showed more selective demographic effects. G students performed significantly higher on Simple and Solvable exam components ($p\_adj = .001$ and $.002$), though not on Serious items. IP students scored higher on Simple and Solvable exam components as well ($p\_adj = .039$ and $.010$), while Serious exam scores showed no format differences.

Evaluating

Students reported varying levels of exposure to CC information across mass media and social media platforms (Figure 5.5). For mass media, most students indicated relatively high exposure, with 37% reporting they encountered climate content at least once a week and 24% encountered it every day. An additional 17% saw/heard it at least once a month, whereas very few selected Not sure or the combined Never / Don't use category (each 2%). Approximately 14% left this item blank.

Patterns were similar for social media exposure, although students were somewhat more likely to report daily engagement. Specifically, 30% said they encountered CC content every day, 23% at least once a week, and 21% at least once a month. Eight percent fell into the combined Never / Don't use category, and 2% were not sure. Overall, students reported regular exposure to climate content, with social media showing higher daily engagement and mass media showing higher weekly exposure.

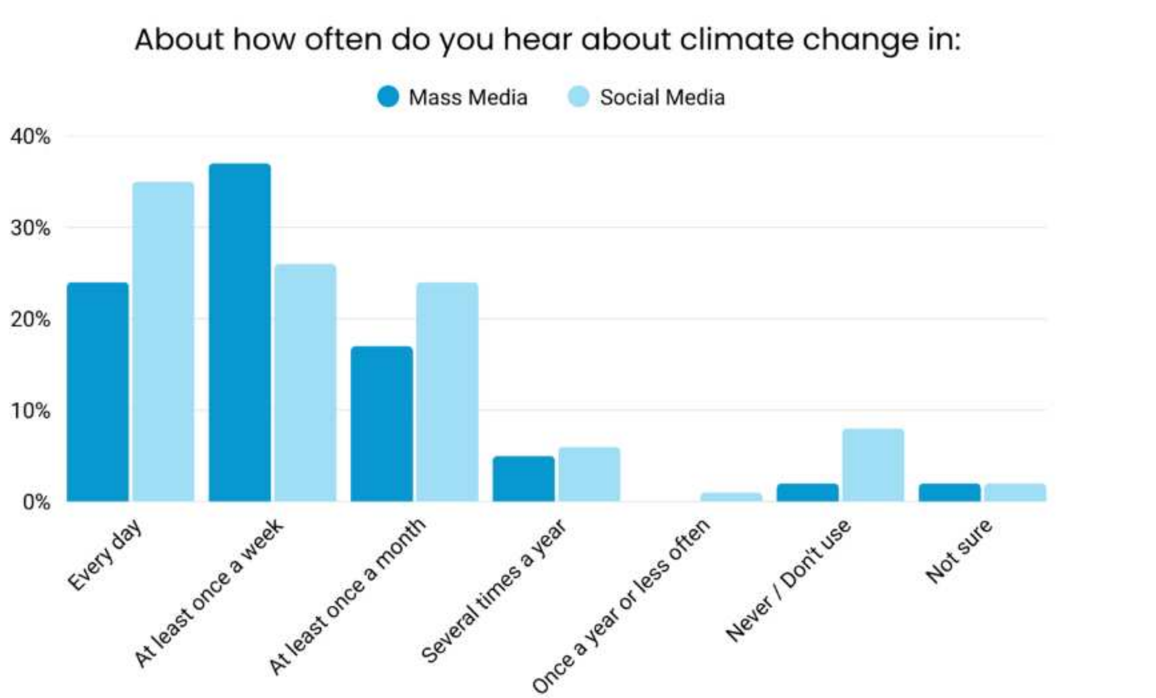

Figure 5.5. Evaluate: Frequency of reported exposure to climate change information in mass media and social media. The percentage of students reporting how often they encounter CC information through mass media and social media. Bars represent the proportion selecting each frequency category, from "Every day" to "Not sure." "Never" and "I don't use social media" were combined into a single category ("Never / Don't use").

Communicating

Exposure to CC in the public sphere includes both seeing and hearing about CC (passive) and hearing and participating in conversations about CC (active). Patterns of communication varied depending on whether students were active discussants or passive listeners of conversations (Figure 5.6). For discussing CC, most students reported actively engaging in climate conversations with friends and family at least occasionally. The largest category was "Occasionally" (48%), followed by "Often" (34%). Fewer students selected "Rarely" (17%), and almost none reported "Never" (1%). Patterns for passive listening about CC were similar to those for active participation. Students most frequently hear climate-related conversations once a week (36%) or once a month (32%), with 13% hearing such conversations every day.

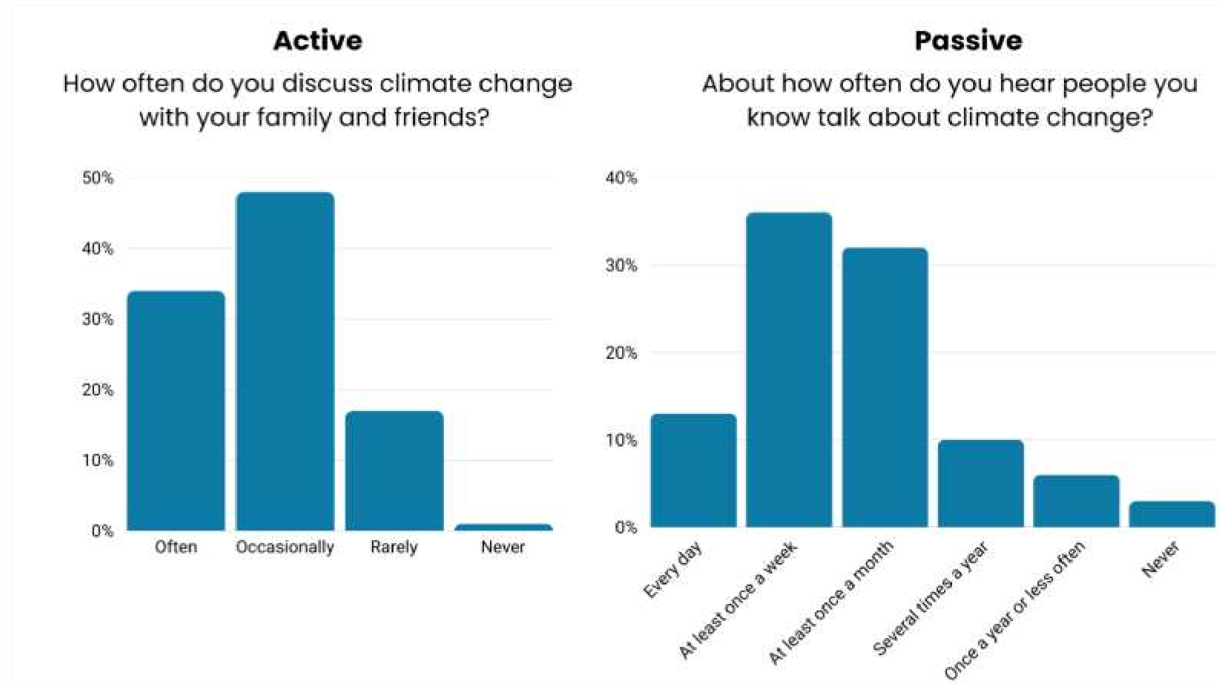

Figure 5.6. Reported frequency of discussing and hearing about climate change**.** The percentage of students reporting how often they (left panel) discuss CC with family and friends and (right panel) hear others in their social circles talk about CC. Categories ranged from "Often" to "Never," with uncommon responses such as "Other" and missing values retained. Students reported discussing CC most commonly "Occasionally" or "Often," and hearing about CC most frequently "At least once a week" or "At least once a month," indicating that CC is a regular topic of informal social communication.

Making Decisions

Decision variables captured three self-efficacy measures. Students' decision-oriented beliefs reflected a strong tendency toward engagement and agency in climate action, with relatively few neutral responses (Figure 5.7). For the belief that *"It's already too late to do anything about climate change,"* responses were clustered toward disagreement: 46% strongly disagreed and 44% somewhat disagreed, while only a small minority somewhat agreed (7%) or strongly agreed (3%). Responses to *"The actions of a single individual won't make any difference in climate change"* were more mixed but still leaned toward disagreement, with 48% strongly or somewhat disagreeing, but there were still 39% strongly or somewhat agreeing. Notably, 11% selected "Not sure," making this item the only one in the

Decision set where uncertainty was expressed at a meaningful level. Finally, responses to *"I feel personally responsible for taking action on climate change"* indicated strong personal agency, with nearly half of students strongly agreeing (54%) and an additional 36% somewhat agreeing. Only a small minority expressed uncertainty (4%) or disagreement (5%).

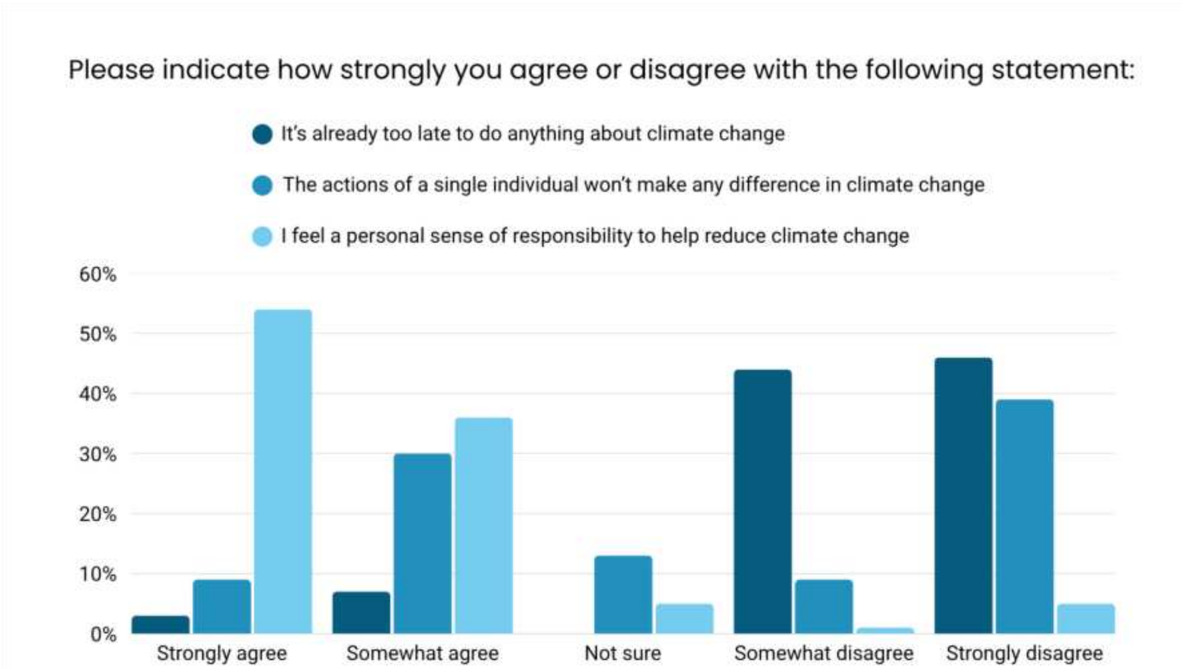

Figure 5.7. Frequency of student agreement with climate-related decision-making statements. Percentage of students selecting each response option for three decision-oriented items: "*It's already too late to do anything about climate change,*" "*The actions of a single individual won't make any difference in climate change,*" and "*I feel a personal sense of responsibility to help reduce climate change.*" Likert scale responses ranged from "Strongly disagree" to "Strongly agree," with "Not sure" retained as a distinct category. Students overwhelmingly disagreed that it is too late to act, showed mixed beliefs about the impact of individual actions, and expressed strong personal responsibility for taking climate action.

Visual Literacy

Demographic Differences

We examined whether Visual Literacy (VL) scores differed across student demographic groups using non-parametric tests. The Kruskal–Wallis tests indicated no significant differences in VL scores among political orientation groups, H (3) = 4.13, p = .248. Because the omnibus test was not significant, no pairwise comparisons were conducted. Wilcoxon rank-sum tests likewise showed no differences across two-level demographic variables. VL scores did not differ by Program level, $W = 1013$, $p = .788$; course Format (in-person vs. online), $W = 805$, $p = .903$; nor Major, $W = 780$, $p = .805$. Collectively, these results indicate that VL performance was statistically consistent across all demographic groups included in this study (Table #).

Table #. Results of Wilcoxon rank-sum and Kruskal–Wallis tests between VL Score and Demographics Factors

VL Score by Demographic Predictor

	Program (UG vs G)	Format (O vs IP)	Major (Sci vs NSci)	PO (4 groups)
	Wilcoxon rank-sum			Kruskal–Wallis
Statistic	W = 1013	W = 805	W = 780	H(3) = 4.13
p-value	p = .788	p = .903	P = .805	p = .248
Result	ns	ns	ns	ns

Abbreviations: UG = Undergraduate; G = Graduate; IP = In-person; O = Online; Sci = Science; NSci = Non-Science; PO = Political Orientation, ns = non-significant

Visual Literacy Across S3

A Friedman test was conducted to examine whether VL performance differed across the three instructional units (Simple, Serious, Solvable). The results indicated a significant effect of unit on VL performance, χ^2 (2) = 15.50, p < .001, suggesting that students' VL scores were not equivalent across units. Follow-up pairwise Wilcoxon signed-rank tests with Holm correction revealed significant differences between: Simple and Serious **(**$p = .024$) and Serious and Solvable ($p = .001$), but not between Simple and Solvable ($p = .336$) (Figure 5.8).

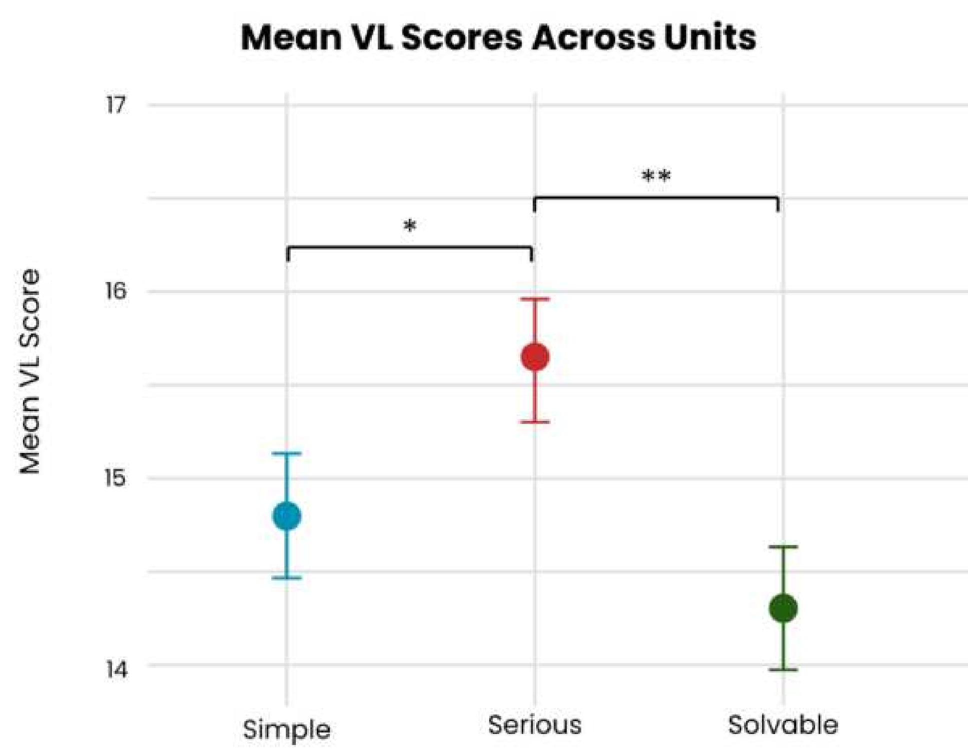

Figure 5.8. Mean visual literacy (VL) scores across the Simple, Serious, and Solvable units. VL performance differed significantly by unit, $\chi^2(2) = 15.50$, $p < .001$. Pairwise Wilcoxon tests (Holm-corrected) showed that Serious scores were significantly higher than Simple ($p = .024$) and Solvable ($p = .001$), whereas Simple and Solvable did not differ ($p = .336$). Error bars represent ±1 SD.

To get a better understanding of how students interacted with the different image types across the VL interventions, we conducted a multinomial mixed-effects logistic regression. We sought to determine whether students selected and submitted image types (Graph/Diagram, Photo, Meme/Comic, or Other) differed significantly across the three course units (Simple, Serious, Solvable) (Figure 5.9).

As Active Consumers, results showed that images selected by the students varied significantly by unit. Relative to Graphs, Photos were significantly more likely to be selected during the Solvable unit than during the Simple unit ($\beta = 1.04$, SE = 0.47, p = .025).

Memes/Comics were substantially more likely to be selected in the Serious unit than in the Simple unit ($\beta = 1.41$, $SE = 0.34$, $p < .001$). These findings indicate that students systematically shifted their preferred image types depending on the instructional framing, choosing scientific imagery to describe “Simple” aspects of CC, favoring humor-oriented memes when describing “Serious" impacts and relying more on real-world photographs when constructing “Solvable" explanations.

As Contributors, results indicated that students were more likely to submit photos during the Serious unit than during the Simple unit, $\beta = 1.71$, $SE = 0.45$, $z = 3.82$, $p < .001$, corresponding to a 5.52-fold increase in the odds of choosing a photo instead of a graph. Photo selection in the Solvable unit showed a nonsignificant upward trend, $\beta = 0.68$, $p = .142$. No significant unit-level differences were observed for meme/comic submissions or “other” formats (all $p > .15$). These findings reinforce that the Serious unit elicited a strong shift toward photo-based representations, while image selection in the Simple and Solvable units remained more graph-oriented or diverse.

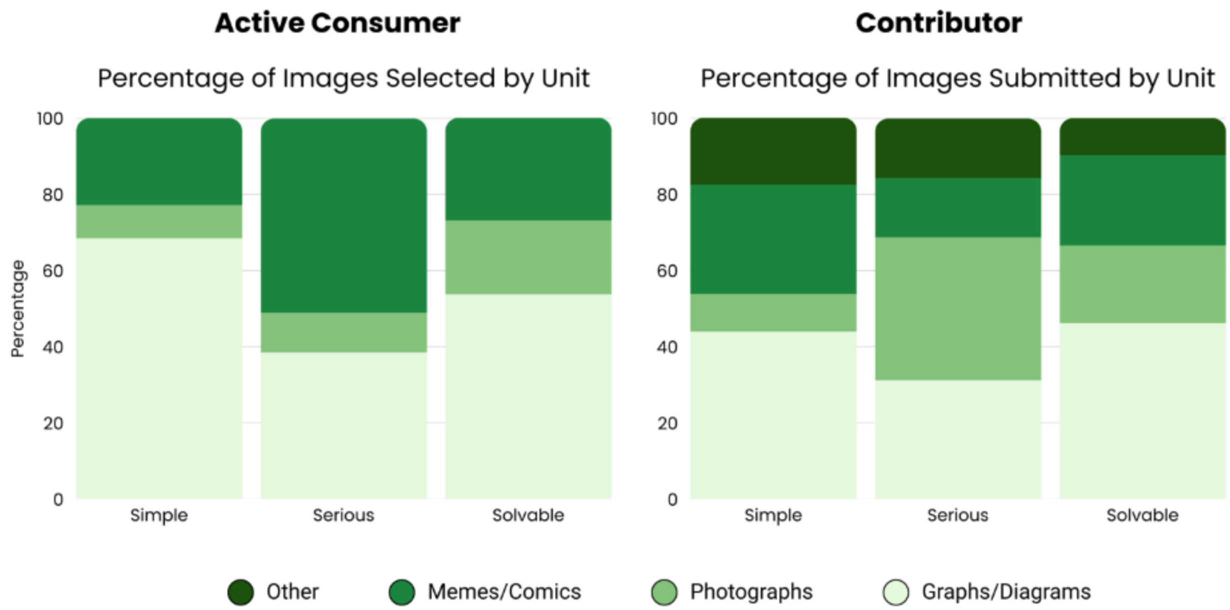

Figure 5.9 Percentage of Images Selected and Submitted by Unit. Stacked bars represent the proportion of students who selected and submitted Graphs/Diagrams, Photos, Memes/Comics, or Other (only for Submitted images) when asked to explain climate-change concepts in each unit. (Left panel) Students most commonly selected Graphs/Diagrams in the Simple unit (69%), shifted toward Memes/Comics in the Serious unit (51%), and increased their use of Photos in the Solvable unit (19%) while most frequently selecting Graphs (54%). (Right panel) In the Simple unit, Graphs (43%) remained the most common. In the Serious unit, Photographs (38%) were the dominant submission type. In the Solvable unit, Graphs (46%) became the most frequently submitted images.

Visual Literacy and Climate Change Literacy

HW performance varied by VL level across the three course units (Figure 5.10). High-VL students consistently earned higher HW scores than Low-VL students, but the magnitude and significance of these differences differed by unit. In the Simple unit, High-VL students outperformed Low-VL students ($W = 647.5$, $p = .036$, $r = .27$), indicating a small–medium effect. A similar pattern emerged in the Solvable unit, where High-VL students again scored significantly higher ($W = 641.5$, $p = .040$, $r = .27$). In contrast, HW scores for the Serious unit did not significantly differ by VL level ($W = 718$, $p = .205$, $r = .20$).

Similarly, when looking at scores on the knowledge assessment, we see that High-VL students scored higher (Figure 5.10). A Wilcoxon rank-sum test indicated that High-VL and Low-VL students differed significantly on the pre-knowledge assessment, (W = 535.50, p = .047). Although significant, the magnitude of this difference is modest and smaller than the post-instruction effect. High-VL students scored significantly higher on the post-instruction knowledge assessment compared to Low-VL students, (W = 401.00, p = .002). This represents a larger and more robust group difference, indicating that VL is strongly associated with the knowledge gains students demonstrated by the end of instruction.

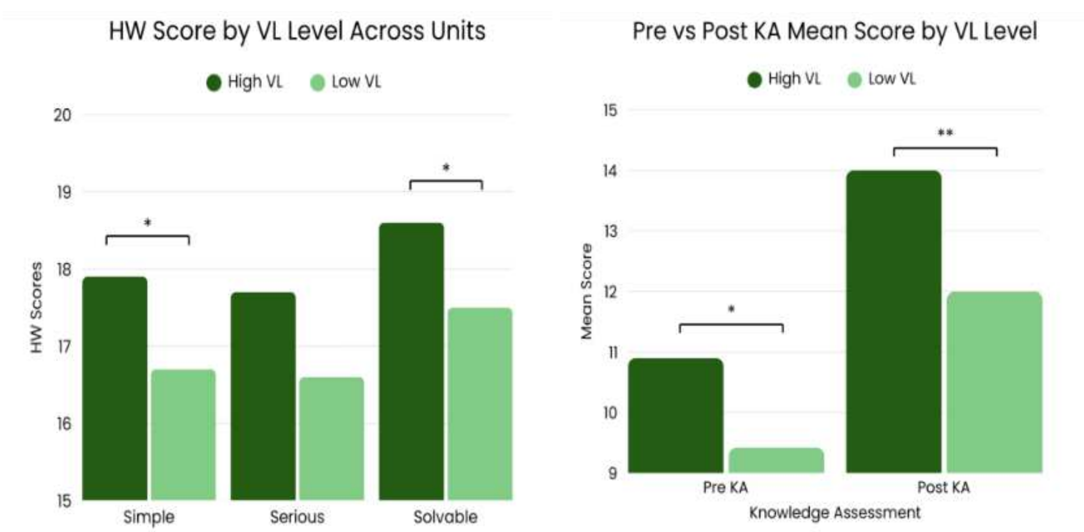

Figure 5.10. (Left Panel) Mean HW scores for High (dark green) and Low (light green) visual literacy (VL) students across the Simple, Serious, and Solvable units. High-VL students scored significantly higher on the Simple (W = 647.5, p = .036, r = .27) and Solvable (W = 641.5, p = .040, r = .27) assignments, whereas no significant difference was observed for the Serious unit (p = .205). (Right panel) Mean scores for pre and post Knowledge Assessments (KA). High VL students score significantly higher in both pre (W = 535.50, p = .047) and post KAs (W = 401.00, p = .002). Significance indicators ($p < 0.05$*, $p < 0.01$**) denote between-group differences based on Wilcoxon rank-sum tests.

The strongest, and only significant relationships emerged within the Understanding domain, where moderate positive associations were observed for post-instruction knowledge scores ($\rho = 0.24$; p-adj = 0.018) and two HW measures (HW Simple, $\rho = 0.21$, p-adj. = 0.017; HW Solvable, $\rho = .024$; p-adj. = 0.018), represented by the darkest green shading in the heatmap (Figure 5.11). Additional Understanding indicators, such as Exam Simple ($\rho = 0.19$), Exam Solvable ($\rho = 0.15$), and Exam Serious ($\rho = 0.08$), showed weaker positive relationships, reflected by medium-green shading (Figure 5.11). Although not statistically significant, within the Evaluate there are weak positive relationships for both social media ($\rho = 0.13$) and mass media exposure ($\rho = 0.11$). For Communicate there is a moderate positive relationship for hearing about CC ($\rho = 0.25$), but a weaker relationship for discussing CC ($\rho = 0.07$). For Decisions, there was a near zero relationship with the variable for personal responsibility ($\rho = 0.03$), and weak negative relationships for the feelings that is was too late to act ($\rho = -0.07$) and that individual actions do not matter ($\rho = -0.08$). The negative associations indicate that an increase in VL score corresponds to a decrease in agreement with these variables.

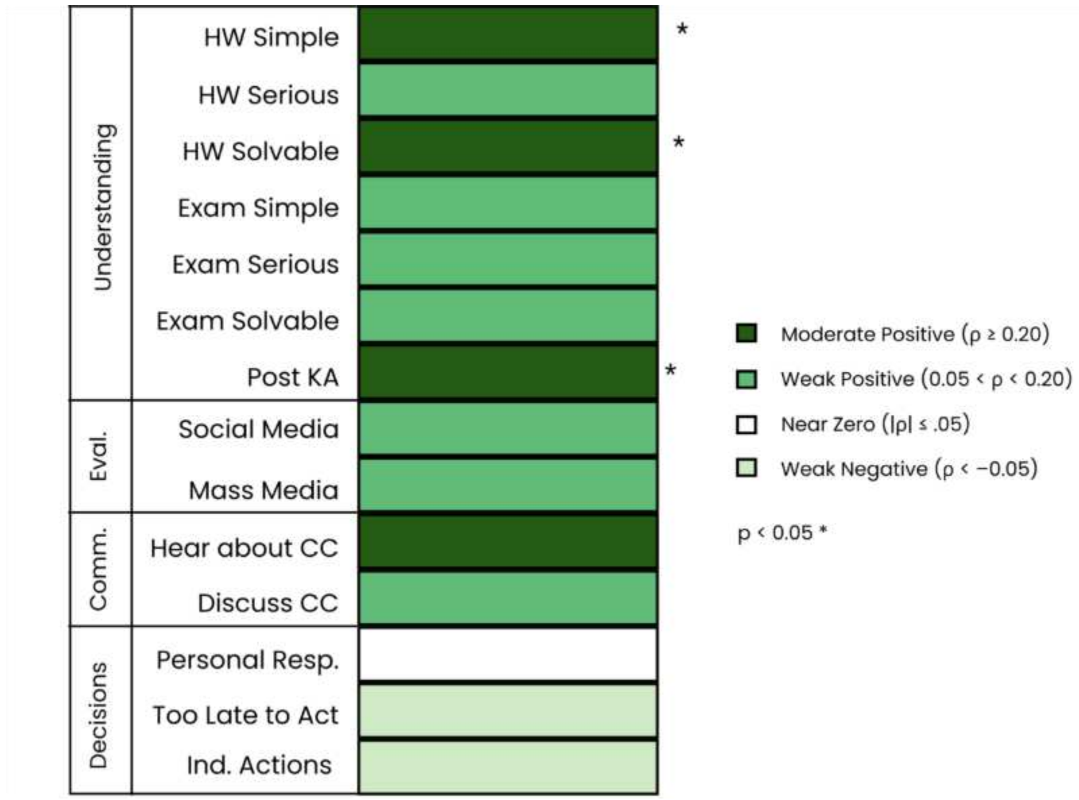

Figure 5.11. Heatmap of Spearman correlations between visual literacy (VL) scores and all climate change literacy (CCL) indicators. This heatmap displays the strength and direction of associations between students' continuous VL scores and 14 CCL variables spanning four domains: Understanding, Evaluate, Communicate, and Decisions. Each cell represents the Spearman correlation coefficient (ρ) for a single CCL indicator, color-coded using a gradient in which darker green reflects stronger positive associations ($\rho \geq .20$), medium green indicates weak positive associations ($0.05 < \rho < 0.20$), white indicates correlations near zero ($|\rho| \leq .05$), and light green represents weak negative associations ($p < -0.05$).

Moderate significant positive relationships were observed within the Understanding domain, most notably for post-KA ($\rho = 0.24$; p-adj = 0.018), HW Simple ($\rho = 0.21$; p-adj. = 0.017), and HW Solvable ($\rho = .024$; p-adj. = 0.018). Non-significant after FDR correction moderate positive relationships were also observed for all exam variables and all Evaluate variables. Communicate variables were split with hearing about CC showing a moderate positive relationship and discussing showing a weak positive relationship. Decision variables also showed a split, with a near zero association for personal responsibility, but weak negative associations with it's too late to act and that individual actions don't matter.

DISCUSSION

As the impacts of CC become increasingly evident, we need a motivated and engaged public that can address this complex issue. A powerful form of engagement that has been shown to have wide ranging effects is the ability and willingness to communicate with others about CC. Beyond individual actions and solutions, communicating about this multi-faceted issue can spur collective action through which long-lasting change in the minds and hearts of people can occur (Goldberg et al., 2019; Hannibal & Vedlitz, 2018; Leombruni, 2015). Of the wider public, university students (mainly Gen X and Millennials) are uniquely poised to be agents of change for CC because they already are already concerned about the issue (Hickman et al., 2021), and display increased communication behavior (Tyson, 2021). To be able to communicate accurately and effectively, students need CCL. In this study, we evaluated how students' VL impacted their CCL.

VL Improves CCL Understanding

Student skills and competencies can explain discipline-specific learning outcomes. In this study, our results supported our hypothesis that students with high VL skills would demonstrate increased gains in CCL Understanding., regardless of major or other demographic factors. For both overall learning and performance on visual-heavy HW assignments, higher level of VL was associated with higher scores. This confirms the importance of being fluent in the visual disciplinary language of a subject to build understanding (Arneson & Offerdahl, 2018b; Trumbo, 1999).

While there was not a significant statistical relationship between VL and the other CCL competencies of Evaluate, Communicate, or Decisions, the correlations tests revealed notable associations with some of these variables, such as media exposure. This suggests that students with higher VL more frequently consume CC media. Others have reported that when a person has increased communication skills (e.g., higher VL), they are more likely to engage in communication behaviors, especially in the sciences (Swords et al., 2023). This is further supported by the positive relationships with hearing and discussing CC (CCL Communicate) that were observed, suggesting that not only do students with greater communications skills immerse themselves passively in hearing and about CC from acquaintances and media, but also actively engage more frequently in conversations about these topics. In fact, some studies have found that real-world, iterative practice engaging with nonexpert audiences may be essential to developing communications skills, thus suggesting that communications skill development is iterative (Capers et al., 2022).

Students Prefer Different Images by S3 Unit

We saw that students prefer to consume different images for different aspects of CC. As shown by the types of images selected within each unit, we saw that students will more likely choose Graphs/Diagrams for Simple, Memes/Comics for Serious, and then were more likely to choose Photographs for Solvable than the other two units. The preference for scientific visualizations when presenting the mechanisms of CC, suggests a connection to the images they are accustomed to seeing and mimic the same language they learn the topic in. The increased choice of memes for the Serious unit may indicate the power of humor in facing the anxiety-producing evidence they encountered (Boykoff & Osnes, 2019). (Peters, 2021) found that CC memes and humor, in general, were useful coping mechanisms for young adults to mitigate anxiety from hearing about CC. There is a plethora of evidence describing the power of humor as a frame to providing comfort and affecting change (Boykoff, 2019; Kaltenbacher & Drews, 2020; Skurka et al., 2018; Zhang & Pinto, 2021), although, there is relatively little research on the impact of memes in university CC education.

Interestingly, we also found that the Serious unit is also where students demonstrated the highest VL scores (Figure 5.8). This may be related to the fact that Serious images are more commonly found in media and students are able to better recognize, interpret, and analyze the content of these images, leading to higher VL scores (Bogert & Balgopal, 2025; O'Neill, 2020; Schäfer, 2020). Alternatively, it may be that memes in general were made by and for these younger generations (Millennial, and Gen Z) (Mooseder et al., 2023b; Murru & Vicari, 2023). Thus, they are more comfortable reading and engaging with these types of images than the other forms (photos and graphs), which are less likely to be found in social media, the media format that they are most commonly engaging with (Mooseder et al., 2023b; Newman et al., 2025; Pearce et al., 2019; Tyson, 2021).

While graphs were the most commonly selected images in the Solvable unit, they were more likely to select Photographs here than Simple and Serious. We believe this suggests an interest in seeing solutions as more tangible and approachable.

Demographic Differences

Our survey findings confirm what others report – most of the students in our study (90%) feel a sense of personal responsibility to solve CC, compared to only (63%) of the general population (Leiserowitz et al., 2023). Additionally, while only 20% of the general public report hearing friends and family talking about CC at least once a month compared to81% of the students in our study reported this. A similar pattern can be seen for active communication participation -- 82% of the students stated that they engage in conversations about CC “occasionally” or “often,” while only 31% of the public do so (Leiserowitz et al., 2023).

To ensure that students are communicating about the science, impacts, and solutions of CC in factually correct and relevant ways, it is critical that they understand the science that supports their claims. This is particularly true for students that are expected to be communicating frequently but may not have extensive scientific training (ie. Non-major business students). Thus, we examined these CC courses that included a range of students from different disciplinary backgrounds. We found that while the overall course improved CC knowledge, as demonstrated by the overall increase in pre vs post knowledge assessment scores, learning outcomes were better for those in the IP sections, for G students, and for the Sci majors (Table #). This confirms prior research that students perform better in face-to-face courses than online, particularly for science instruction (Co, 2025; Photopoulos et al., 2023). Like others have reported, we found that political orientation likely affects CC understanding (Stockus & Zell, 2025). In a study on adults in the US, Stockus & Zell (2025) found that Democrats had better knowledge about CC and greater support for climate policies than Republicans.

Limitations

A limitation of our study was that there was only one type of image for each type in each unit. This may have led to a limited number of representations across the visuals. For example, the only people that were present in the images were found in the Memes/Comic. While not explicitly a design choice, this may have affected how students chose these images, as it has been found that images that show people tend to have higher engagement (León et al., 2022). We also only showed the students static visuals, and with the rise in popularity short-form video formats in social media, this could be a missed opportunity to see the effects of dynamic imagery (Xie, 2023). Additionally, our intervention did not include a robust in the measurement of students as VL Contributors. For example, there was only one student who submitted their own designed image.

Implications

CC educators are positioned to prepare their students to make scientifically informed decisions that can prevent and mitigate the impacts of CC. Educators can also motivate their students to communicate to others about this pressing issue. We have found that improving student VL can lead to improved CC understanding. This is foundational for building their holistic CCL (see Chapter 2). This has been found to be true for many other science disciplines, so it is not surprising we see evidence of the results for CC education (Arneson & Offerdahl, 2018b; McTigue & Flowers, 2011; O'Neil, 2011). VL skills are often assumed, particularly for Millennials, and Gen Z, often called "digital natives" who have been immersed in technology their whole lives (Oblinger et al., 2005; Prensky & Berry, 2001). However, research has found that technological exposure does not necessarily lead to increased VL (Brumberger, 2011). As such, intentional and explicit instruction in VL is essential for developing disciplinary literacy (Arneson & Offerdahl, 2018b; Krejci et al., 2020). Thus, when teaching about CC, educators should provide opportunities for students to both consume a variety of images as well as contribute their own created visuals.

Research has shown that even science students who feel they have a high level of understanding of CC, are less likely to communicate about solutions (Bowen et al., 2025). These findings support the need to present students with a wide range of images when teaching them about a topic. Engagement with diverse images that align to their preferences and needs, particularly for complex topics with many different perspectives, can lead to improved learning outcomes (Duan & Bombara, 2022). With a strong foundation as active consumers of visual information, students are then better prepared to succeed as contributors in communicating about these issues (Glazer, 2011).

While we found that overall VL impacts CCL, future studies could investigate which individual VL skills (e.g. Analyzing, Evaluating, Creating) had the largest impact on CCL. What else remains to be well-studied is what variables motivate one to communicate about CC (Bowen et al., 2025). Future research should provide more opportunities for evaluation of the higher-order VLS, described in the study by Arslan and colleagues (2012). Additionally, some research has suggested that worldview factors may play a greater role than CC information in building CCL (Kahan et al., 2012), but there is more research needed, particularly when considering the inter-relatedness of VL, worldview, and CCL for younger populations (Aksit et al., 2018).

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CHAPTER 6 - WHAT IN THE WORLDVIEW? RESEARCH BRIEF ON HOW WORLDVIEW RELATES TO STUDENT VL AND CCL

INTRODUCTION

Climate change (CC) is a cognitively complex and multi-faceted issue that is often shown using a variety of images (Avgerinou, 2007). For students to understand the science, impacts, and solutions of CC and be prepared to evaluate information, communicate, and make informed decisions (i.e., exhibit climate change literacy (CCL)), they must also have a strong foundation of visual literacy (VL) (Chapter 5). However, VL is culturally specific with symbols and representations that are interpreted differently across communities (Esbjörn-Hargens, 2010). To consider the development of CCL and VL, the cultural, affective, and value-based elements that shape students' understanding, motivation, and ability to understand and address CC should be considered (Lee et al., 2020). Worldview (WV), defined as the *inescapable, overarching systems of meaning and meaning-making that to a substantial extent inform how humans interpret, enact, and co-create reality* (De Witt et al., 2016), includes factors which are critical components of how people make sense of CC information and formulate their responses. WV is also shaped by demographic characteristics, personal experiences, cultural attitudes, political ideologies, and religious beliefs (Lee et al., 2015).

While learners may not be aware that their WV shapes how they interpret CC information, it is critical for researchers to acknowledge that this might be the case (Azevedo & Marques, 2017; Dupigny-Giroux & Cole, 2018; Wang et al., 2018). For the general public, WV factors have been found to be more influential than knowledge in developing CC risk perceptions (Kahan et al., 2012). However, because young adults in university are believed to still be developing their WV and have certain “plastic,” or malleable, perspectives, knowledge development has been found to have a bigger effect on risk perception for this demographic (Aksit et al., 2018; Vollebergh et al., 2001). Given the highly politicized nature of CC in the US, educators sometimes consider the dual role of developing knowledge while addressing student WV (Stevenson et al., 2014; Zummo, 2023). The interplay between WV and VL in the context of CCE remains under explored. Understanding this relationship can contribute to more tailored and effective CC education systems for diverse groups of students. Thus, we sought to answer the question:

Does worldview moderate the relationship between student visual literacy and climate change literacy?

METHODS

Context and Participants

This study draws on the same student group described in Chapter 5. Participants were enrolled in either an upper-division undergraduate course (100-level) or a parallel graduate seminar (500-level) focused on CC. Both courses were taught by the same atmospheric science instructor during the Fall 2023 semester following the Simple, Serious Solvable (S3) instructional framework (Diaz-Clark et al., 2025). Of the 106 students enrolled, 102 consented to participate. The sample included both in-person (69%) and online learners, with most (61%) enrolled in science-related degree programs. Students were asked to identify their political orientation because of the politicized nature of CC in the United States. All data were obtained under an IRB protocol (no. 4235), and only de-identified student records were used in analyses.

Data Collection

Knowledge Assessment

To determine how students' fundamental CC knowledge may have changed after instruction, we used an assessment administered both before and after instruction. The Climate Knowledge Assessment (KA) was developed and tested by Aksit et al. (2018). The instrument consists of 21 multiple-choice questions designed to assess students' content knowledge of climate-related science. It was designed for adult learners. The questions cover several science concepts, and while these pertain mainly to topics covered in the Simple portion of the course, the assessment can be used to determine what knowledge students hold about CC before the S3 and how this might change after instruction. The questions are either single response, or multiple response, and are scored using an all or nothing approach where no partial points are given. The responses can be analyzed and compared as a raw score out of 21 possible points.

Perception Survey

The pre/post composite survey was developed to gain a better understanding of connection between WV, and preconceived ideas about CC (beliefs, risk perception, policy support, and communication behavior). This composite survey comprised questions from the Integrative Worldview Framework and the Climate Change in the American Mind surveys.

WV was evaluated using the Integrative Worldview Framework (IWF) developed by DeWitt and colleagues (2016). The IWF was developed to map people's WVs and how they interface with CC. When developing this measurement, the authors moved away from the traditional *Cultural Cognition Theory* (Kahan et al., 2012) & *World Values Survey* that they believed was too limiting in its binary measures and was not dynamic enough to encompass a larger range of WV-related questions. The IWF incorporates philosophical, sociological, and psychological perspectives to analyze WV through ontology, epistemology, axiology, anthropology, and societal vision. This framework separates WVs into the categories of *traditional*, *modern*, *postmodern*, and *integrative*, each denoted by their differing WV aspects (see Table 1 from DeWitt et al., 2016). This framework was chosen because it presented an organization of WV that was compatible with our analysis.

Slightly modified items from the Climate Change in the American Mind survey conducted by the Yale Program on Climate Change Communication (YPCCC) and the George Mason University Center for Climate Change Communication (Mason 4C) were also included in the composite survey The YPCCC and Mason 4C have been collecting data with participants representing the American public since 2008 and have carefully tracked the changing viewpoints and beliefs over time. For our survey, we changed the term “global warming” to “climate change” in all the questions. This was to better reflect the expectations and common verbiage of the students being evaluated. While the questions cover beliefs, emotional responses, risk perceptions, engagement, social perceptions, possible impacts, and communications of CC, we chose a selection of the questions to analyze in this study that we thought best informed our research questions.

Table 6.1 IWF worldview delineation categorized by their stances on the five WV aspects (DeWitt et al., 2016)

	Traditional worldview	Modern worldview	Postmodern worldview	Integrative worldview
Ontology	Religious/metaphysical monism. Reality as singular, transcendent. Universe as purposively constructed whole. God-created universe *ex nihilo*. Transcendent God/Creator is separate from profane world; dualism. Nature as embodiment of meaningful, imposed order (e.g. God's creation).	Secular materialism. Reality as singular, immanent. Mechanistic universe brought about by random selection. Material reality devoid of meaning, intentionality, consciousness; dualism, disenchantment. Nature as instrumental, devoid of intrinsic meaning and purpose. Resource for exploitation.	Post-materialism. Reality as pluralistic, perspectival, constructed. Multiple cosmogonies/cosmogony as social construct Reality as discontinuous and fragmented, meaning as social construct; anti-essentialism. Nature as constructed through a plurality of cultural values, meanings, and interests.	Holism/integralism (unity in diversity). Reality as transcendent *and* immanent. Universe as evolving, creative manifestation of Source/Spirit. Outer and inner reality co-arising, interdependent; re-enchantment. Nature as intrinsically valuable. Frequently seen as divine force that humanity is part and expression of.
Epistemology	Naïve realism; emphasis on concrete-literal interpretations of religious doctrine (literalism, dogmatism). Religious/conventional authority (scripture, divine revelation, tradition). Implicit methodology Substantive rationality	(Post-)positivism; emphasis on reality as objectively knowable, (empiricism, reductionism, scientism). Secular authority (science, the state). Quantitative methods; methodological monism. Procedural rationality	Social constructivism; emphasis on reality as constructed (pluralism, relativism). Internalization of authority (e.g. moral, emotional, intuitive, artistic knowing) Qualitative methods; methodological pluralism Skeptical rationality?	Critical realism, pragmatism; emphasis on reality as approachable through integration of sources of knowledge Triangulation of authority (scientific, spiritual/religious/philosophical, and subjective knowing) Mixed methods; integrative pluralism Synthetic rationality?
Axiology	Traditional values (e.g. security, tradition, conformity, obedience, humility) Emphasis on community, family Pre-conventional morality?	Rational-secular, materialist values (e.g. power, achievement, hedonism, stimulation) Emphasis on independent individuality Conventional morality?	Self-expression, post-materialist values (e.g. openness to change, self-direction) Emphasis on unique individuality Postconventional morality?	Self-expression/self-transcendence values (e.g. universalism, self-actualization)? Emphasis on embedded, relational individuality Universal morality?
Anthropology	Humanity in managerial stewardship role vis-à-vis nature Prime purposes determined by larger order and social roles. Human being as sinful/fallen from grace. Dependent on religious/metaphysical authorities for salvation. Ethnocentric identity?	Humanity in promethean control over nature Prime purposes of a material, hedonistic nature. Human being as self-optimizing, independent being. *Homo economicus*. Sociocentric identity?	Humanity in cautious relationship to nature Prime purposes are found within, intrinsic. Human being as self-expressing, unique individual. Worldcentric identity?	Humanity in unity and synergy with nature Prime purposes found within, serving the larger whole ('service through self-actualization'). Human being as evolutionary co-creator, with a vast—though generally unrealized—potential. Planetcentric identity?
Societal vision	Traditional societies, emphasis on (subsistence) farming. Traditional and religious authorities and values as source of solutions to societal and environmental problems.	Industrial societies, emphasis on mechanized modes of production (e.g. industrial/conventional agriculture). Technological optimism: science and technology as solutions to societal and environmental problems.	Post-industrial societies, emphasis on service economy and creative industries. Scepticism of status quo, idealism: mobilization of the public through revealing injustices as prime solution to societal and environmental problems.	Increasing emphasis on services, creative industries, and social/sustainable entrepreneurship. Integrative vision: emancipation of the public through consciousness growth and a synthesis of interests and perspectives as solutions to societal and environmental problems

Data Analysis

Worldview

The IWF presents respondents with 17 sets of four statements, each representing a different epistemic orientation: Traditional, Modern, Postmodern, and Integrative (Table 6.1). Within each set, participants selected the statement with which they most agreed and the one with which they least agreed, producing a forced-choice profile across all WV dimensions using a best–worst scaling approach (Lee et al., 2008). Each of the 17 item sets was converted into a three-point scale reflecting the participant's relative preference among the four WV statements: 1 = most agree, 0 = not chosen, and –1 = least agree. Scores for each WV type were then summed across the 17 sets, producing four continuous indices representing the extent to which the participant endorsed each WV orientation. A participant's predominant WV was determined by identifying the WV type with the highest total score, reflecting the orientation most consistently selected as "most agreeable" and least frequently rejected across all sets. When two or more WV scores were tied for the highest value, the participant was categorized as Mixed, indicating no single dominant WV pattern.

Climate Change Literacy, Visual Literacy, and Worldview

Before examining relationships among climate change literacy (CCL), visual literacy (VL), and worldview (WV), composite scores were created for each of the five CCL competencies: Understanding, Evaluate, Communicate (Visual), Communicate (Frequency), and Decisions. Each competency consisted of several task-based or self-report indicators specific to that dimension of literacy. Because these indicators varied in scale (e.g., exam percentages, homework points, Likert scores), distributional properties, and response format, all contributing variables were standardized (z-scored) prior to aggregation. Composite scores were calculated by averaging the standardized indicators for each participant, a method for combining heterogeneous educational measures while maintaining equal weighting and interpretability (Aiken et al., 1991).

Internal convergence and structural coherence were evaluated for each competency. First, indicator correlations were inspected to ensure that items within a competency demonstrated moderate positive associations in theoretically consistent patterns (Briggs & Cheek, 1986; Cortina, 1993). Second, one-factor exploratory factor analyses (EFA) were conducted using minimum residual extraction to assess unidimensionality. Factor loadings, communalities, and factor score adequacy metrics were examined to determine whether each set of indicators reflected a single latent construct. Although global model-fit indices can be conservative for mixed-format data, factor-score correlations and loading magnitudes indicated that each composite adequately represented a unified underlying competency. Together, these procedures ensured that all CCL composites were psychometrically defensible and suitable for use in regression-based analyses.

With validated composite scores established, a series of hierarchical multiple regression models were constructed to examine how demographics, WV, and VL contributed to students' performance on each CCL competency. Each model included three steps. Model 1 entered demographic predictors (program level, course format, major, political orientation, and pre-instruction knowledge where applicable). Model 2 added WV group, treated as a dummy-coded categorical variable representing Traditional, Modern, Postmodern, Integrative, and Mixed orientations. Model 3 added overall VL (VL_Score) to test whether VL explained additional variance beyond demographics and WV. For each competency, unstandardized regression coefficients (B), significance levels, and model R^2 values were extracted. Improvement in model fit was assessed using changes in explained variance (ΔR^2) and ΔF tests comparing nested models. This analytic framework enabled a direct evaluation of the relative contributions of demographic, epistemic, and cognitive factors to each dimension of CCL.

RESULTS

Worldview

Students represented all the WV orientations, though the distribution was not uniform (see Figure 6.1). Integrative WVs were the most common (n = 41), followed by Postmodern (n = 30) and Mixed WVs (n = 19). Far fewer students were categorized as Modern (n = 6) or Traditional (n = 5). The distribution reflects a sample that leans toward more pluralistic and interpretive epistemic orientations, with comparatively few students holding strictly modernist or traditionalist WVs. This imbalance is important context for interpreting the hierarchical regression results, particularly for competencies where WV categories contributed minimal explanatory power.

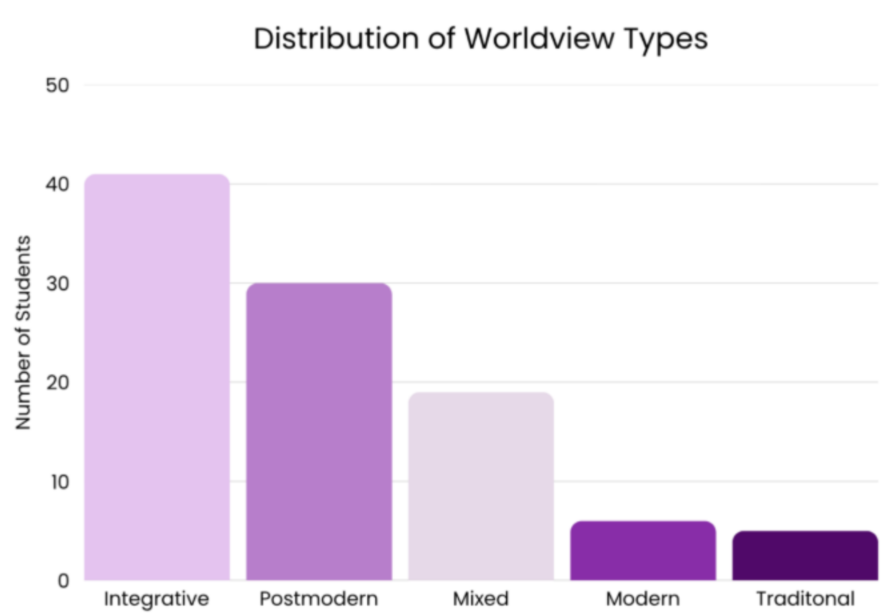

Figure 6.1. Distribution of student WV types. The sample was predominantly Integrative (n = 41) and Postmodern (n = 30), with fewer students classified as Mixed (n = 19), Modern (n = 6), or Traditional (n = 5).

Visual Literacy, Worldview, and Climate Change Literacy

We conducted a series of hierarchical multiple regressions to examine how demographics (Model 1), WV group (Model 2), and VL (Model 3) contributed to performance on each of the five CCL competency composites. Table 6.2 presents a consolidated overview of these analyses, including unstandardized regression coefficients (B), significance indicators, and model-level changes in explained variance (R^2 and ΔR^2). The table is structured to allow side-by-side comparison across competencies and models, with rows corresponding to each predictor and columns representing the three hierarchical steps.

Table 6.2. Hierarchical Regression Model Results for CCL ~ D + WV + VL

Independent Variables	Model 1 CCL ~ Demographics					Model 2 CCL ~ Demographics + WV					Model 3 CCL ~ Demographics + WV + VL				
	Und.	**Eval.**	**Com (Visual)**	**Com (Freq)**	**Dec.**	**Und.**	**Eval.**	**Com (Visual**	**Com (Freq)**	**Dec.**	**Und.**	**Eval.**	**Com (Visual)**	**Com (Freq)**	**Dec.**
Step 1: Demographics															
Intercept	.21	.11	-.01	**-.43***	0.18	0.16	.18	.18	-.74	-.58	-.46	.00	-.30	-1.23	-1.08
Pre KA	**.04***	.18	.01	.02	.03	**.04***	.02	.04	.1	.13	.03	.2	.04	.03	.12
Program (UG)	**-.59*****	.08	.05	**.50***	0.04	**-.63*****	.00	.01	.45	.07	**-.62*****	.01	.02	.46.	.08
Major (Non-Science)	-.09	-.28	.27.	.00	**-.40***	-.08	-.26	**.33***	.01	**-.42***	-.09	-.26	**.33***	.01	**-.42***
Format (O)	**-.30***	.34	.18	-.12	-.39.	**-.33***	.41	.14	-.14	-.43	**-.35 ***	.41	.14	-.14	-.43.
Republican	-.18	.69	-.19	.85.	**-.98***	-.07	.63	-01	**1.07***	-.54	-.02	.64	-.07	**1.11***	-.5
Independent	-.22	.04	-.25	.24	.14	-.25	-.03	-.28.	.24	.21	-.20	-.02	-.25	.27	.24
Other	.01	.03	-.25	.44	.15	.03	.12	-.25	.46	.08	.09	.13	-.23	.49	.11
Step 2: Worldview															
Modern						-.11	.26	-.61	.13	.49	-.13	.28	-.65	.1	.45
Postmodern						.16	-.10	-.13	.46	**.77***	.15	-.11	-.15	.44	.75
Integrative						-.04	-.45	-.23	.23	**.93***	-.02	-.44	-.23	.25	**.94***
Mixed						.13	-.32	-.09	.37	.68	.11	-.32	-.08	.37	.69.
Step 3: Visual Literacy															
VL Score											**.02***	.00	.01	.01	.01
R^2	.59	.12	.1	.15	.3	.62	.14	.16	.17	.36	.65	.14	.18	.17	.36
Adj R^2	.55	.04	.02	.08	.24	.55	.02	.04	.05	.26	.58	.00	.04	.04	.26
ΔR^2	—					.02	.03	.06	.02	.06	**.03***	.00	.02	.01	.01
ΔF	—					.96	0.48	1.24	.35	1.46	**5.75***	.07	1.5	.52	.91

* $p < .05$
** $p < .01$
*** $p < .001$

CCL Understanding

The first set of regressions examined predictors of students' conceptual understanding of CC. As shown in Table 6.2, Model 1 (demographics only) explained a substantial portion of the variance in Understanding scores ($R^2 = .59$). Within this baseline model, program and course format were significant predictors: UG scored lower than G students, and O students scored lower than IP students. Pre-course climate knowledge was also a small but significant positive predictor.

Adding WV groups in Model 2 did not produce a significant improvement in model fit ($\Delta R^2 = .02$, n.s.), and none of the WV coefficients reached significance, suggesting that WV clusters alone did not explain additional variance in conceptual understanding beyond demographics and prior knowledge.

In Model 3, the addition of VL produced a statistically significant improvement ($\Delta R^2 = .03$, $p < .05$). VL emerged as a significant positive predictor, indicating that students with stronger visual-interpretation skills also demonstrated stronger climate-change conceptual understanding. Overall, Understanding was the competency most strongly predicted by the full set of demographic and cognitive variables.

CCL Evaluate

Hierarchical regressions predicting Evaluation scores are also summarized in Table 6.2. Model 1 accounted for relatively little variance ($R^2 = .12$), and none of the demographic variables emerged as significant predictors. Adding WV groups in Model 2 did not improve model fit ($\Delta R^2 = .03$, n.s.), and none of the WV groups contributed significantly to students' ability to critique and assess climate information.

Model 3 introduced VL, but the addition of VL did not meaningfully change predictive power ($\Delta R^2 = .00$, n.s.). Across all three models, no predictors reached conventional levels of significance. These results suggest that Evaluation competency was comparatively stable across student demographics, political orientations, WVs, and visual-literacy levels.

CCL Communicate (Visual)

Model 1 explained a modest amount of variance ($R^2 = .10$), with no demographic variables achieving significance. After adding WV groups in Model 2 ($\Delta R^2 = .06$, n.s.), one demographic variable, major, became significant: non-science majors showed higher visual-communication scores. Additionally, Modern WVs showed a marginal negative trend, indicating slightly lower visual-communication scores for students in this group.

Model 3 incorporated VL, but the addition of VL did not meaningfully improve prediction ($\Delta R^2 = .02$, n.s.). While VL was positively associated with scores, the effect did not reach statistical significance. Overall, Visual Communication showed only minimal relationships with student characteristics, WV groups, or cognitive skills.

CCL Communicate (Frequency)

Model 1 explained a moderate proportion of variance ($R^2 = .15$). Republican political orientation was associated with higher reported communication frequency.

Adding WV groups in Model 2 did not improve the model ($\Delta R^2 = .02$, n.s.), and no WV category emerged as a significant predictor. In Model 3, VL again did not add explanatory power ($\Delta R^2 = .01$, n.s.) and was not itself a significant predictor.

The one consistent result across models was that Republican-identified students communicated about CC more often than Democrat-identified students, though this was significant only in Model 2. Otherwise, communication frequency appeared only weakly related to the measured demographic, WV, or literacy variables.

CCL Decisions

Model 1 explained a moderate portion of variance ($R^2 = .30$). Non-science majors and Republican-identified students both scored lower on Decisions. Format (online vs. in-person) showed a marginal negative trend.

Model 2 significantly improved model fit with the addition of WV variables ($\Delta R^2 = .06$). Specifically, Integrative WV groups were positively associated with higher decision-making scores. This competency was the only one in which WV clusters contributed meaningfully above and beyond demographics and political identity.

In Model 3, VL did not significantly increase predictive power ($\Delta R^2 = .01$), nor was VL a significant individual predictor. Thus, decision-making was shaped primarily by major, political orientation, and WV.

Across all five CCL competencies, demographic variables played a stronger role in predicting performance than WV or VL. WV provided meaningful contributions only for Understanding and Decisions. VL contributed unique predictive value only for CCL Understanding, although the effect was modest. The Evaluate competency was not predicted by any demographic, WV, or VL variable, suggesting that different mechanisms may underlie evaluative reasoning in climate contexts.

DISCUSSION

This study examined whether worldview (WV) meaningfully shapes the relationship between visual literacy (VL) and climate change literacy (CCL), building on the preceding dissertation chapter that demonstrated a string association between VL and CCL Understanding (see Chapter 5). While the broader literature has long suggested that WV influences how individuals attend to, interpret, and act upon climate information, often shaping both scientific reasoning and public engagement, few empirical studies have tested these relationships within formal educational settings or in relation to visual-interpretive skills (Aksit et al., 2018; Kahan et al., 2012). Overall, the results indicate that while demographics continue to exert substantial influence across several CCL competencies, WV contributed meaningfully only in select areas, and VL's influence appears largely domain-specific rather than generalizable across the full set of CCL competencies.

Visual Literacy and Demographics: A Confirmatory Pattern

Consistent with the findings of the previous dissertation chapter (Chapter 5), VL uniquely predicted conceptual understanding of CC even after controlling for demographics and WV. This pattern reinforces arguments that VL is an essential cognitive tool for navigating an increasingly image-saturated scientific and media landscape and that visual representations play a critical role in shaping accurate understanding of CC (Arslan et al., 2012; Mooseder et al., 2023). Importantly, the VL effect emerged only for Understanding and not for the other four CCL competencies. This suggests that VL may be most influential for cognition-forward tasks that rely on constructing, refining, and applying conceptual knowledge. Other competencies may instead draw on affective, dispositional, or sociocultural factors not captured by VL measures.

Demographic factors emerged as the most consistent predictors across competencies. This finding reinforces existing evidence that CCL and beliefs, can be shaped by media use, prior knowledge, and sociopolitical identity (Hornsey et al., 2016; Rosenthal, 2022; Shwom et al., 2017; Zummo, 2023). Particularly notable is the robust gap between undergraduate and graduate students in Understanding and between science and non-science majors in Decisions, suggesting that both disciplinary exposure and academic maturity influence how students process and make choices with climate information.

Worldview Distribution in the Sample

Students in this sample represented all the WV orientations of the IWF, though the distribution was uneven. The predominance of Integrative and Postmodern orientations aligns with the idea that students choosing to take this course are self-selecting and display higher CC concern (De Witt et al., 2016). The comparatively small number of Modern and Traditional students, however, provides additional context. Although the hierarchical regression models include five categories, estimates for low-frequency groups may be less stable and less representative of broader patterns. This distributional imbalance likely contributed to the limited explanatory power of WV variables from the IWF alone, for this study population, in looking at several competencies (Bogert, 2024).

Role of Worldview Across Competencies

Contrary to expectations and much of the climate-communication literature, WV did not significantly shape students' capabilities in Evaluation, Visual Communication, or Communication Frequency. In these areas, demographic variables, especially major, political identity, and course format, were more influential than underlying WV. This may reflect the structured nature of classroom instruction, where students are engaging with climate content in ways that remove differences in their WVs (Aksit et al., 2018). Evaluation showed no meaningful predictors at all, likely due to the highly skewed responses from participants (see Chapter 5).

Neither WV nor VL predicted Visual Communication or Communication Frequency. However, WV did play a significant role in CCL Decisions. Students with Integrative and

Postmodern orientations made stronger climate-related decisions, even after accounting for demographic factors. This pattern aligns with theoretical expectations that postmodern and integrative anthological frameworks may promote openness to complexity, systems thinking, and multiple lines of evidence, all of which contribute to self-efficacy of decision-making in CC contexts (De Witt et al., 2016). In contrast, students with more rigid or hierarchical orientations (e.g., Modern, Traditional) may rely more heavily on fixed assumptions or perceived authority structures when approaching climate issues, potentially constraining adaptive decision-making.

Limitations

The uneven distribution of WV categories likely reduced statistical power for detecting effects among less-represented groups (Harrell & Levy, 2022). Additionally, the VL measure captured students' interpretive skills but not their communicative design abilities, which may explain the limited relationships with Communication competencies.

Implications

These findings complicate commonly asserted narratives about the dominance of WV in CC education (da Rosa, 2022; Stevenson et al., 2014; Zummo, 2023). Our results support a more nuanced interpretation of the importance of WV in explaining university students' CCL. VL predicts conceptual climate understanding, but its influence does not generalize across all facets of climate literacy. WV influences certain action-oriented competencies (Decisions), but not comprehension, evaluation, or communication focused tasks. When considering the design of CC educational strategies, these patterns suggest that developing students' VL skills remain an essential strategy for strengthening CC understanding but may not directly improve communication or evaluative behavior. Similarly, addressing WV differences may be most critical when instruction involves higher level CCL decision-making. Together, these insights point toward the need for multi-component CC curricula that separately target conceptual, evaluative, communicative, and decision-oriented learning pathways. Future research could incorporate more nuanced measures of WV and consider qualitative methods including conducting interviews to better inform the complexities of individual WV.

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CHAPTER 7 – GENERAL OVERVIEW

Literacy includes the skills and abilities to understand information, as well as make informed decisions and contribute meaningfully to the subject (Norris & Phillips, 2003). This dual orientation is foundational to both visual literacy (VL) and climate change literacy (CCL). This dissertation examined climate change education (CCE) across contexts, and it was clear that visual forms of information help learners make sense of CC. Yet, the opportunities for learners to contribute to the visual and communicative landscape of climate learning are often limited, as I found in all of my studies. Making meaning of CC requires interpreting a range of visual representations, but addressing CC in our society requires communicating ideas (i.e. generating new images), and making decisions based on knowledge, evidence, and values. As shown in (Figures 2.6 and 2.7), the skills and competencies that make up VL and CCL can be organized into Consumer (readerly roles) and Contributor (writerly roles), each aligned using Bloom's cognitive taxonomical rankings (Bloom et al., 1956; Duffy et al., 2019). Used as a conceptual foundation throughout the dissertation, I apply the framework in this final chapter to discuss major findings, implications, and directions for future research.

VL AND CCL CONSUMER

Visuals to support conceptual understanding

CC is often taught through images. Students encounter diagrams of the greenhouse effect, graphs of climate scenarios, maps of drought, photographs of climate impacts, and memes making light of it all (Boykoff & Osnes, 2019; O'Neill & Smith, 2014). The systematic review in Chapter 2 revealed that the use of images and visual activities is ubiquitous across CCE interventions. Most often, students engaged with visuals to develop their CCL Understanding, particularly of the Science and Impacts of CC (Figure 2.8). Students become skilled in decoding representations of the physical science of CC yet receive fewer structured opportunities to engage with the social dimensions, local contexts, or solution pathways that are equally necessary for a holistic understanding. A more balanced approach would integrate CC content more intentionally.

Structuring content as Simple, Serious, Solvable

The Simple, Serious, Solvable (S3) framework provides one pathway to balanced instruction. As explained in Chapter 3, this design helps learners build from the mechanisms to the impacts and finally consider solutions while maintaining conceptual coherence. We saw in the learning outcomes evaluated in Chapter 5, that this structure was beneficial for improving CC knowledge (Figure 5.4). How each of these units is presented visually is also important. We found that students had observed preferences for particular images depending on the S3 unit (Figure 5.9).

For Simple, they gravitated toward graphs and diagrams. The preference for scientific visualizations when presenting the mechanisms of CC, suggests a connection to the images they are accustomed to seeing and mimic the same language they learn the topic in. When explaining CC impacts in Serious, they preferred memes and comics. The increased choice of memes for the Serious unit may indicate the power of humor in facing the anxiety-producing evidence they encountered (Boykoff & Osnes, 2019). As they progressed into considering solutions, they often chose photographs. We believe this suggests an interest in seeing solutions as more tangible and approachable.

These patterns show that students intuitively match visual genres to the varying cognitive and emotional needs that they encounter for different aspects of CC (Duan & Bombara, 2022).

This is an opportunity for educators to better engage students by using different types of images. However, students should not only be presented with a range of images, but also receive instruction to properly engage with the visuals (i.e. develop their VL).

Climate education is highly visual, so students need VL

Explicit instruction to develop the VL skills necessary is remarkably rare. There is repeated evidence that at every level of CCE, like other scientific disciplines, educators are assuming that students have either already developed these skills or will do so as on their own (Avgerinou & Ericson, 1997; Offerdahl et al., 2017). However, this has been shown to not be the case. For example, even early-stage science graduate students often have difficulty representing data in ways that are both scientifically accurate and clearly communicated (Timmerman et al., 2013)

While reading and creating visuals (e.g. graphs) and science communications are part of expected science educational competencies (AAAS, 2011; NGSS 2013), there is little evidence that developing the skills to do this are being scaffolded in classrooms, particularly for the disciplinary-specific discourse of CC. Like all science disciplines, CC has its own visual language that requires educational structuring (Walsh, 2015).

As evidenced in this dissertation, VL skills are vital to developing Consumer CCL. Across learner populations, higher VL was associated with stronger conceptual understanding of CC mechanisms, impacts, and solutions (Chapter 5). This raises a critical question. If visual literacy supports conceptual learning, why are these skills not systematically taught in CCE?

Educators as Consumers

Educators (PK-20) play a pivotal role in mediating how students develop VL. However, these skills are often not taught because teachers themselves do not feel they have high levels of

VL (Huilcapi-Collantes et al., 2020). This is reflective of teacher education programs having the same deficits in building VL skills observed in other science curricula (Aberšek, 2008). Simultaneously, teachers have been found to feel ill-prepared to teach CC. This may be because they do not understand the science or because they do not have an established curriculum (Wise, 2010). Additionally, they may be feeling pressure teaching such a politicized topic (Plutzer et al., 2016; Scheer et al., 2025). These deficits sought us to investigate how teachers conceptualized and visually representing CC info. We looked at the differences between in-service and pre-service teachers to help elucidate how experience and different levels of training (teacher education prep vs PD) may affect their conceptions.

VL AND CCL CONTRIBUTOR

Educators as Contributors

The drawing-to-learn activity in chapter 4 revealed that teachers bring different perspectives to their visual representations of climate change. In-service teachers with more classroom experience often showcased richer, more contextualized representations that included people, communities, and climate solutions. Their drawings conveyed CC as a phenomenon that affects both ecological systems and human systems, and they made use of multiple visual strategies to communicate complexity. In contrast, early-career teachers tended to produce more abstract, global, and mechanistic depictions of climate change. Their images often reflected textbook-style representations and demonstrated a degree of psychological distance from human and local impacts (Duan & Bombara, 2022). These differences demonstrate how experience shapes both the content teachers emphasize and the representational strategies they use.

This pointed to an opportunity for teacher education and professional development programs to better meet the needs of teachers. If teachers are to guide students toward holistic climate literacy, they need opportunities to engage with diverse representational forms and to reflect on their own visual and conceptual assumptions. Because teachers shape the learning environment, professional development and teacher education becomes essential to affecting student CCL as what teachers know and believe directly affects classroom learning (Herman et al., 2017; Hestness et al., 2014; McCaffrey & Buhr, 2008). Research indicates that high-quality professional development can support teachers in both refining their own visual literacy and adopting pedagogies that make visual reasoning explicit for students (Huilcapi-Collantes et al., 2020). The results of this drawing activity also highlighted the power of having learners take on the role of VL and CCL Contributors.

Students need opportunities to act as visual contributors

For students, designing and creating visuals provides potential to develop from being CCL Consumers, to developing the higher-order skills of CCL Contributors. The systematic review identified examples where visual production supported communication and engagement. These activities align with research on multimodal learning and drawing-to-learn frameworks, which emphasize that generating drawings and conceptual models helps learners organize and express their ideas (Chang et al., 2020; Edlund & Balgopal, 2021). Students who created outreach materials, built environmental models, or documented their experiences through photo journaling also demonstrated increased investment in climate issues and a deeper sense of agency (Burkholder et al., 2017; Rooney-Varga et al., 2014; Stafford & Brain, 2022). This suggests that these Contributor activities may lead to students reflecting on their assumptions, values, and worldviews.

In Chapter 6, we found that worldview (WV) did not strongly predict conceptual learning, but it potentially played a role in CCL decision-making. Students with Integrative

WVs, were more likely to show high self-efficacy in acting on CC. This suggests that climate action, even within educational contexts, is shaped by epistemic commitments and value systems (De Witt et al., 2016). Building CCL Contributor competencies therefore requires supporting learners not only in interpreting visuals or producing representations, but also in reflecting on their WV (Dupigny-Giroux & Cole, 2018; Harold et al., 2016). Visual production may provide avenues for such reflection, but educational interventions must be designed to address the deeper orientations that support climate-related action.

A notable limitation of the VL intervention in Chapter 5 was that students were not required to create or design any visuals. While they did have the opportunity to do so, all but one student chose to use existing images for the submission component of the intervention. I believe this speaks to the higher-order task requirement of the VL Create skill, and the increased cognitive load of this activity (Bloom et al., 1956). Additionally, I believe this may be a reason there was only statistical significance revealed for VL score and CCL Understanding. However, this provides an opportunity for future research.

FUTURE RESEARCH DIRECTIONS

Investigating motivations to communicate on social media

Our media environment is such that students hold powerful potential to be agents of change in their social circles. With the rise of social media, anyone can be a CC communicator. Analyzing motivations behind students' intentions to communicate about climate issues using visuals can help inform educators and communicators on ways to engage these young adults. Understanding these dynamics can also help educators design visual learning experiences that support both CCL and CC engagement.

Expanding conceptualizations of worldview

Future research should incorporate more comprehensive and qualitative approaches to worldview. While the Integrative Worldview Framework provided valuable insights, additional constructs such as individualism, hierarchy, egalitarianism, and communitarianism may reveal more nuanced relationships between WV and climate reasoning (da Rosa, 2022). Interviews and additional drawing-based elicitation may deepen our understanding of how WV shapes climate interpretations.

Studying students beyond climate-focused courses

Because this dissertation focused on students who chose to enroll in these climate courses, future research should examine visual and climate literacies in broader educational contexts. Initiatives like Climate Across the Curriculum emphasize that climate education should permeate all academic disciplines (Molthan-Hill et al., 2025). Understanding how VL and CCL are developed for a wider, more diverse student audience could provide additional insights.

CONCLUSION

Across this dissertation, VL emerged as an essential foundation for developing CCL. Learners rely on visuals to interpret the scientific mechanisms, understand impacts, and imagine solutions. Yet CCE too often treats visuals as transparent rather than as complex representational systems that require explicit instruction. At the same time, becoming a CCL Contributor demands more than interpretive skills. It requires opportunities for learners to generate visuals, to communicate, and to reflect on their values and WV to make informed decisions.

The work presented here demonstrates that integrating VL with CCL fosters deeper engagement, stronger conceptual understanding, and greater communicative capacity. As climate change intensifies, educators and researchers must prioritize approaches that support learners as both consumers and contributors of climate knowledge. Doing so will help cultivate a more informed, empowered, and resilient public capable of confronting the challenges of a changing planet.

APPENDICES

5.1 VISUAL LITERACY INTERVENTION

Images

Simple

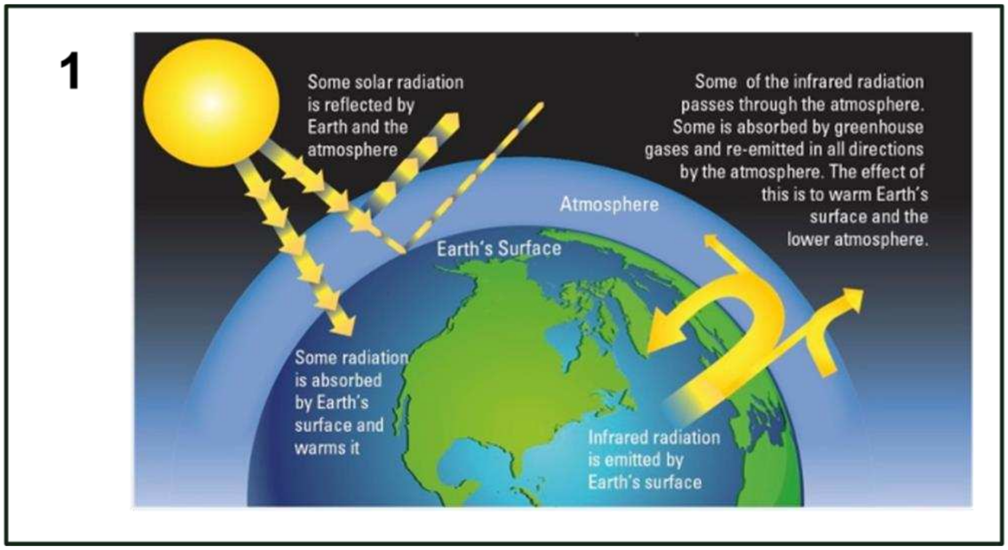

Figure A5.1.1. Scientific Diagram/Graph presented in the visual literacy intervention in the Simple Unit. Source: *Earth's Greenhouse Effect*. United States Environmental Protection Agency. https://www.epa.gov/sites/default/files/styles/huge/public/2021-04/earths_greenhouse_effect_us_epa_20121.png?itok=CQmcvb-W

2

Figure A5.1.2 Photograph presented in the visual literacy intervention in the Simple Unit
Source: The Conversation. (2019). Climate explained: how much of climate change is natural? How much is man-made? Retrieved from https://theconversation.com/climate-explained-how-much-of-climate-change-is-natural-how-much-is-man-made-123604.

3

Figure A5.1.3 Meme/Comic presented in the visual literacy intervention in the Simple Unit
Source: #climemechange on Instagram

Serious

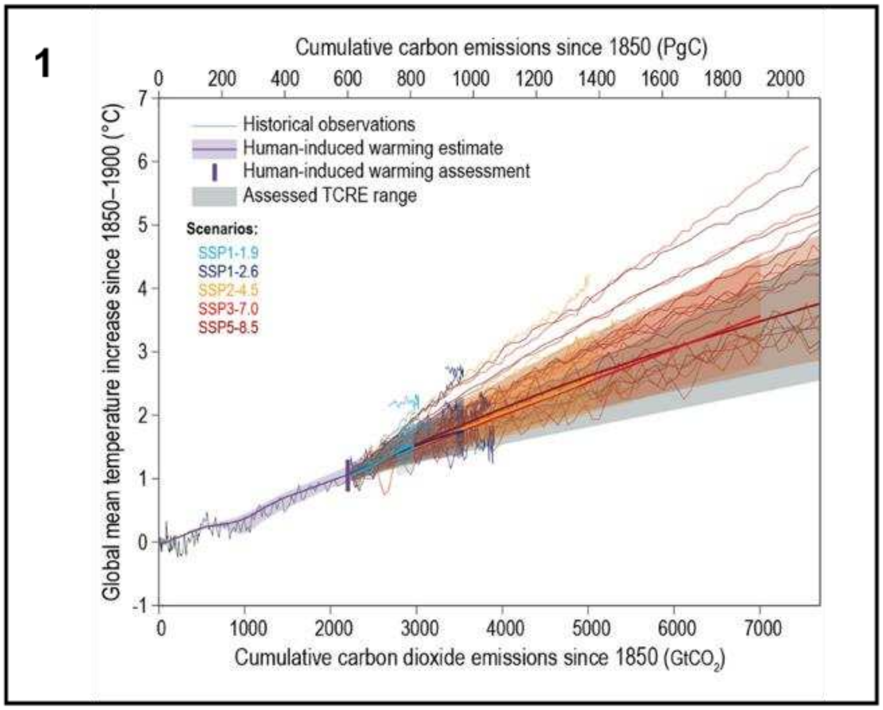

Figure A5.1.4 Scientific Diagram/Graph presented in the visual literacy intervention in the Serious Unit
Source: *The Trump Team Has a Plan to Not Fight Climate Change*. (2020). WIRED The Trump Team Has a Plan to Not Fight Climate Change. https://www.wired.com/story/the-trump-team-has-a-plan-to-not-fight-climate-change/

Figure A5.1.5 Photograph presented in the visual literacy intervention in the Serious Unit
Source: Washington Post. (2020). California wildfires burn 771,000 acres in one week, killing 5 and degrading air quality. Retrieved from https://www.washingtonpost.com/weather/2020/08/20/california-wildfires-evacuations/.

Figure A5.1.6 Meme/Comic presented in the visual literacy intervention in the Serious Unit
Source: @Queersatanic Instagram, 2021 https://www.instagram.com/p/CQd3e1xBS2l/

Solvable

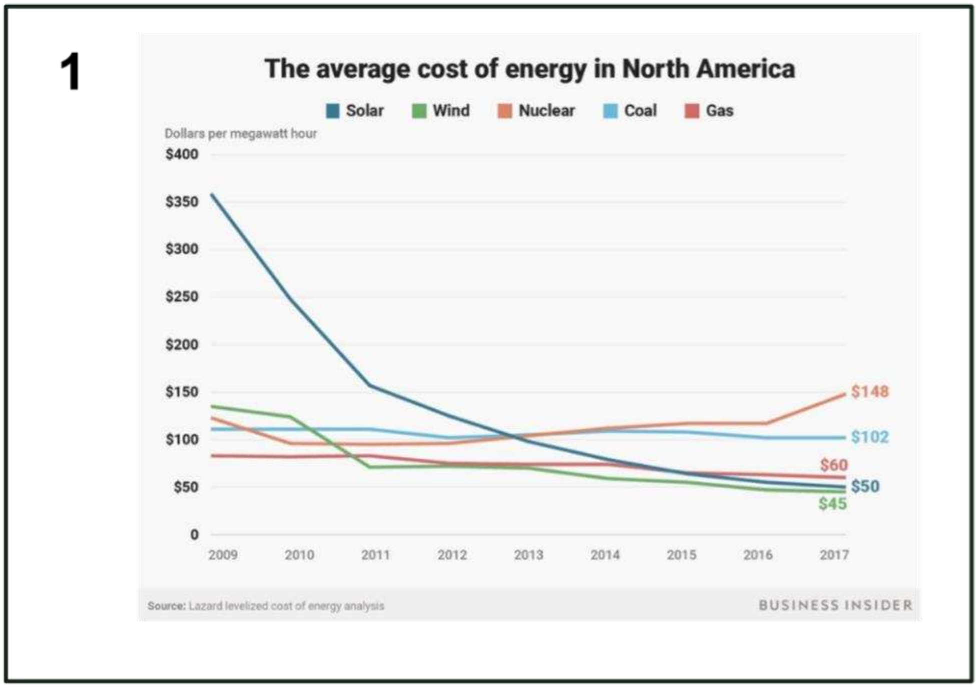

Figure A5.1.7 Scientific Diagram/Graph presented in the visual literacy intervention in the Solvable Unit
Source: Business Insider. (2018). *One simple chart shows why an energy revolution is coming — and who is likely to come out on top*. Retrieved from https://www.businessinsider.com/solar-power-cost-decrease-2018-5.

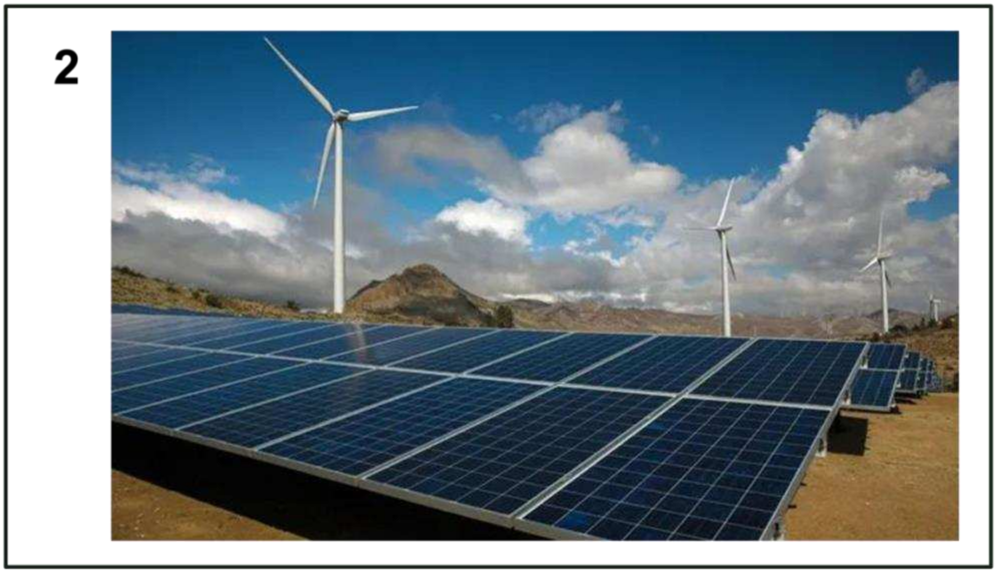

Figure A5.1.8 Photograph presented in the visual literacy intervention in the Solvable Unit
Source: NPR. (2022). *California just ran on 100% renewable energy, but fossil fuels aren't fading away yet*. Retrieved from https://www.npr.org/2022/05/07/1097376890/for-a-brief-moment-calif-fully-powered-itself-with-renewable-energy.

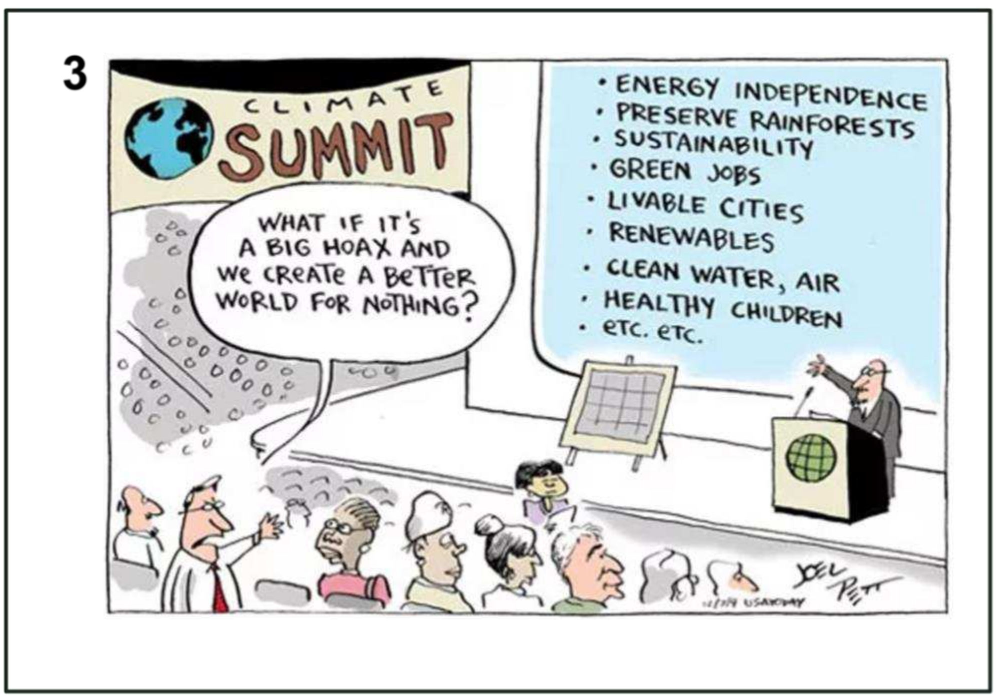

Figure A5.1.9 Meme/Comic presented in the visual literacy intervention in the Solvable Unit
Source: Reddit (2011) What if we create a better world for nothing? (Cartoon)
https://www.reddit.com/r/energy/comments/f0omd/what_if_we_create_a_better_world_for_nothing/

Questions

Review the three images. If you wanted to explain to a friend or family member why understanding climate science and change is "*(simple, serious, or solvable)*", which image would you choose to help you explain this?

Choose one of the three images below and answer the following questions.

1. Which image did you select? Please explain in as much detail as possible why you chose this image.
2. How would you interpret this image? Please use as much detail as possible in your description. There is no right or wrong answer.
3. How would you explain this image to your friend or family member if you were discussing climate change?
4. Would you share this image with your friends and/or family on social media? Why or why not?
5. How do you think this image represents climate change as "*simple*"? Please explain what concepts from the Simple Unit are represented in this image.

5.2 VISUAL LITERACY CODEBOOK

Table A5.2.1. Visual Literacy Codebook and Scoring

Visual Literacy Skills	**General Description**	**Complete (3)**	**Incomplete (2)**	**Low (1)**	**Missing (0)**
Recognize	How many of the symbols and mechanistic parts of the image are mentioned (>1 relevant features: RR; =1 relevant features: R; mistakes/missing: M). This can includes mentioning the type of image (meme/comic, photograph, video, diagram/graph, etc.) but just saying "image" would not count and only account for this once even if they identify the different images. Includes description of the layout of the image. For the memes/comic, humor can be included as a relevant feature. Mentioning captions/text/written descriptions.	Accurately identifies >1 relevant visual features and/or symbolic elements of BOTH images (RR/RR); OR accurately identifies >1 symbols for one image, but only 1 symbol for the other (RR/R)	Accurately identifies only 1 feature or symbolic element in BOTH images (R/R); OR identifies >1 symbols on one image, but misidentifies or inaccurately describes symbols in another (RR/M); OR If there is at least one correct identification for each image and there are some additional misidentifications present for both (RM/RM)	Accurately identifies 1 feature or symbol for at least 1 of the images with the other missing OR completely misidentified (R/M)	Does not mention symbolic elements or only misidentifies for either of the images (M/M)
Interpret	How scientifically accurate (mistakes /missing: M) and in-depth (describes a majority of the message of the image; ID) or superficial (only describes part of the image message (a minority of the total elements); S) the description of the image is using discipline relevant language.	Fully accurate and clear description that mentions majority (3 or more) of elements of the image message and how they are being represented in the image using relevant disciplinary language for BOTH images (ID/ID)	Descriptions are present and accurate, but lacking in depth (only a few (less than half) elements mentioned) for BOTH images (S/S), with no mistakes; OR 1 description is clear and in-depth, but the other is superficial (ID/S); OR 1 description is clear and in-depth, but has minor mistakes and the other is superficial, but without mistakes (IDM/S); OR 1 description is clear and in-depth with no mistakes, and the other is superficial with minor mistakes (ID/SM); or both descriptions are in-depth, but one has minor mistakes (IDM/ID)	BOTH descriptions are in-depth AND have mistakes (ID M/IDM); OR BOTH have mistakes, but one is in-depth and the other is superficial (IDM/SM); OR both are simple, and one has a mistake (S/SM)	BOTH descriptions are superficial AND factually incorrect; OR both descriptions are missing (SM/SM)
Analyze	How well they make disciplinary connections (applications) beyond just the	BOTH descriptions make connections beyond the	BOTH images make connections beyond the image, but only	Only one makes connections beyond and with the unit	No broader connections not unit

	content of image itself (B) (mentioning factors that are not visually present in the image, but they accurately make connections to). And how it is relevant to the unit topic and overall course (U) (they mention relevant class topics in the appropriate unit).	message of the image AND explicitly mention unit topics (BU/BU)	one makes unit connections or the unit connections made are incorrect (BU/B; BU/BM; BUM/B); OR BOTH make unit connections, but no connections beyond (U/U); OR Both make connections beyond but no unit connection (B/B); OR Both make unit connections, but only one makes connections beyond the image (BU/U; BUM/U; BU/UM); OR Only one makes connections beyond, and the other makes unit connections (B/U; BM/U; B/UM)	(BU/M) and the others are missing/incorrect; OR only one makes unit connections and the others are missng/incorrect (U/M); OR only one makes connections beyond (B/M)	connections (purely descriptive) or all are incorrect. (M/M)
Evaluate	Justification (J) of their choice in image for whatever relevant reason (e.g. easy to read, most relevant). Consideration of their audience (A) (specifically mention others in a context of communicationg; if they just mention others or use "we" if not in the context of understanding a message, then not an A).	Thorough, well-reasoned justification that explains why image effectively communicates concept AND explicitly considers audience for BOTH images (JA/JA)	Clear justification for both images, but no audience acknowledgement (J/J). OR clear consideration of audience for both images, but missing justification for one of the images (JA/A); OR justification for both, but only one has audience acknowledgement (JA/J)	BOTH mention audience, but no justificaion (A/A); Only one justification and one audience acknowledgement amongst both (J/A; JA/M) - in the case where the justification and/or audience is explicitly acknowledged as the same for both images, treat the same as if they were given independently.	No justification nor audience acknowledgement (M/M)
Find	Whether or not student was able to find and upload an image with a working link. If they decide to use the same image as mine, mark as 0 for Find, but grade the Use as CRR. If the link included does not work, mark as M (for IRR, these will likely all be working links)			Meets assignment requirements; visual is accessible (F)	Does not meet requirements or missing. (M)
Use	Clarity (C = clear & UC = unclear) of the image and the level of which the image and is related to CC in general (R) (relates to climate change in another unit; e.g. in the Simple	Image is clear and specifically relevant to the unit topic (CRR)	Image is clear and relevant to the topic (CR)	Image is clear and irrelevant (CIR)	Image is unclear, and by default, irrelevant (UCIR)

	unit intervention using an image of wildfire, which is Serious) or specifically represents the unit concept (RR); or irrelevant (IR). C is required for any R to apply				
Create	Whether or not the student created their own/adapted or used a pre-existing visual. Binary coding of whether they specified that their image was made (D) or if they just uploaded an image or provided a link (L)			Demonstrates effort and/or originality; image purposefully created or adapted to support understanding. (D)	Image was not an original creation or adaptation (L)

5.3 CLIMATE CHANGE KNOWLEDGE ASSESSMENT

Aksit, O., McNeal, K.S., Gold, A.U., Libarkin, J.L., & Harris, S. (2018). The influence of instruction, prior knowledge, and values on climate change risk perception among undergraduates. *Journal of Research in Science Teaching*, *55*(4), 550-572. doi: 10.1002/tea.21430

Correct Answers are marked in bold.

1. Which is the best definition of a positive feedback loop in the climate system?
   A. A change in the climate system leads to a response that benefits climate change.
   B. A change in the climate system leads to a response that slows down climate change.
   C. A change in the climate system leads to a response that speeds up climate change.
   D. A change in the climate system leads to a response that harms climate change.
   E. I do not know.

2. Which of the following will occur if the amount of ice floating in the ocean decreases?
   A. More sunlight will be reflected back into space and Earth's temperature will decrease.
   B. Less sunlight will be reflected back into space and Earth's temperature will increase.
   C. More sunlight will be reflected back into space and Earth's temperature will increase.
   D. Less sunlight will be reflected back into space and Earth's temperature will decrease.
   E. I do not know.

3. Which of the following contributes to the transfer of thermal energy from place to place around the Earth?
   A. The movement of ocean water but not the movement of air.
   B. The movement of air but not the movement of ocean water.
   C. Both the movement of ocean water and the movement of air.
   D. Neither the movement of ocean water nor the movement of air.
   E. I do not know.

4. How does sunlight affect temperature on Earth?
   A. Sunlight warms the air directly, but the air does not warm the land.
   B. Sunlight warms the land directly, but the land does not warm the air.
   C. Sunlight warms the air directly, and the air warms the land.
   D. Sunlight warms the land directly, and the land warms the air.
   E. I do not know.

5. Which of the following is the best definition of a greenhouse gas?
   A. An atmospheric gas that is produced as plants grow.
   B. An atmospheric gas that absorbs infrared radiation.

C. An atmospheric gas that produces acid rain.
D. An atmospheric gas that absorbs ultraviolet radiation.
E. I do not know.

6. How has the amount of carbon dioxide in the atmosphere changed since the start of the Industrial Revolution 150 years ago?
   A. The amount of carbon dioxide has remained the same.
   B. The amount of carbon dioxide has decreased.
   C. The amount of carbon dioxide has increased.
   D. I do not know.

7. Which of the following best describes how plants take in carbon dioxide?
   A. Plants take in carbon dioxide from rain.
   B. Plants take in carbon dioxide from sunlight.
   C. Plants take in carbon dioxide from air.
   D. Plants take in carbon dioxide from soil.
   E. I do not know.

8. Which of the following would most likely occur if the oceans stopped absorbing carbon dioxide?
   A. Carbon dioxide in the atmosphere would remain the same.
   B. Carbon dioxide in the atmosphere would increase.
   C. Carbon dioxide in the atmosphere would decrease.
   D. I do not know.

9. Which is the best description of the differences between climate and weather?
   A. Climate does not change over time, and weather does change over time.
   B. Climate changes over time, and weather does not change over time.
   C. Climate changes over long periods of time, and weather changes over short periods of time.
   D. Climate changes over short periods of time, and weather changes over long periods of time.
   E. I do not know.

10. Which of the following statements about global warming over the past 50 years is most accurate?
    A. Global warming over the past 50 years is slightly due to natural processes and mostly due to human activities.
    B. Global warming over the past 50 years is mostly due to natural processes and slightly due to human activities.
    C. Global warming over the past 50 years is about equally due to natural processes and human activities.

D. Global warming over the past 50 years has not occurred whether due to natural processes or human activities.
E. I do not know.

11. Which of the following statements about air temperature change over the past million years is most accurate?
    A. Air temperature change over the past million years is slightly due to natural processes and mostly due to human activities.
    B. Air temperature change over the past million years is mostly due to natural processes and slightly due to human activities.
    C. Air temperature change over the past million years is about equally due to natural processes and human activities.
    D. Air temperature change over the past million years has not occurred whether due to natural processes or human activities.
    E. I do not know.

12. Which is the most common form of radiation given off by the Sun?
    A. The Sun mostly gives off visible radiation.
    B. The Sun mostly gives off infrared radiation.
    C. The Sun mostly gives off ultraviolet radiation.
    D. The Sun does not give off radiation.
    E. I do not know.

13. How much incoming sunlight do greenhouse gases absorb?
    A. Greenhouse gases absorb almost no incoming sunlight.
    B. Greenhouse gases absorb about half of the incoming sunlight.
    C. Greenhouse gases absorb most incoming sunlight.
    D. I do not know.

14. Which is the most common form of radiation given off by Earth's surface?
    A. The Earth’s surface mostly gives off visible radiation.
    B. The Earth’s surface mostly gives off infrared radiation.
    C. The Earth’s surface mostly gives off ultraviolet radiation.
    D. Earth’s surface does not give off radiation.
    E. I do not know.

15. What do greenhouse gases do?
    A. Greenhouse gases absorb energy emitted by Earth.
    B. Greenhouse gases reflect energy emitted by Earth.
    C. Greenhouse gases reflect energy reflected by Earth.
    D. Greenhouse gases absorb energy reflected by Earth.

E. I do not know.

16. Where will a photon emitted by a greenhouse gas molecule most likely go?
    A. In an upward direction relative to Earth's surface.
    B. In a downward direction relative to Earth's surface.
    C. In a random direction relative to Earth's surface.
    D. I do not know.

17. Averaged over long time periods, how does the amount of energy arriving from space compare to the amount of energy leaving Earth?
    A. The amount of energy arriving from space is greater than the amount of energy leaving Earth.
    B. The amount of energy arriving from space is less than the amount of energy leaving Earth.
    C. The amount of energy arriving from space is roughly equal to the amount of energy leaving Earth.
    D. I do not know.

18. Which of the following could cause the Earth's surface temperature to change? CHOOSE ALL THAT APPLY.
    A. Changes in the tilt of the Earth's axis.
    B. Changes in the reflectivity of the Earth's surface.
    C. Changes in methane concentrations in the atmosphere.
    D. Changes in carbon dioxide concentrations in the atmosphere.
    E. I do not know.

19. Which of the following can be caused by climate change? CHOOSE ALL THAT APPLY.
    A. Climate change can cause food shortages.
    B. Climate change can cause changes in temperature.
    C. Climate change can cause water shortages.
    D. Climate change can cause changes in weather.
    E. I do not know.

20. What information do ice cores from glaciers contain about Earth? CHOOSE ALL THAT APPLY.
    A. Ice cores contain information about Earth's air temperature.
    B. Ice cores contain information about Earth's seasonal precipitation.
    C. Ice cores contain information about Earth's carbon dioxide concentration.
    D. Ice cores contain information about Earth's daily weather events.
    E. I do not know.

21. Which statements about non-greenhouse gases are accurate? CHOOSE ALL THAT APPLY.
    A. Non-greenhouse gases do not absorb a lot of energy given off by the Sun.
    B. Non-greenhouse gases do not absorb a lot of energy given off by the Earth.
    C. Non-greenhouse gases absorb a lot of energy given off by the Earth.
    D. Non-greenhouse gases absorb a lot of energy given off by the Sun.
    E. I do not know.

6.1 INTEGRATIVE WORLDVIEW FRAMEWORK SURVEY

Developed by de Witt, A., de Boer, J., Hedlund, N., & Osseweijer, P. (2016). A new tool to map the major worldviews in the Netherlands and USA, and explore how they relate to climate change. Environmental Science & Policy, 63, 101–112. https://doi.org/10.1016/j.envsci.2016.05.012

These survey questions were given to students enrolled in the undergraduate ecology course (from Chapters 2 and 3)

1. For me, to live a good life is...
    a. ... to support those who are oppressed and dominated
    b. ... to respect the tradition and honor my community
    c. ... to offer my unique 'gifts' to the larger whole of life
    d. ... to be independent and do whatever I enjoy
2. (select)
    a. Who I am is defined by my social position and/or my achievements
    b. I feel part of the vast, interconnected whole that is life and the universe
    c. I feel more like a citizen of the world than a citizen of a country
    d. Who I am is defined by my religion and upbringing
3. The most important thing in my life is...
    a. ... to be successful and have people recognize my achievements
    b. ... to actualize my inner potential and thereby serve the (cultural) evolution of humanity
    c. ... to do things my own way and forge my own path in life
    d. ... to be of service to my family, community, and/or country
4. (select)
    a. Science and technology can make beneficial contributions when society is actively engaged with technological developments
    b. Science and technology are often corrupted by special interests, e.g., of big corporations
    c. One of the negative effects of science and technology is that they break down people's ideas of right and wrong
    d. Science and technology are definitely making our lives healthier, easier, and more comfortable
5. (select)
    a. In an afterlife we will be punished or rewarded for our actions in this life
    b. I don't know what happens to us after we die
    c. I believe that the evolution of our consciousness continues after our death
    d. I don't believe in an afterlife of any form
6. In society...
    a. ... we should place more emphasis on art, culture, and moral development
    b. ... we should have greater respect for religious authority and tradition
    c. ... we should place more emphasis on science and technology
    d. ... we should place more emphasis on inner growth and self-actualization

7. (select)
    a. When individuals thrive and blossom, they naturally start working for a better world for all
    b. Everybody needs to take care of, and stand up for, oneself
    c. Society should offer decent care for every individual
    d. Each individual needs to sacrifice his/her desires to serve the community and society at large
8. (select)
    a. Humans can improve on nature
    b. Aware of their deep connectedness, humans and nature can work together in mutually enhancing ways
    c. When it comes to interfering with nature, mankind has no right to play God
    d. Interfering with nature is risky because it may be too complex for us to understand
9. (select)
    a. God stands far above life on earth
    b. People look at the world from different perspectives, which are all equally valid
    c. Reality is complex: it is both scientific and spiritual at the same time
    d. The universe is governed by mechanical, natural laws
10. (select)
    a. The suffering that happens to people does not have meaning but is random
    b. The suffering that happens to people is the will of God
    c. I use the pain and suffering in my life as opportunities for inner growth
    d. The suffering in the world is created and maintained by existing power structures
11. When I'm forming an opinion on an issue...
    a. ... I tend to trust scientists and other experts
    b. ... I tend to trust my own judgment, feelings, and intuition
    c. ... I tend to trust traditional or religious leaders
    d. ... I try to honor all perspectives and combine them into a larger whole
12. (select)
    a. Science is the ultimate source of trustworthy knowledge
    b. Morality, art, and intuition are important for gaining knowledge about the world
    c. We depend too much on science and not enough on faith
    d. In order to gain understanding of the world, science needs to be integrated with other forms of knowledge, such as spiritual insight
13. (select)
    a. Things in nature are generally more perfect than those made by humans
    b. On a deep level, I feel like I am one with nature
    c. Humans should behave as protectors of creation
    d. By mastering nature, the human being can find freedom
14. I strive for...
    a. ... a sober, simple, and humble lifestyle
    b. ... a wholesome and natural lifestyle
    c. ... a diverse and expressive lifestyle
    d. ... a comfortable and fun lifestyle
15. (select)

    a. Life was miraculously created by a higher power
    b. How life originated is still unclear, despite what science and religion say about it
    c. I see the universe as a creative expression of an evolving consciousness or 'Spirit'
    d. Life was brought about through biological evolution (not steered by a higher power)

16. (select)
    a. People ascribe different values to nature, and all of them are important
    b. Nature has value because humans are able to use and enjoy it
    c. Nature has value in and of itself, even if it has no value for humans whatsoever
    d. Nature is created by God and is therefore valuable

17. It is very important to me...
    a. ... to adapt myself to others and behave appropriately and socially
    b. ... to be imaginative and express myself in the way I think and live
    c. ... to have enough money to have and do nice things
    d. ... to explore my inner world so I can live from my 'true' or 'deeper' self