12-2023

Chemistry Instructors' Perspectives On Incorporating Climate Change Instruction in Undergraduate Chemistry Courses

Patrick Wilson
University of Northern Colorado

UNIVERSITY OF NORTHERN COLORADO

Greeley, Colorado

The Graduate School

CHEMISTRY INSTRUCTORS' PERSPECTIVES ON INCORPORATING CLIMATE CHANGE INSTRUCTION IN UNDERGRADUATE CHEMISTRY COURSES

A Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree of
Doctor of Philosophy

Patrick Wilson

College of Natural and Health Sciences
Department of Chemistry and Biochemistry
Chemical Education

December 2023

This Dissertation by: Patrick Wilson

Entitled: *Chemistry Instructors' Perspectives on Incorporating Climate Change Instruction in Undergraduate Chemistry Courses*

has been approved as meeting the requirement for the Degree of Doctor of Philosophy in College of Natural and Health Sciences in the Department of Chemistry and Biochemistry, Program of Chemical Education

Accepted by the Doctoral Committee

____
Melissa Weinrich, PhD, Research Advisor

____
Aaron Apawu, PhD, Second Member

____
Lucinda Shellito, PhD, Committee Member

____
Emily Holt, PhD, Faculty Representative

Date of Dissertation Defense: September 22, 2023

Accepted by the Graduate School

____
Jeri-Anne Lyons, Ph.D.
Dean of the Graduate School
Associate Vice President for Research

ABSTRACT

Wilson, Patrick. *Chemistry Instructors' Perspectives on Incorporating Climate Change Instruction in Undergraduate Chemistry Courses*. Published Doctor of Philosophy dissertation, University of Northern Colorado, 2023.

Education plays an important role in preparing current and future generations for the challenges ahead caused by climate change. The purpose of this dissertation was to examine the educational influence textbooks and undergraduate instructors have on their students. Three studies were carried out to explore these influences on climate change instruction. The first study looked at the extent, type, and location of climate change topics across 24 undergraduate general chemistry textbooks. Gas chemistry concepts were the most prevalent topic connected to climate change. However, the distribution of climate change related material varied considerably across books. The majority of climate change content was within peripheral regions of the textbook and not in the main text.

The second study was comprised of a series of 16 interviews of post-secondary chemistry instructors evaluating their perspectives on climate change content in their teaching. Most of the interview participants discussed the importance of climate change to them personally, but the extent of including climate change topics in their teaching varied. Climate change concepts were best connected in their instruction by using real-world examples. Instructors who taught the same course frequently, had the ability to make changes to the material, and had some previous knowledge about the science of climate change, and spoke about being successful in including climate change topics in their courses. Some of the restrictions instructors faced to adding

climate change into their courses included inadequate time to make changes, a desire to avoid any political implications, not enough knowledge about the science of climate change, a lack of educational materials (such as textbooks, workbooks, and other activities), and limitations to course design. The use of an incremental approach to adding climate change topics was discussed as a pragmatic approach for improving teaching climate change in their courses. An interdisciplinary strategy was also highly encouraged to institute effective change schoolwide.

The third study built upon the results of the interview study to develop a national survey to examine the perspectives of chemistry instructors nationwide. Chemistry instructors at 259 postsecondary institutions were contacted resulting in a total response rate of 417 participants. Like the interview study, the majority of instructors rated climate change as a highly valued topic; however, the majority of respondents either taught climate change peripherally or not at all. They also mentioned time constraints as the largest reasons for their courses lacking climate change inclusion. Instructors who taught climate change in multiple ways cited agency over their course content and interest from their students as important influences over their decision-making. Gas chemistry, as reflected in the textbook study, was the most common topic area for inclusion. Tenure status, teaching experience, academic roles, and year of first appointment were not influences on the level of climate change inclusion. The development of accessible and integrable materials is needed to bridge the divide between time-constrained instructors and their ability to incorporate climate change materials into their undergraduate chemistry courses.

ACKNOWLEDGEMENTS

There are many individuals I would like to express my gratitude for their support throughout my time at UNCO. I first would like to recognize my PhD advisor Dr. Melissa Weinrich who has been a guiding and supportive force since I first started my graduate journey. I appreciate all of her patience in helping hone my writing skills and advice on improving my teaching techniques. I would not be the researcher that I am without you. To my committee, your enthusiasm and feedback has greatly improved my project and opened me up to new methods of presenting data. To all of the graduate students that shared the burdens of the graduate school lifestyle, your comradery and friendship is something that I will cherish for the rest of my life. I also would like to extend a special thank you to the undergraduate students I was fortunate enough to mentor during my project. Tori, Neveah, and Tia, you are wonderful people and whose contributions made everything run more smoothly and made what would have otherwise been a grind, a rather lovely experience. I know you will all be successful in your own personal and academic pursuits. To the UNCO Chemistry and Biochemistry department, I am eternally grateful for your support in funding my graduate studies these last five years. To my partner Lindsay, graduate school has been a challenging and rewarding experience, but I cannot imagine any of my success being possible without you. I know that you would disagree with that sentiment, but I truly believe that this title is much yours as it is mine. To my in-laws, you’ve been with me to share every success and provide support for each frustration. Whether you realize it or not, you’ve been integral to all my achievements. Finally, I would like to acknowledge my parents. You set the foundation for the person that I’ve become. In particular,

to my mother, I never thought that I would share your passion for teaching, but your example has guided me every step of the way. I often think about how you might view the turns in my journey, but I can say with confidence that I have and will continue to do as you last told me, make you proud.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Chemistry plays an important role in the development of many sectors of the modern world ranging from agriculture, energy, and industrialization. The progress made throughout the end of the 19th century from the Industrial Revolution lays the foundation of consequences for the environment. It was during this time that Svante Arrhenius first identified the connection between carbon dioxide (CO_2) generated from coal burning powerplants as a greenhouse gas and that it is responsible for atmospheric warming (Arrhenius, 1897). Throughout the coming century more evidence continued to accumulate and implicated greenhouse gases as a source of a pending ecological disaster (Doherty et al., 2009). Over the course of these years a multitude of scientists, international organizations, and average citizens have sought action to address the growing negative effects of climate change. However, these actions have moved slowly or have stalled entirely (Shi et al., 2015).

Well-meaning, designed, and organized chemistry instruction can operate as a reasonable route to a better-informed student who may contribute more meaningfully to society (Gulacar et al., 2018). Positioned at the center of this reform is the role that the instructor plays in fostering this learning and development. Most current undergraduate chemistry instruction follows the structure established in Johnstone's (1993) triangle, which denotes the instruction of chemical content under three fundamental levels: 1) The macroscopic level, the descriptive/observation level which encompasses concepts such as color changes, precipitation reactions, mixtures, and even explosions; 2) the sub-microscopic level that examines atoms and molecules which includes principles such as structure and geometry; and 3) the symbolic level, which is comprised from the previous two levels and interprets those phenomena through mathematics and chemical formulas. However, work from Peter Mahaffy (2006), proposed an addendum to Johnstone's triangle through the addition of another point containing the "human element". Without the inclusion of this "human element," chemical education instruction retains a reputation of teaching concepts that are ethereal and disconnected from real-world implications.

The selection of educational materials, such as textbooks, can influence the structure and delivery of course content (Grossman & Thompson, 2008). The organization and sequence of content in a course is often related to the topics found in the course's textbook (Schmidt et al., 2002). However, a recent study examining the content of climate change in select undergraduate chemistry, biology, and physics textbooks revealed less than 4% of the pages discussed climate change (Yoho & Rittmann, 2018).

Several other studies have also presented the inclusion and implementation of more socially conscious instruction, such as socio-scientific issues (SSI) (Ariza et al., 2021; M. Chowdhury et al., 2021; Flener-Lovitt, 2014; T. Sadler, 2011; Wang et al., 2018). These topics encompass economic, ecologic, cultural, societal, and politically minded sustainability issues (Nuangchalerm, 2010). Student experiences with socio-scientific topics have reported a greater understanding of the science underlying the topic and are also motivated in these areas because of these knowledge gains (Flener-Lovitt, 2014; Rahayu, 2021; Stolz et al., 2013). However, despite the evidence presented by these and other similar studies displaying positive gains in student conceptions of content knowledge and motivation in science, the implementation of socio-scientific based instruction continues to be low (Nida et al., 2020). Instructors also view the importance of socio-scientific topics though also recognize a gap in incorporating these topics within their own instructional course design (Eilks et al., 2018).

Purpose of the Study

The purpose of this dissertation was to examine the educational influence textbooks and undergraduate instructors have on their students. This dissertation study examined the gap in undergraduate chemistry instructor attitudes toward climate change with their practice of socio-scientifically minded instruction. Instructors were interviewed and surveyed to gauge their perspectives on the importance of climate change in chemistry and understand their thoughts regarding the inclusion or incorporation of climate change topics in their instruction. Furthermore, strategies for connecting climate change topics were addressed as a means of informing on future curricular adaptations.

Previous work conducted by Feierabend et al. (2011) examined secondary teacher perspectives on climate change over a decade ago in Germany. Our work focused directly on undergraduate chemistry professors in the United States to clarify and expand upon the positions previously demonstrated from the work of Feierabend. The perspective of these undergraduate chemistry instructors was explored according to the following research questions.

Research Questions

Q4.1 To what extent are climate change and chemistry concepts connected in general chemistry textbooks?

Q4.2 Where is climate change connected to chemistry topics in general chemistry textbooks?

Q5.1 How do instructors make decisions about how to include or not include climate change in their instruction?

Q5.2 What are instructors' perspectives on strategies for including climate change and other related subtopics in their instruction?

Q5.3 In what ways do post-secondary chemistry instructors incorporate climate change in their instruction?

Q6.1 At the national level, in what ways do undergraduate chemistry instructors incorporate climate change into their courses?

Q6.2 How do post-secondary instructors make decisions about including climate change in their instruction?

Q6.3 How are these decisions influenced by teacher thinking, personal and contextual factors?

Summary

The first study looked at general chemistry textbooks because general chemistry is a key entry point for many STEM students. General chemistry courses are commonly the only chemistry classes some undergraduate students will take. Thus, there is a need to better understand the extent that climate change content is included in general chemistry textbooks. In this study, the current most popular general chemistry textbooks were examined for their climate change content to discover the extent of climate change content presented.

Next, the second study looked at the role the instructor plays in the delivery of course content specific to climate change in chemistry. The decision-making process, along with their reasoning for whether to include or not include climate change in their instruction provides further understanding for the instructors' teaching practice.

The third study took the foundational information gathered from the second study to apply the teacher thinking, personal and contextual factors into a nationwide perspective. The development and deployment of a national survey was used to capture a broad range of teaching perspectives on climate change in chemistry education.

These three studies examined the educational influence textbooks and undergraduate instructors have on their students.

CHAPTER II

REVIEW OF LITERATURE

Current Perspectives on Climate Change Instruction

Chemistry has played a central role throughout industrialization. Chemistry education shares a responsibility for the development of the modern world and is thus linked with providing a more sustainable future. The United Nations adopted the 2030 Agenda in September of 2015 as a measure for supporting sustainable development and connecting those implications with education (Rosa, 2017). A goal of the 2030 Agenda follows four areas. First, content for learning should include important topics, e.g., climate change. Next, learning environments and pedagogical designs should place a focus upon exploratory, action-oriented content to create the space to allow for transformative learning. Third, focused learning outcomes should examine not only current, but future, potential impacts on later generations. Lastly, we should empower students in transforming their societies into a greener, more sustainable future.

Throughout the last few decades, undergraduate and graduate students have increasingly expressed their concerns over the growing implications of climate change. Undergraduate students have unanimously identified climate change as a serious threat that is induced by humans (Aksit et al., 2018; Corner et al., 2012; A. N. Versprille & Towns, 2015; Wachholz et al., 2014). Implementation of climate science topics across undergraduate curriculums have been slow to adapt and are reflected in the gap between the topics most concerning to students within their collegiate education (Molthan-Hill et al., 2022).

Traditionally chemistry education is approached through the examination of topics through the lens of matter. These concept items were later organized into the representation of a triangle by Alex Johnstone (1993), to whom the model is aptly named as Johnstone's triangle. Each corner of the triangle represents a core tenant of chemistry education. The macroscopic level includes descriptions of chemical changes that the observer can see, such as color changes, the formation of precipitates, or even explosions. Next, the sub-microscopic level views the molecular interpretations of how these systems operate through concept items such as molecular structures, geometries, and mechanisms. Lastly, the symbolic level is left to take the previous representations and place them in the context of formulas and mathematics that can adequately model and describe each of the previous scientific phenomena.

One item considered missing from Johnstone's original model is a fourth category, described by Mahaffy (2006) as the "Human Element", acts to shift the perspective of abstractive concepts with a more personal connection to the students and become more integrated with their daily lives. These contextual improvements seek an emphasis on topics that reflect the nature of science and include social, cultural, and humanistic aspects. Thus, the alteration of Johnstone's triangle emerges more as a tetrahedron which integrates the students as a direct connection with the chemistry topics that are covered in their courses. Sadler describes the objectives of a responsible scientific curriculum:

> These new goals require deep epistemological conceptual shifts so teachers can transform their pedagogical orientation from being purveyors of scientific knowledge to moderators and mediators of a classroom culture that mirror society in which students are challenged to make informed scientific decisions and exercise moral reasoning (Sadler, 2011, p. 293).

As challenges arise for the current and future generations, education at large should strive to align students with the tools to face and overcome these obstacles. For chemistry education, the traditional practice of how education is approached cannot continue as business as usual.

Real-World Connections in Education With Socio-Scientific Based Instruction

Socio-scientific teaching is designed to address the disconnect between real-world topics and current curricular course designs (Ariza et al., 2021). Instruction under these paradigms focuses on ecological, economic, societal, cultural, and political sustainability. The teaching of science topics in coordination with society is not an overtly new perspective. John Dewey (1995) drew this connection by suggesting that science taught in school should also incorporate moral dimensions. Dewey takes this further by adding that metacognition is essential to the process of science and that scientific education is insufficient if the focus remains on ready-made material. Socio-scientific issues continue to evolve and provide more areas linking a social connection of science with the students to better foster a more globally conscious citizenry.

Specifically in chemistry education, socio-scientific teaching has been adapted across differing areas of the chemistry curricular. For example, topics such as environmental sustainability and phosphate mining have been explored to connect students with a reflective look on real-life examples of chemistry in action and the implications those processes have on sustainability (Zowada et al., 2019). Multilevel assessment structures have been enacted to demonstrate the gains that can be obtained through the development of a course that is designed around socio-scientific issues (Klosterman & Sadler, 2010). There are also examples of laboratories including socio-scientific issues through an argument-based inquiry instruction to better develop student understandings of sustainability (Grooms et al., 2014). Each of these previous curricular interventions carries a key limitation across their implementation. The active participation of instructors tends to be either limited or low which signifies a general lack of expansion of socio-scientific styles of instruction amongst various faculty (Rahayu, 2021).

The majority of current education research examining the connection of instructors' views on teaching socio-scientific topics issues (such as climate change) was conducted in Germany and Indonesia or focused on the secondary education level. One such survey conducted in Indonesia by Nida et al. (2020) sought to understand secondary science teachers' perceptions and experience with socio-scientific based education. Though the inclusion of socio-scientific based practices varied among the respondents, nearly all viewed such topics as a valuable pedagogical vehicle for their instruction. However, the implementation of socio-scientific based practices in their classrooms was not carried out very often. The trend of instructors' holding the view of socio-scientific topics as important while also experiencing a gap in their own instructional course design is a trend that is repeated in Germany with a similar study design (Eilks et al., 2018).

A case study from Feierabend et al. (2011) focused more specifically upon chemistry instructor's views on climate change and how their views relate to these instructors' teaching. The sampled instructors were chemistry teachers in Germany in grammar and comprehensive schools. The majority of those teachers voiced the importance of climate change as an issue, but provided a disconnect where climate change would be incorporated into their subjects or broadly within the chemistry curriculum itself (Feierabend et al., 2011). Despite presenting such a divide between instructor views and practice in their classrooms, no such study exists examining instructors at the post-secondary level. This acts as the foundational root where the research questions for this study were generated. One of the perspectives of this study was to understand whether the trends observed in other countries were also presented consistently in the undergraduate institutions in the United States.

Theoretical Framework

The basis and framework for this study was developed through two sources: the Teacher Centered Systemic Reform Model (TCSR) created by Gess-Newsome et al. (2003) and Visualizing the Chemistry of Climate Change (VC3) created by P. Mahaffy et al. (2017).

Instructor Centric Model for Conceptual Change

Educators play a central role in shaping the understanding of their students while also influencing change. One of the first exploratory elements of instituting the idea of conceptual change was developed through Thomas Kuhn's *The Structure of Scientific Revolutions,* which situates the course of how scientific concepts develop and therefore influence change (Kuhn, 2021). These changes do arise and are often correlated with the views of the instructors that are engaging with the teaching and learning process (Duit et al., 2008). Previous work from Duit et al. (2008) has demonstrated a limiting capacity of instructor views on the teaching and learning process that further includes sections of the nature of science along with scientific processes. The development of an instructor's conceptions can be viewed as a major obstacle in improving their instructional practice (Anderson & Helms, 2001). Some of these barriers have previously been described as technical, political, or cultural (Johnson, 2006); others have put forward a growing lack of interaction between instructor collaboration combined with the restrictive decision-making structures of the traditional pedagogical methods (Davis, 2003). Through evaluating the approach of instructors' conceptions, the ability to provide inroads for change can become better realized and further translated into transformative action.

Reform efforts in education have a history of challenges in implementation and lacking sustainability. Woodbury and Gess-Newsome (2002) describe this phenomenon as the paradox of “change without difference”. They describe teacher thinking as a key pillar of reform efforts that seldom change how instructors attempt to implement changes. This led them to develop the Teacher-Centered Systemic Reform Model (TCSR). The model follows in the footsteps of previously designed conceptual change theories by recognizing the central role that instructor characteristics, such as the context of their thinking and course interactions as influential factors in the mechanisms of educational reform (Gess-Newsome et al., 2003). Thus, the instructor becomes important in shifting the paradigm of educational reform due to their distinct interaction with their students and the sphere of influence that is maintained over their course.

How an instructor conducts the instruction of their courses is a representation of the teacher’s pedagogical content knowledge and reflection of curricular design. Students’ gains in knowledge and understanding can be examined through the lens of Constructivist theory (Fosnot, 2013). Within the theory of constructivism is the Teacher-Centered Reform model (TCSR) that was developed in part by Gess-Newsome et al. (2003) which highlights the relevant thinking, interactions, and influence as it relates to the instructor’s role as a main factor in the direction of reform. The means by which reform is achieved through this model is through the inclusion or incorporation of one (or more) of the following items: contextual factors, personal factors, and instructor thinking. Contextual factors include cultural, school-wide, and course factors. Next, this framework considers the instructor’s personal factors such as their individual demographics and previous teaching experience. Last, this framework considers the instructor’s thinking, which involves their own knowledge and beliefs centered around their teaching that also includes the students and the course content. A connection between the instructor and all three domain areas provides the links between the belief around teaching along with any inclinations to making changes in their teaching practice (Popova et al., 2020). It takes only a small group of instructors to enhance and develop reform efforts which have the capabilities of transformative change both within the course as well as the institution at large (Cohen, 2002). Improvements in learner-centered reforms are limited by the influence of the teacher (Serin, 2018).

Visualizing the Chemistry of Climate Change

Teacher thinking can be further explored through the conceptualization of climate change as applied to principles in chemistry. Visualizing the Chemistry of Climate Change (VC3) was created through the collaboration of experts in the fields of climate science, chemistry, and education and was developed under the Climate Literacy framework developed by the U.S. Climate Change Science Program (Mahaffy et al., 2017). The program compiled federal research related to climate change and lays the foundation for what would define an individual who is competent on the scientific understanding of climate change (Wuebbles et al., 2017). Mahaffy et al. (2017) then generated a concept map which correlated the core general chemistry concepts with climate literary principles. They identified student conceptions of climate change and adapted these conceptions into the learning objectives for the framework.

In this map, climate principles describe the conditions for how the climate operates and the impacts that nature and humanity have on driving climate change (Mahaffy et al., 2017). The connection to chemistry was established through topics that create a bridge between climate principles and core chemistry topics. The bridging topics described aspects of climate change more specifically from the context of the climate change principles. Core chemistry topics emphasized the most important subcategories related to chemistry and included such topics as equilibrium, kinetics, and gases. Together, these categories drew direct connections between chemistry and climate change. For example, one climate change principle describes the regulation of climate through complex interactions in Earth’s system. The connection with chemistry was made through describing how the relationship between CO_2 and other greenhouse gases is related to chemical bonding. It is from this framework’s perspective that the research was carried out.

CHAPTER III

METHODOLOGY

The purpose of this dissertation was to examine the educational influence textbooks and undergraduate instructors have on their students. The methods described here encompass the three studies carried out for this dissertation. The selection process and data analysis techniques to elucidate climate change content within general chemistry textbooks along with instructor perspectives, attitudes, and potential inclusion of climate change and related climate topics in their educational practice. All the study protocols involving human subjects for educational research were approved by Institutional Review Board (IRB) of the University of Northern Colorado (see Appendix A for interview IRB approval letter and Appendix E for survey IRB approval letter).

Textbook Selection

Undergraduate general chemistry textbooks were selected based upon commonality of use. To achieve this, online book retailers (AbeBooks, Amazon, Barnes & Noble, and CampusBooks.com) were queried and the most popular textbooks were selected based upon each website's bestselling ranking. Twenty-four textbooks were selected. In order to not promote or dissuade the use of any of these books, the specific books are not identified.

Development of Textbook Coding and Analysis Strategy

The concept map developed by Mahaffy et al. (2017) was used as the main coding strategy for the general chemistry textbooks. Both main and sub codes were derived from the

VC3 interactive map. Areas considered core chemistry concepts served as the main codes, where the connecting ideas between chemistry and climate change served as the basis for the subcodes within each of the core chemistry concepts. For example, the *chemical bonding* main code corresponded with the VC3 subcode of global warming potential. Further additions to the codebook were made to provide context as to where the instances of climate change content were found in the book. These areas were subdivided by main body text, margins (which include subparagraphs or details not delegated to the main text), figures, and assessment questions (which were either example or end-of-chapter questions). The complete codebook consisted of 18 main codes and 153 related subcodes in total.

Textbooks were coded according to the number of instances that either explicitly discussed or referenced climate change. Counts were made by how frequently they appeared at the paragraph level (meaning how many times climate change was mentioned per paragraph). A key word search was employed to identify the areas in the text which provided direct mentioning of climate change topics. The key words used in this study were “climate change,” “global,” “warming,” and “greenhouse.” These words were identified through the corresponding book’s table of contents, index, or an electronic word search. Once we identified the key terms in the text, we evaluated the surrounding paragraphs to determine if they fit within the context of climate change topics. The analysis was iterated for each of the four key words for each subsequent paragraph until the relation of the content to climate change was absent. Codes were assigned to the codebook based upon their context as they relate to the VC3 framework and recorded in a spreadsheet for each code and subcode. For example, book chapters related to chemical bonding would serve as the main code and the subcodes were selected based upon their context to chemical bonding. The number of codes gathered were based upon the number of occurrences in the text at the paragraph level. Additionally, as codes were recorded into the VC3 portion of the codebook, locations of codable instances were also recorded as belonging to the main body of the text, textbox or reference in the margins, figures/data/tables, or example and/or end of chapter problems. Areas of content that did not specifically relate to climate change were not included under the codable instances of this coding strategy (e.g., discussion of chemical bonding that was not connected to a climate concept).

Textbook Study Validity and Reliability

Content validity was established through the alignment textbook topics with the core chemistry concepts provided by VC3. The intercoder agreement was achieved through frequent meetings among the researchers to establish agreement across four of the researchers' codebooks. Upon discussion the group gathered codes into a master codebook. Once a consistent commonality of coding was accomplished, researchers were left to complete the remaining ten on their own. Of the ten textbooks left to be examined, the intercoder agreement was calculated between these books to find an overall percentage of agreement to be 97%.

Sampling of Interview and Survey Participants

Stratified sampling methods were used to identify undergraduate chemistry instructors from across the United States for online interview recruitment. Selection was organized based on regional areas of the United States (such as West, Midwest, Northeast, and South). Recruitment (Appendix B) for this study was carried out through email communications from email addresses gathered from their corresponding department websites. Consent was obtained electronically from all participants (see Appendix C). Each of the participants was labelled with a number to ensure confidentiality. In total, 16 individuals participated in this research hosting a diverse background in chemistry experience and areas of expertise (Table 3.1).

Table 3.1

Interview Participant Demographics

Participant	Course	Position at university	Age range	Gender	Race
1	Allied Health	Lecturer	35-44	Male	White
2	Analytical	Professor	55-64	Male	White
3	Biochemistry	Senior lecturer	45-54	Female	White
4	Analytical	Professor	45-54	Female	White
5	Biochemistry	Professor	35-44	Male	White
6	General	Assistant professor	35-44	Female	White
7	Chem for non-majors	Professor	55-64	Male	White
8	Inorganic	Assistant professor	35-44	Female	Black
9	Physical	Assistant professor	35-44	Male	White
10	Physical	Adjunct professor	45-54	Male	White
11	General	Career instructor	35-44	Female	Asian
12	Biochemistry	Professor	55-64	Female	White
13	Biochemistry	Professor	35-44	Male	White
14	General	Teaching professor	55-64	Female	White
15	Environmental	Professor	45-54	Female	White
16	General	Vice provost, distinguished professor	55-64	Female	White

The survey study also targeted undergraduate chemistry instructors. Individuals who participated in the interview study were excluded for recruitment in the survey study. Survey participants were sampled from departments organized according to the listing provided by The U.S. News & World Report 2023 ranking of chemistry departments (*The Best Chemistry Programs in America, Ranked*, 2023). Contact email information for survey participants was gathered from these departmental websites. Data collection ceased after 259 schools were sampled resulting in 6459 undergraduate chemistry professors contacted. Both state and private schools were selected ranging from R1 to non-research institutions. A total of 417 participants fully completed the survey.

Recruitment for the survey study was carried out via email communications as identified according to their prospective departmental websites (Appendix F). Electronic consent forms were collected from all participants prior to involvement with the survey (Appendix G). We did not save identifiable information outside of the participant's basic demographics. Neither the interview nor survey studies provided compensation for participation.

Interview Data Collection

Participant data was collected through a semi-structured interview protocol (Appendix D) that took approximately 30 to 60 minutes. The interviews were conducted over Zoom from fall 2021 through summer 2022. After the interview, AI-created Zoom transcripts were checked for accuracy. Repeated words and stammers (for example “um” and “ah”) were removed. Any identifying information mentioned by the participants was de-identified and aliases were provided. For example, the name of a school was replaced with “[school name].” The interview protocol was designed to determine how instructors viewed climate change in relationship to their instructional practice. Once the participant’s view of climate change as an educator was established, the interview sought to connect the decision-making processes for how climate change was or was not included in their teaching. Participant’s teaching philosophy was also discussed to establish teacher’s values on teaching with their instructional practice. At the end of the interview, instructors were asked about their thoughts on improving how climate change was taught in chemistry. This question also served as a point of reflection for the instructor’s own teaching on the subject. Instructors considered their approaches to include climate change in their teaching and also gave their perspectives on how the topic could be addressed in other areas of chemistry or other courses.

Interview Analysis

Open coding was applied to the interview transcripts using reflexive coding analysis (Braun & Clarke, 2019) in NVivo 12 to identify themes related to climate change and/or other related subtopics as they were included (or not) within their course(s). Coding was carried out following Braun and Clarke’s (2019) process of data familiarization, generation of codes, constructing, reviewing, and defining themes. Codes identified from the transcript were comprised of short annotations relating to climate change in their teaching. From the codes produced, the series of codes were compared and grouped according to their conceptual relationship to one another, then were further grouped into larger themes. These themes were further organized according to the research questions.

Interview Study Validity and Reliability

Once the codebook had been developed by the first author, three coders independently coded a random sample of 25% of the total interviews collected. Several weekly meetings were held to review and begin establishing the intercoder agreement for each of the codes from the independent researchers’ codebooks. There was initially an intercoder agreement of 92.4%. Following discussions on the disagreements, the researchers came to agree on all codable items. The remaining interviews were coded independently by two researchers. Further meetings were held to answer any related coding questions.

Survey Design and Development

The survey design and questions were developed through responses to the previous interview study (Wilson, Sayers, et al., 2023) and a small pilot program. The pilot program sampled 35 undergraduate chemistry instructors from the state of Colorado and participants did not overlap with the final study. Changes made to the survey following completion of the pilot study were in forced answer questions and not in content related areas. This prevented key questions from being skipped by participants, such as their level of climate change inclusion in their teaching, ranked choice options for their decision making, and factors that influence their inclusion of climate topics. Qualtrics software was used in the survey design and delivery system. Electronic consent was acquired before access was given to the survey questions; a copy of the consent form can be found in Appendix G. To minimize potential participants from self-selecting out of the study, the language of the recruitment email focuses on teaching topics rather than explicitly about climate change.

After consent was received, the participants were first asked to select from a list of chemistry classes that they teach. Next, they selected a focus course which was applied to the remainder of the survey. The structure of the survey then focused on the level of inclusion, attitudes, and influences to how climate change was (or was not) included in their instruction. For example, the level of climate change inclusion was split into three options: “multiple ways,” “in passing,” or “not included.” Instructors were shown a list of connected chemistry topics with climate change adapted from Mahaffy’s Visualizing the Chemistry of Climate Change (VC3) (Mahaffy et al., 2017). For example, chemical reactions were a common topic connected with climate change through the stoichiometry of combustion reactions as related to the greenhouse effect. The question of selecting the level of climate change inclusion was then reintroduced after the VC3 framework in case a participant was not previously aware of connections that they may be making with climate change topics. Free response areas were opened following these items to allow participants the option to provide additional context. Reasons for whether climate change was taught or not were gathered using ranked choice design. The top rank indicated the highest reason for their decision to include (or not include) climate change in their teaching. For example, participants who taught climate change tangentially received ranked choice options for both reasons why and why not, whereas those who indicated that they did not include that topic only receive the ranked choice options for why not. Likert scale items were presented to assess participants’ levels of influence as to how influential (or not) climate change was with their instruction. A value of 5 indicates an item that was not very influential for the participant to include climate change in their teaching and a value of 1 was very influential for the inclusion of climate change, and a 3 was a neutral position as being neither influential nor not influential for climate change inclusion. The last sections of the survey evaluated common personal factors related to the participants. Examples of some of these items included age, tenure status, and gender.

Survey Data Analysis

Statistical analysis and data plots were carried out using R 4.3.1 (Team, 2021). Violin plots were created using the tidyverse R package (Wickham et al., 2019) from the ggplot2 geom_violin() function. Crosstab and stacked bar charts were converted based on the percentage of response for each of the corresponding categories and generated using Microsoft Excel.

Survey Study Validity and Reliability

The survey design and question content were first reviewed by a climate scientist and education expert to establish content validity. Next, a pilot study was also employed prior to the main survey to optimize the formatting of the survey and establish face validity. Following a six-week pilot collection period, the only changes made to the format of the survey were the addition of force checks for certain question and correcting the flow of the questions examining instructor’s level of climate change content (directly, indirectly, or not at all) so that their ranked choice options matched the level of climate change inclusion. Concurrent validity was established by comparing the study’s results to previous work (Feierabend et al., 2011). Method triangulation further established validity by combining the analysis of the interview study and compared those results from the survey study.

CHAPTER IV

ANALYSIS OF CLIMATE CHANGE IN GENERAL CHEMISTRY TEXTBOOKS

This chapter will be submitted to the *Journal of Chemical Education*

Contributions of Authors and Co-authors

Manuscript in Chapter IV

Author: Patrick Wilson

Contributions: Designed study. Conducted data collection and preparation. Conducted data analysis. Conducted intercoder agreement. Wrote first draft of this manuscript.

Co-Author: Nevaeh Duarte

Contributions: Provided feedback on study design. Conducted data collection and analysis. Participated in intercoder agreement. Wrote drafts of the literature review.

Co-Author: Tia Harris

Contributions: Provided feedback on study design. Conducted data collection and analysis. Participated in intercoder agreement. Wrote drafts of the literature review.

Co-Author: Tori Sayers

Contributions: Provided feedback on study design. Conducted data collection and analysis. Participated in intercoder agreement. Wrote drafts of the literature review.

Co-Author: Melissa Weinrich

Contributions: Designed study. Advised on data collection and analysis. Reviewed and provided feedback on drafts.

Abstract

Climate change has the potential to push humans across the limits at which we can exist. Chemistry is essential in understanding the complexities of climate change, as many of the processes involve chemical relationships. Education can provide knowledge that contributes to students' and future researchers' ideas of climate change. Textbooks are an influential tool in the development of course curricula and support instructors' decision making which can impact student understanding. This study examined the extent, type, and location of climate change content present in 24 undergraduate general chemistry textbooks (for STEM majors and non-majors). Visualizing the Chemistry of Climate Change (VC3) served as the theoretical framework and basis for the codebook. Textbook items were considered codable instances if they were linked back to the core chemistry concepts outlined by VC3. Of the core chemistry concepts reviewed, gases were the most prevalent topic connected to climate change. Topics regarding organic chemistry and equilibrium concepts were among the least frequent codable instances. The distribution of climate change content was also uneven among the sampled textbooks. Only 3 textbooks contained more than 100 codable instances and 3 other books did not contain any climate change material. Most instances connecting climate change to chemistry appeared in peripheral regions of the books and not in the main text. Without available materials to connect core chemistry concepts with real-world issues, like climate change, instructors become burdened with developing their own content. Supplemental materials, such as VC3, can provide a bridge to climate change content deficits, but there is a need for textbook materials to be more effective in presenting the chemistry of climate change.

Introduction

Climate change is a vital and pressing issue. The Planetary Boundaries concept defines environmental conditions, such as ocean acidification and changes in biosphere integrity, for which humanity can safely operate (Rockström et al., 2009). Climate change has the potential to push humans across the limits at which we can exist (Lade et al., 2020). At this point, humanity has already crossed six of the nine planetary boundaries (Richardson et al., 2023). A majority of United States citizens are aware of climate change and motivated to mitigate future impacts (Sparkman et al., 2022). Education on climate change can help foster a generation of intelligent, skilled, and well-equipped individuals with the knowledge to act on these future challenges.

Chemistry is essential in understanding the complexities of climate change, as many of the processes involve chemical relationships (Ravishankara et al., 2015). Climate change education is an important tool in generating an informed society that prepares communities to face climate challenges (Molthan-Hill et al., 2022).Few resources exist that incorporate chemistry and climate change (Mahaffy et al., 2017) as well as materials that aid in the inclusion of systems thinking in chemical education (Aubrecht, 2018; York & Orgill, 2020). Instructors who do enact systems thinking in their teaching practice are limited in their implementation due to lacking explicit scaffolding to connect more complex topics, such as the human factor in chemical processes (Szozda et al., 2023). Educational materials, like textbooks, can play an integral role in the manner and style of how chemistry topics are addressed in a course.

The presentation of material in the course is often reflective of the sequence and topics found in the course's corresponding textbook (Schmidt et al., 2002). Moreover, curricular materials can substantially shape teachers' ideas on how to teach their content (Grossman & Thompson, 2008). Textbooks influence how instructors teach and what is learned by the students

(Matić & Gracin, 2016; Miguel, 2015; Valverde et al., 2002; You et al., 2019). Textbooks are one major type of curricular material, acting as an intermediary between the instructor and the content (Valverde et al., 2002), while also having a direct impact on student success (van den Ham & Heinze, 2018). They allow students to work through material at their own pace and promote self-regulated low to mid order learning, such as remembering, understanding, applying, and analyzing. However, they are generally considered ill-designed to advance higher order learning (Lau et al., 2018).

Due to the importance of climate change, the role of chemistry in climate change, and the influence of textbooks on content taught, it is important to understand the extent to which chemistry textbooks make these connections. Currently, the presence of climate change topics in science textbooks (encompassing undergraduate level biology, chemistry, and physics) averages less than 4% of pages (Yoho & Rittmann, 2018). General chemistry is a key entry point for STEM students in undergraduate education, and a starting point to explore how climate change is connected to chemical principles in textbooks. General chemistry courses are commonly the only chemistry classes some undergraduate students will take. Thus, there is a need to better understand the extent that climate change content is included in general chemistry textbooks. In this study, the current most popular general chemistry textbooks were examined for their climate change content to discover the extent of climate change content presented.

Research Questions

Q4.1 To what extent are climate change and chemistry concepts connected in general chemistry textbooks?

Q4.2 Where is climate change connected to chemistry topics in general chemistry textbooks?

Theoretical Framework

Visualizing the Chemistry of Climate Change (VC3) (Mahaffy et al., 2017) framed our study. The VC3 was created through the collaboration of experts in the fields of climate science, chemistry, and education and was developed under the Climate Literacy framework developed by the U.S. Climate Change Science Program. The program compiled federal research related to climate change and lays the foundation for what would define an individual who is competent on the scientific understanding of climate change (Wuebbles et al., 2017). Mahaffy et al. (2017) then generated a concept map which correlated the core general chemistry concepts with the CCSP's literary principles. They identified student conceptions of climate change and adapted these conceptions into the learning objectives for the framework.

In this map, climate principles describe the conditions for how the climate is regulated and the impacts that nature and humanity have on driving climate change (Mahaffy et al., 2017). The connection to chemistry was established through topics that create a bridge between climate principles and core chemistry topics. The bridging topics described aspects of climate change more specifically from the context of the climate change principles. Core chemistry topics emphasized the most important subcategories related to chemistry and included such topics as equilibrium, kinetics, and gases. Together, these categories drew direct connections between chemistry and climate change. For example, one climate change principle describes the regulation of climate through complex interactions in Earth's system. The connection with chemistry can be made through describing how the relationship between CO_2 and other greenhouse gases is related to chemical bonding. It is from this framework's perspective that the research was carried out.

The layout of chemistry concepts in VC3 is a scaffold for characterizing how chemistry textbook content is connected to climate change. This study seeks to use the framework provided by Mahaffy et al. (2017) to analyze the extent of climate change topic inclusion in undergraduate general chemistry textbooks.

Methods

Textbook Selection

Undergraduate general chemistry textbooks were selected based upon commonality of use. To achieve this, online book retailers (Abe Books, Amazon, Barnes & Noble, and CampusBooks.com) were queried and the most popular textbooks were selected based upon each website's bestselling ranking. Twenty-four textbooks were selected. In order to not promote or dissuade the use of any of these books, the specific books are not identified.

Development of Codebook and Coding Strategy

The concept map developed by P. Mahaffy et al. (2017) was used as the main coding strategy for the general chemistry textbooks. Both main and sub codes were derived from the VC3 interactive map. Areas considered core chemistry concepts served as the main codes, where the connecting ideas between chemistry and climate change served as the basis for the subcodes within each of the core chemistry concepts. For example, the *chemical bonding* main code corresponded with the VC3 subcode of global warming potential. Further additions to the codebook were made to provide context as to where the instances of climate change content were found in the book. These areas were subdivided by main body text, margins (which include subparagraphs or details not delegated to the main text), figures, and assessment questions (which were either example or end-of-chapter questions). The complete codebook consisted of 18 main codes and 153 related subcodes in total.

Textbooks were coded according to the number of instances that either explicitly discussed or referenced climate change. Counts were made by how frequently they appeared at the paragraph level (meaning how many times climate change was mentioned per paragraph). A key word search was employed to identify the areas in the text which provided direct mentioning of climate change topics. The key words used in this study were “climate change,” “global,” “warming,” and “greenhouse.” Once we identified the key terms in the text, we evaluated surrounding paragraphs to determine if they fit within the context of climate change topics. The analysis was iterated for each of the four key words for each subsequent paragraph until the relation of the content to climate change was absent. Codes were assigned to the codebook based upon their context as they relate to the VC3 framework and recorded in a spreadsheet for each code and subcode. For example, book chapters related to chemical bonding would serve as the main code and the subcodes were selected based upon their context to chemical bonding. The number of codes gathered were based upon the number of occurrences in the text at the paragraph level. Additionally, as codes were recorded into the VC3 portion of the codebook, locations of codable instances were also recorded as belonging to the main body of the text, textbox or reference in the margins, figures/data/tables, or example and/or end of chapter problems. Areas of content that did not specifically relate to climate change were not included under the codable instances of this coding strategy (e.g., discussion of chemical bonding that was not connected to a climate concept).

Validity and Reliability

The intercoder agreement was achieved through frequent meetings among the researchers. Content validity was established through the alignment textbook topics with the core chemistry concepts provided by VC3. For the first set of fourteen textbooks, group meetings were held to establish agreement across four of the researchers' codebooks. Upon discussion the group gathered codes into a master codebook. Once a consistent commonality of coding was accomplished, researchers were left to complete the remaining ten on their own. Of the ten textbooks left to be examined, the intercoder agreement was calculated between these books to find an overall percentage of agreement to be 97%.

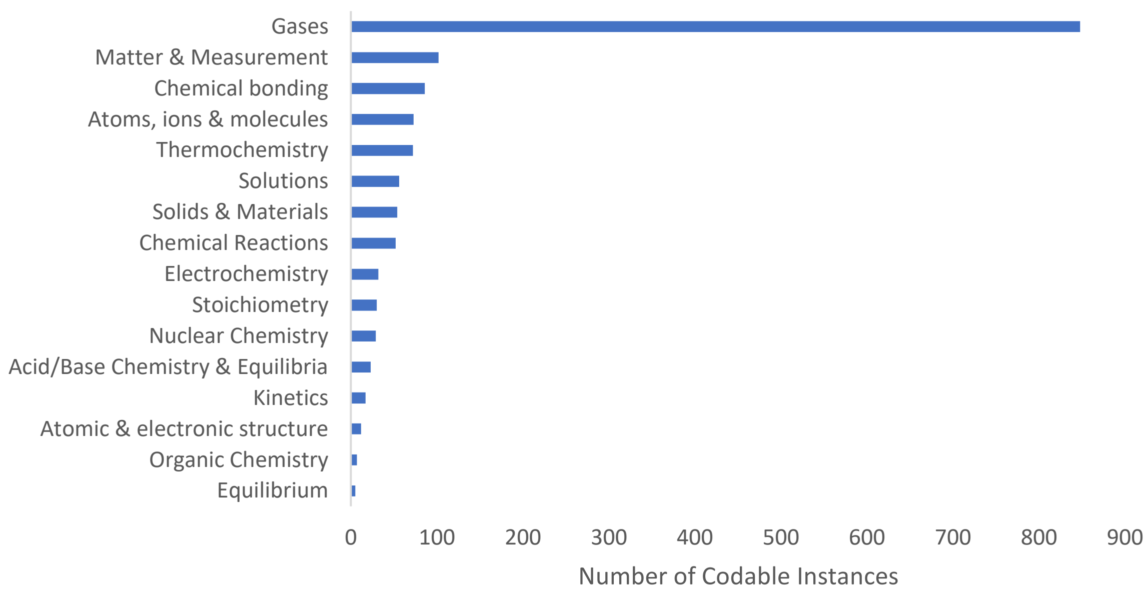
Results and Discussion

The Chemistry of Climate Change Coding

Though some degree of variability appeared across all of the sampled textbooks, the most common code was *gases* (Figure 4.1). Textbooks that made any connection between chemistry and climate change overwhelmingly did so through the lens of gas topics. Outside of the gases main code, other prominent codes were *matter and measurement*, *chemical bonding*, and *atoms, ions, and molecules*.

Figure 4.1

Distribution of Main Codes of Core Chemistry Topics Connected to Climate Change Across All Surveyed Textbooks



Within the main codes for *gases*, the most frequent subcodes were CO_2 and other greenhouse gases (Table 4.1). However, global warming potential subcode occurred half as often. This suggested that even though textbooks spoke of climate change through greenhouse gases, the connection to these gases' warming potential was not as frequently made explicit. Subcodes involving either fossil fuels, or combustion was another high counted area. These appeared in textbooks as examples of real-world implications of combustion reactions. They also tied into the role that humanity has played in the extraction and burning of these fuels. Subcode areas that had little-to-no content in the selected textbooks were kinetic-molecular theory and the role of pheromones in insect communication. The main codes *kinetics* and *organic chemistry* (which also contained subcodes for both kinetic molecular theory and the role of pheromones, respectively) had no codable instances. Kinetic molecular theory was discussed in these textbooks but was not related to climate change and thus was not counted. The role of pheromones in insect communication was likely too specific for the surveyed general chemistry textbooks and did not appear at all.

Table 4.1

Breakdown of Subcodes for Gases

Gas Subcodes	Number of Codable Instances
CO_2 and other greenhouse gases	300
Global warming potential & "super-greenhouse gases"	178
Combustion of fossil fuels & production of atmospheric gases	83
Chemistry of human activity	67
Absorption of energy by molecules in different spectral regions	51
Fossil fuels	44
Chemistry in the natural environment	35
Importance of chemistry in contributing solutions to global challenges	24
Carbon capture & storage	24
Nature of models and modeling	17
Mechanisms for & difference between stratospheric ozone depletion & tropospheric warming by greenhouse gases	13
Complexity of natural systems & contributions from chemistry	7
Stoichiometry	5
Chemistry & human health	2
Roles of pheromones in insect communication	0
Kinetic-molecular theory	0

The second most coded main code was *Matter and Measurement*. Sub-coded areas looked at the ways models were used in the characterization of climate change. The models and modeling subcode had the majority of instances within the section (Table 4.2). Books that included these codes often described climate change through examples such as atmospheric models or CO_2 concentration in ice cores. The separation and analysis of seawater was the only subcode among this category that did not contain any codable instances. If books were not relating climate change models to the productions, activity, and characterization of greenhouse gases, then it was also unlikely that any of these more peripheral subcodes would have been emphasized.

Table 4.2

Subcode Instances for Matter and Measurements

Matter and measurements	Number of codable instances
Models and modeling	48
Nature of models and modeling	23
Nature of science and uncertainty	11
Data collection, analysis, interpretation	6
Measurements	5
Hypothesis testing	4
Complexity of natural systems and contributions from chemistry	3
Importance of chemistry in contributing solutions to global challenges	2
Separation and analysis in characterizing seawater, detection of trace substances	0

The *chemical bonding* main code mirrored the coding distribution of *gases*. CO_2 and other greenhouse gases were the subcode with the largest portion of codes, but global warming potential was present less often (Table 4.3). When relating climate change to chemical bonding it often occurred in the context of bonds absorbing energy. However, like gases, many books did not fully distinguish this relationship with a molecule's potential to warm the atmosphere.

Table 4.3

Chemical Bonding Subcodes Across All Surveyed Textbooks

Chemical bonding subcodes	Number of codable instances
CO_2 and other greenhouse gases	27
Absorption of energy by molecules in different spectral regions	22
Global warming potential and "super-greenhouse gases"	15
Nature of models and modeling	6
Combustion reactions	3
Photosynthesis	3
Fossil fuels	3
Chemistry of the natural environment	3
Nature of light and electromagnetic spectra	2
Chemistry of human activity	1
Speciation of carbon, nitrogen, oxygen, and phosphorous	1

The *atoms, ions, and molecules* code had the greatest number of codable instances in reference to measuring isotope data (Table 4.4). The data was most often represented in the analysis of ice cores as a means of describing and comparing the atmospheric composition between pre-industrial and current contexts. Additionally, these examples were expanded into climate models and used to clarify the inherent uncertainty in the scientific modeling of nature. Furthermore, examples were drawn from the comparison of the pre and postindustrial atmospheric compositions to link the changes with human activity.

Table 4.4

Breakdown of Atoms, Ions, and Molecules Subcodes Across 24 Surveyed Textbooks

Atoms, ions & molecules subcodes	Number of codable instances
Isotope ratios to obtain temperature proxy data	26
Nature of science & uncertainty	15
Speciation of carbon, nitrogen, oxygen & phosphorous	12
Nature of isotopes	8
Data collection, analysis, interpretation	6
Models & modeling	5
Measurements	1

Infrequent Climate Change Topics in Textbooks

General chemistry spans a wide range of concepts, and several core chemistry concepts had very few connections to climate change. Equilibrium was the lowest main code with only five instances. For instance, examples involving carbonic acid formation from dissolved carbon dioxide in the water were described in terms of acid/base concepts rather than explicitly about equilibrium.

The second lowest coded category across the sampled textbooks were sections involving organic chemistry (seven instances). The division of subcodes had several single incident codes, which were more often common topics found in other book sections. These included examples such as fossil fuels, combustion reactions, and chemistry of the natural environment. Since organic chemistry is a topic typically left to its own named course, it was of no surprise to find the code making such a limited appearance. The main code of *atomic and electronic structure* (12 instances) was relatively infrequent. This was because the subcode of this main concept, for example the absorption of energy by molecules in different spectral regions, was also shared with and more commonly associated with *chemical bonding*. However, both main codes had the absorption subcode as the greatest number of codable instances (7 for *atomic and electronic structure*). The two subcodes for models and modeling, along with the nature of models and modeling had no codable instances presented.

Characterization of Total Codable Instances Across Textbooks

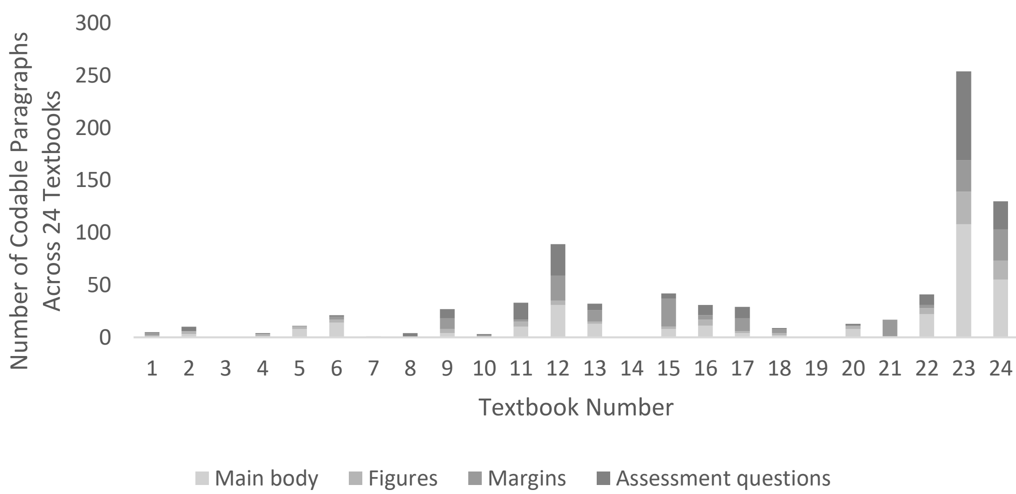
The amount climate change content coded within each of the sampled textbooks varied considerably. Out of the 24 books studied, six contained more than 100 codable instances. One book had the highest total of 833 codes and was also a textbook written for non-STEM majors. The next top coded books for STEM majors contained 254 and 250 codes. Only five textbooks had over 50 codable instances per book, leaving the remaining 13 books with less than 50 instances. Of those remaining 13 books, four textbooks had less than 10 instances and two books had no mention of climate change at all. Books that contained higher amounts of codable instances addressed climate change in multiple ways, such as linking chemical bonding properties to the greenhouse effect covered in a thermochemistry chapter. Low coded books (those under 50 instances) had limited references to climate change in their main text and instead used the margins and end-of-chapter questions to fill in some of those details.

Climate Change Topic Locations in Textbooks

According to these books, 38% of the climate change instances occurred in the main text. The majority of instances occurred outside the main text in assessment items (28%), in the margin spaces outside the main text which also includes extraneous essays (22%), and figures (12%). Much of the assessment content presented examples through end-of-chapter questions to expand on related content not directly discussed in the main text. The typical format for many of these end-of-chapter questions among the surveyed books appeared as short-form vignettes, or anecdotes used to expand or relate the chapter's content to an example involving climate change. Despite using the end-of-chapter question sections to promote examples of climate change concepts, the design of these questions tended to be more algorithmic or contrived where the context is not needed to explore the problem. Only one of the sampled textbooks (book #8) relied on assessment questions alone to introduce climate change concepts in their text (Figure 4.2). In this figure, a single paragraph was only coded once (even if there were multiple different types of codes within the paragraph). If climate change was mentioned in a textbook, then the book typically contained elements of all four subcategories, which suggest multiple ways of making connections to climate change issues.

Figure 4.2

Distribution of Climate Change Content per Textbook



Next Steps and Limitations

The focus of this study was on the ways in which climate change topics were covered in undergraduate general chemistry textbooks. One key element this study did not address was how instructors incorporated textbook content in their practice. The role the instructor plays in the delivery of course content is essential, and the manner along with the extent of topics covered is often at the instructor's discretion. Further study is necessary to understand the role and manner in which instructors include, or not include climate change related topics in their instructional practice.

The coding framework generated from Mahaffy's VC3 was designed to make connections between climate change and chemistry. Climate change is a multidisciplinary topic and though chemistry can encompass a wide range of issues, one framework is not comprehensive. There could be elements of climate change not described through VC3 that were omitted from the analysis. For example, Meehan et al. (2018) examines climate change content inclusion from the broader perspective of undergraduate science.

The search criteria focused on the explicit use of the terms global warming and climate change. There could have been certain topics or examples that were missed due to being presented as a more subtle connection with climate change.

This study examined a multitude of general chemistry textbooks and there exists the possibility of other books discussing climate change that were not included. There are some universities which produce their own textbooks that may or may not contain climate change information. As those books require specific permissions and are not widely published, they were not captured by the sampling in this study.

Conclusions and Implications

Textbooks serve an important role as an educational tool in how courses are designed, structured, and implemented. The organization of textbooks plays a significant role in the delivery of course content to students (Matić & Gracin, 2016; Lester, 2007; Rezat et al., 2021; Rezat & Sträßer, 2012). Climate change topics were sporadically located throughout many of these undergraduate general chemistry textbooks. The coverage of climate change in textbooks must be reflective of the importance of the subject material. How climate change is distributed within textbooks provides insight as to how instructors might include these topics in their teaching practice and further serves as a baseline for where climate change issues are contained within the text. Currently, the majority of undergraduate general chemistry textbooks leave climate change to be mentioned anecdotally or through disconnected examples. This leaves the instructor with additional duties of drawing outside resources to integrate climate change content into their instruction.

An understanding of climate change is essential to enacting future actions (Oreskes, 2004, 2018). However, with so many of these textbooks either containing few instances discussing climate change or leaving the topic to be mentioned in peripheral book regions, such as within the margins or end-of-chapter questions, contradicts the importance of climate change. This could be in part due to the highly politicized nature of the topic in popular discourse, limiting the desire for controversy to be introduced within the textbook. Most students who take general chemistry are not chemistry majors. For many, general chemistry is the only sequence of chemistry courses they take throughout the undergraduate experience. This leaves students with learning about climate change somewhere else, shifting the responsibility away from the chemistry discipline. If other introductory level STEM courses treat climate change the way it is treated in general chemistry textbooks (Yoho & Rittmann, 2018), then some of the public's lack of climate literacy starts to become clear. Textbooks are a powerful educational tool, but like any device, are restrained by their applications. Without a greater integration of critically important scientific topics, such as climate change, into textbooks, these topics may flounder in their inclusion in courses.

Content gaps in connecting topics between climate change and chemistry could further implicate a lack of student understanding and contribute to misconceptions. These items typically involve the nature of carbon dioxide, alternative greenhouse gases outside of carbon dioxide, and the connection between the carbon cycle and water (Jarrett & Takacs, 2020). The consequence of which could lead to the occurrence of some of the more common misconceptions surrounding the science of climate change. Students most often lack the proper contextualization surrounding climate change to fully understand the topic (Shepardson et al., 2009). Previous work has also established that misconceptions have a tendency to persist through related concept instruction, but through addressing these items directly the issues may be overcome (McCuin et al., 2014). The manner in which climate change is presented in textbooks may relate to these continued misconceptions among students.

How climate change is included within the text provides insight on how an instructor may incorporate those topics into their own instruction. Perceptions of the instructors also play an influential role in their use of textbooks. Differences in the type of students in a course change how instructors represent the materials to their students (Mesa & Griffiths, 2012). Students also denote more motivation to use their textbooks when given direction from their instructors (Berry et al., 2010). From the student perspective, course assessments motivated them to use textbook resources (Hoeft, 2012). Importantly for textbooks that focus their climate change content on content in the margins, without connecting to a form of course assessment, students will likely not be exposed to that content. For general chemistry specifically, students rated end of chapter problems as the most helpful component in their textbooks, where examples of real-world applications and examples were the lowest (Smith & Jacobs, 2003). Many of the textbooks used end-of-chapter questions to contextualize their concepts with descriptions or examples of climate change. However, these questions used climate change as a were focused more on answering a chemistry concept rather than exploring the chemistry of climate change as a topic. Questions, design in this way, leave students with more algorithmic and contrived answers, rather than using higher levels of applying critical thinking skills relating to data representation, comparing, or correlating data (Dávila & Talanquer, 2010). Future studies will be needed to see the connection between climate change content, the instructor, and the influence on student learning.

The inclusion of climate change content in general chemistry textbooks does not require entirely new forms of educational development. The use and incorporation of such supportive materials, such as those outlined by VC3, creates a scaffold for integrating climate change and chemistry (P. Mahaffy et al., 2017). One example of a key item from VC3 covers the composition of the atmosphere as important to many biological and chemical processes that make life possible on this planet. Molecules are characterized through data interpretation provided by techniques such as gas chromatography, infrared, and mass spectroscopy. Data-based instruction further reinforces the contributions of humans to global carbon dioxide production through the analysis of Keeling Curves. These properties are related back to the chemistry of gases by using the ideal gas law and kinetic molecular theory of gases to describe how predictive models of the atmosphere are created. The greenhouse effect is discussed based on natural fluctuations in global temperatures and through anthropogenic sources, such as vehicle combustion and industrial processes. In each of these lessons, a common structural format orients the content in the forms of “what do we know,” “why do we care,” then ends with reflective “questions for thought.” With a more real-world oriented and problem-solving approach, other textbooks could adapt and approach these critically important topics.

CHAPTER V

UNDERGRADUATE INSTRUCTORS' APPROACH TO THE TEACHING OF CLIMATE CHANGE IN CHEMISTRY

This chapter will be submitted to *Chemistry Education Research and Practice*.

Contributions of Authors and Co-authors

Manuscript in Chapter V

Author: Patrick Wilson

Contributions: Designed study. Conducted data collection and preparation. Conducted data analysis. Conducted intercoder agreement. Wrote first draft of this manuscript.

Authors: Tori Sayers

Contributions: Provided feedback on study design. Conducted data analysis for research question one. Participated in intercoder agreement. Wrote drafts of the results section for research question one.

Author: Melissa Weinrich

Contributions: Designed study. Advised on data collection and analysis. Participated in intercoder agreement. Reviewed and provided feedback on drafts.

Abstract

Education provides an opportunity to develop solutions for climate change. The influence that instructors have on their students shapes their learning. This qualitative interview study examined undergraduate chemistry instructors' perspectives on climate change in their teaching. The interviews were coded inductively using thematic analysis to identify these participants' views on teaching climate change topics. Many of the interview participants spoke on their view of the importance of climate change though the extent of inclusion of the topic in their instruction varied. Real-world examples were discussed as an effective means of integrating climate change with their chemistry instruction. Some instructors thought that climate change was not related to their course even if they thought the topic was highly important. Barriers some instructors experienced included lack of climate change knowledge, lack of textbook materials, the desire to avoid politics, and time and course expectations. Instructors who had more agency over their course had the ability to focus more on topics like climate change. Knowledge of climate change was also paired with their ability to use educational resources effectively in their instruction. An incremental approach to adding changes to teaching climate topics was offered as a practical solution for improving teaching climate change in their undergraduate chemistry course. Expansion of climate change topics into an interdisciplinary approach was also highly encouraged by the interview participants.

Introduction

Humanity has contributed to the growing global problem of climate change. The Intergovernmental Panel on Climate Change (IPCC) has projected serious ramifications for the status of the planet even if the most aggressive actions are taken (Lee et al., 2023; Ming et al., 2021). The planetary boundaries framework outlines environmental issues which will result in the greatest endangerment of humanity (Lade et al., 2020), such as biodiversity, access to natural resources, and biogeochemical flows (Folke et al., 2021; P. G. Mahaffy & Elgersma, 2022). Two prominent strategies to address climate change are mitigation and adaptation which require an adequately educated populace to implement (Baskaran, 2016). Education is necessary to build upon the societal pressures to influence meaningful change (Ledley et al., 2017). The structure and delivery of this content is complex due to the need for a systems perspective which incorporates multiple disciplines such as physics, chemistry, biology, etc. Chemistry plays an essential role in understanding climate science (Matlin et al., 2016).

The United Nations, along with other governmental and professional organizations have provided recommendations and resources for improving the presentation of climate change information (Bodansky, 1993; Doherty et al., 2009; Leslie, 2016; Ming et al., 2021). Despite the overwhelming scientific consensus, topics surrounding climate change are particularly politically divisive in the United States. However, Americans often misperceive the acceptance of climate change and the support for climate action by more than 50% (Sparkman et al., 2022). An assessment of where climate change education occurs, in addition to potential barriers for instruction may inform on potential reform efforts (Reid, 2019). Chemistry instructors' influence and perspective will be important in those reforms along with shaping students' response to the impacts of climate change.

Research into German secondary chemistry instructors' attitudes regarding climate change found instructors viewed the topic to be important to teach, though the extent of integration of the topic into their teaching varied extensively (Feierabend et al., 2011). Additionally, Indonesian science instructors also expressed the importance of increasing student competency around understanding issues like climate change, though nearly all lacked integration of such content into their instruction (Nida et al., 2020). Despite these examples, no such study has been conducted in the United States regarding undergraduate chemistry instructor's perspectives on teaching climate change in their courses. Our study seeks to answer the following research questions:

Q5.1 How do instructors make decisions about how to include or not include climate change in their instruction?

Q5.2 What are instructors' perspectives on strategies for including climate change and other related subtopics in their instruction?

Q5.3 In what ways do post-secondary chemistry instructors incorporate climate change in their instruction?

Theoretical Framework

Educators play a central role in influencing change within their students. Instructor's views can have an impact on the teaching and learning of the nature of science and scientific processes (Duit et al., 2008). An instructor's conceptions can also act as potential obstacles to improving their own instructional practices (R. D. Anderson & Helms, 2001). Examples of these barriers could be described as technical, cultural, or political (Johnson, 2006). However, the adoption of educational reform efforts in chemistry is limited (Lund & Stains, 2015; Raker et al., 2021). Studying instructor's conceptual processes provides insight into how greater change can be turned into further transformative action.

Efforts in education reform have a history of challenges with issues starting from implementation to sustainability of reforms. Woodbury and Gess-Newsome (2002) describe this phenomenon as "change without difference". They describe teacher thinking as a key pillar in reform efforts that seldom change the manner instructors seek to implement changes. The Teacher-Centered Systemic Reform Model (TCSR) further emphasizes teacher thinking as a key mechanism for educational reform (Gess-Newsome et al., 2003). The instructor is an important figure in the shifting paradigm of educational reform based on their interaction with students along with the sphere of influence that is maintained within the classroom.

The instructor's conduct in their course represents the teacher's pedagogical content knowledge as well as their curricular design (Gess-Newsome et al., 2003). The TCSR highlights relevant thinking, interaction, and influence as it relates to the instructor's role as the primary vehicle for course reform. Contextual factors, personal factors, and instructor thinking influence reform through this model. Contextual factors involve areas of cultural, school-wide and course areas. Personal factors describe information regarding the instructor's educational background, teaching experience, age, and ethnicity. Instructor thinking comprises course planning, experiential expectations, which also includes the knowledge and beliefs around teaching. Instructor thinking, including their knowledge and belief around teaching, also extends to the types of students taught and the course content. Each domain factor (teacher thinking, conceptual, personal) connects with a willingness to make meaningful changes in their teaching practice (Popova et al., 2020). Only a small number of instructors are needed to promote reform efforts which have the capability of transformative change not only within their courses but can extend outward to the institution at large (Cohen, 2002). It is through the perspective of this framework that the following research was conducted.

Methods

This qualitative study investigated instructor perspectives about including climate change in their educational practices in college chemistry courses. All the protocols used in this study were approved by the Institutional Review Board (IRB) of the University of Northern Colorado (see Appendix A for IRB approval letter).

Participants

Stratified sampling methods were used to gather undergraduate chemistry instructors from across the United States for online interviews. Selection was organized based on regional areas of the United States (such as West, Midwest, Northeast, and South). Recruitment for this study was carried out through email communications from email addresses gathered from their corresponding department websites. Consent was obtained electronically from all participants (see Appendix CB. Each of the participants was labelled with a number to ensure confidentiality. In total, 16 individuals participated in this research hosting a diverse background in chemistry experience and areas of expertise (Table 5.1). No compensation was provided for participation in this research study.

Table 5.1

Participant Demographics

Participant	Course	Position at university	Age range	Gender	Race
1	Allied Health	Lecturer	35-44	Male	White
2	Analytical	Professor	55-64	Male	White
3	Biochemistry	Senior lecturer	45-54	Female	White
4	Analytical	Professor	45-54	Female	White
5	Biochemistry	Professor	35-44	Male	White
6	General	Assistant professor	35-44	Female	White
7	Chem for non-majors	Professor	55-64	Male	White
8	Inorganic	Assistant professor	35-44	Female	Black
9	Physical	Assistant professor	35-44	Male	White
10	Physical	Adjunct professor	45-54	Male	White
11	General	Career instructor	35-44	Female	Asian
12	Biochemistry	Professor	55-64	Female	White
13	Biochemistry	Professor	35-44	Male	White
14	General	Teaching professor	55-64	Female	White
15	Environmental	Professor	45-54	Female	White
16	General	Vice provost, distinguished professor	55-64	Female	White

Data Collection

Participant data was collected through a semi-structured interview protocol (Appendix D) that took approximately 30 to 60 minutes. The interviews were conducted over Zoom during fall of 2021 through summer 2022. After the interview, AI-created Zoom transcripts were checked for accuracy. Repeated words and stammers (for example "um" and "ah") were removed. Any identifying information mentioned by the participants was de-identified and aliases were provided. For example, the name of a school was replaced with "[school name]." The interview protocol was designed to determine how instructors viewed climate change in relationship to their instructional practice. Once the participant's view of climate change as an educator was established, the interview sought to connect the decision-making processes for how climate change was or was not included in their teaching. Participant's teaching philosophy was also discussed to establish teacher's values on teaching with their instructional practice. At the end of the interview, instructors were asked about their thoughts on improving how climate change was taught in chemistry. This question also served as a point of reflection for the instructor's own teaching on the subject. Instructors considered their approaches to include climate change in their teaching and also gave their perspectives on how the topic could be addressed in other areas of chemistry or other courses.

Data Analysis

Open coding was applied to the transcripts using reflexive coding analysis (Braun & Clarke, 2019) in NVivo 12 to identify themes related to climate change and/or other related subtopics as they were included (or not) within instructors' course(s). Coding was carried out following Braun and Clarke's (2019) process of data familiarization, generation of codes, constructing, reviewing, and defining themes. Codes identified from the transcript were comprised of short annotations relating to climate change in their teaching. From the codes produced, the series of codes were compared and grouped according to their conceptual relationship to one another, then were further grouped into larger themes. These themes were further organized according to the research questions.

Validity and Reliability

Once the codebook had been developed, three coders independently coded 25% of a random sample of the total interviews collected. Several weekly meetings were held to review and begin establishing the intercoder agreement for each of the codes from the independent researchers' codebooks. There was initially an intercoder agreement of 92.4%. Following discussions on the disagreements, the researchers came to agree on all codable items. The remaining interviews were coded independently by two researchers. Further meetings were held to answer any related coding questions.

Results and Discussion

Instructor Decision-Making About Climate Change Inclusion

Instructors' decision-making about climate change instruction was guided through multiple factors (Table 5.2). The perspective that climate change is an important topic for their students to understand motivated the inclusion of the topic in their teaching. Student interest in climate change also served as a source of encouragement for instructors to include the topic in their courses. The ability for the instructors to incorporate climate change topics in their teaching was guided by their previous knowledge of climate change, their agency or ability to exert changes in their teaching, and the awareness and utilization of educational resources.

Table 5.2

Areas That Guided Instructor Decision-Making

Code	Definition	Example
View of the importance of climate change	Instructors view climate change as an important and essential topic for students to understand	I think, to me, it’s important as an educator (to come back to your question) to have students understand what’s going on, and how it’s going to negatively impact future generations (P11)
Students’ interest in climate change	Students’ interest in climate topics influences instruction for including climate change topics in their classes	That’s one of our most popular classes, we don’t offer a lot of electives, but that one is constantly full, because I think students are interested (P13)
Instructor incorporation of climate change from previous knowledge, agency, and use of educational resources	The instruction has a clear understanding of climate science and the ability to use related sources in class	I did a post-doc actually in [location], on atmospheric chemistry. […] climate change is the topic of about seven weeks of class (P15)

***Instructors’ Views of Importance of Climate Change Guides Decision-Making*.**

Instructors that expressed climate change as an important issue also communicated the necessity of having students be knowledgeable about future climate related challenges (Table 5.2). For example, a participant said:

> Participant #11 (General): I teach chemistry, we do come across situations where I'm using some examples in my own classroom to talk about how certain reactions or certain processes impact the climate, right. But I think, to me, it's important as an educator to come back to your question, right to have students understand what's going on, and how it's going to negatively impact future generations.

Perspectives on the importance of climate change have grown throughout the United States (Marlon et al., 2022). However, though instructors may view climate change as an important issue, many instructors do not incorporate climate change in their instructions (M. Chowdhury et al., 2021; Dawson, 2012).

Students' Interest in Climate Change.

How students engage with climate change material influenced instructors to either include or not include climate change. Participant #7, an instructor who taught chemistry for non-majors at a rural institution described the students' interest in climate change as a driver for their inclusion of the topic in their course Current generations of students broadly show interest in learning about climate change (Nadeem, 2021). Reflective of Participant #7's experience, undergraduate students in particular desire to learning more about mitigation efforts (Jordan et al., 2023; Tolppanen et al., 2022).

Another instructor, who also thought climate change was important, considered the student population of their course, pre-health majors. The goals of those students were focused on their health-related career goals. This instructor's viewpoint was that any content not related to those goals would not hold the students' interests.

> Participant #1 (Allied Health): It's less related to medicine... They are all incredibly motivated students, but they just want an A in the class like they have, they don't have any interest in the material whatsoever. That just enough interest to get an A in the class.

This instructor's decision making was guided by the idea that any content that could be perceived as outside of achieving career goals would be met by a lack of interest from students. However, pre-health education has also indicated the need to address complications of climate change on healthcare patients (Morin et al., 2022). There is potential to connect climate change with a pre-health course that aligns with the future demands of those professions.

Instructor Knowledge, Agency and Resources Available Guide Decision Making

Several characteristics were presented among the interview participants that contributed to their reasoning for connecting climate change and chemistry in their teaching. Instructors who had previous knowledge about climate change could draw on their experience when teaching their subjects. However, they also had to have agency in their courses to make changes as well as have access to resources to facilitate those changes to their courses. The participants that did not incorporate climate change in their teaching were often hindered by one, or more of those reasons.

Use of Resources Guiding Decision-Making

The use of educational sources can act as a tool for incorporation based upon the presence and extent of climate topics (Table 5.3).

Table 5.3

Instructor Use of Resources

Code	Definition	Example
Guided by textbooks	Material contained within textbooks influence the structure and content of climate change details in courses	I did have to write it up in our electronic textbook, including figures, homework problems, you name it, all sorts of stuff. Because you can imagine that in general, this is like, if I asked you to teach Gen Chem, you're not going to go writing your own textbook (P14)
Institutional influence	The university sponsors or encourages activities that promote the inclusion of climate change in course content	I took part in a weeklong intensive teaching workshop here; and that really helped me focus more on alignment of the class (P15)
Guided by assessment	Structure of assessment highlight the importance to include a topic within instruction	I know that I can't really get students to engage if it's not something I can test them on, it's got to be really, like tightly link to what we're already expect them to know (P14)
Not enough climate change resources	A lack of teaching resources and support prevent inclusion of climate change in courses	And our textbook also it doesn't really, if I were to quickly look it up, it doesn't really talk specifically anything about climate change (P11)

Guided by Textbooks

Educational resources like textbooks can aid in the structure and design of the course (Schmidt et al., 2002; Valverde et al., 2002). For Participant #11, another general chemistry instructor, the textbook acted as a hinderance. They said, "our textbook also it doesn't really, if I were to quickly look it up, it doesn't really talk specifically about anything about climate change." In this example, the lack of climate change content was left up to the instructor to fill in the gap with other resources.

This is contrasted to Participant #14, a general chemistry professor, who was the author of their program's general chemistry textbook. The inclusion of climate change topics in their book was scaffolded in such a way that the content appeared in multiple places throughout the book, like figures, homework problems in addition to the main text.

Institutional Influence

The institutions of some of the interview participants sponsored teaching workshops and seminars to aid in aligning course objectives and with their teaching. Participant #15, an environmental chemistry instructor, described how they used the workshop as an opportunity to improve their course alignment.

> Participant #15 (Environmental): I took part in a weeklong intensive teaching workshop here. And that really helped me focus more on alignment of the class. And so that made me think critically about what do I want students to get out of each topics that I cover […] I added carbon capture.

Other instructors took mandates from their institutions around themes such as ethics in science to choose to incorporate climate change within that framework.

> Participant #14 (General): Our whole university wants us to incorporate ethics into the curriculum. And as part of that, they have faculty do weeklong trainings in ethics, and as part of that training, you're expected to put together an assignment for your class. And I had begun to develop a ethics activity around climate science before I participated in the actual workshop. So, I was starting to kind of get the feel, but then I did the workshop,

refined it more. And basically, then over the last, again, three or four years now been sort of slowly working on an ethics activity.

Support for professional development has an established practice in improving educational reforms (Little, 1993; Rhoton & Bowers, 2001). Professional development that incorporates climate change not only improves students understanding of the topic (Drewes et al., 2018), but improves teacher and student self-efficacy (Li et al., 2021; Shea et al., 2016). Faculty will also need continued support to effectively teach climate change topics (Kirk et al., 2014).

Guided by Assessment

An uncommon theme among faculty was the perspective of the importance of a class topic being reflected on an assessment. To ensure that this level of significance is not lost upon the students, one participant also incorporated elements of climate change in classroom assessments.

> Participant #14 (General): Because just telling them stuff or trying to throw a topic in there, if it doesn't connect back to what I'm going to be putting on a test and what to expect, it's a waste of time [...] So I had to make sure that it connected up with what we were doing.

Many students triage their study time to focus upon the topics that are most expected to appear in their assessments. When this instructor decided to introduce topics or give related examples, they ensured those concepts were linked back to an assessment.

Not Enough Climate Change Resources

Several of the interview participants expressed a lack of teaching resources as a barrier to their ability to integrate climate change into their course materials. Textbooks were a common area where these topics were viewed as being insufficient or absent altogether.

> Participant #13 (Biochemistry): I think that biochemistry one does, again, in that realm of photosynthesis in terms of carbon fixation. It might be just like a little sidebar… so it might be a quarter of a page, and that's it. So, it's not something that really comes up frequently. And if I do want to bring it up, it's usually me bringing it up.

Other instructors echo the sentiment of the lack of climate change inclusion in textbooks and a need to make more explicit the chemistry of climate change.

> Participant #7 (Chemistry for Non-Majors): Over the years, the atmospheric chemistry is squished […] And because I feel that the climate change was so important, I wanted to make sure they understood all the different parts and the textbook treats it all somewhat lightly, that they make it sound serious, but they don't give them enough details to understand the connection. So, the vibrational modes of CO_2 or water. They don't explain that. And so how can you understand how the sunlight is getting its energy trapped in the atmosphere if you don't explain that.

Textbook issues came up among five of the participants. Either the instructors had to bring in outside materials to include climate topics or in the case of participant #14, develop their own textbook all together. These decisions aligned with the instructor's self-reported importance of climate change demonstrating their motivation to select topics that are valued by them.

Instructor Has Knowledge About Climate Change and Access to Resources

The expertise of many of the interview participants varied across each of the major subdisciplines of chemistry (Table 5.4).

Table 5.4

Previous Knowledge of Climate Change Guided In-Class Inclusion

	Code	Definition	Example
Reason to include	Instructor has knowledge about climate change and access to resources	The instruction has a clear understanding of climate science and the ability to use related sources in class	I took a class in atmospheric chemistry that had a climate change unit (P4)
Reason to not include	Lack of climate change knowledge	Instructor does not have enough knowledge or experience with climate change	I'm afraid I'm not really very familiar with these that are specific to climate change (P10)

For example:

> Participant #4 (Analytical): I took a class in atmospheric chemistry that had a climate change unit. I'm, trying to, you know, a lot of the classes or some of my environmental classes were talking about just, you know, the global carbon cycle and stuff like that. So of course, it was part of those discussions.

During this instructor's undergraduate training, they took a course specifically in atmospheric chemistry which developed their scientific understanding of climate change. Participant #15 took part in a postdoc which informed their background in climate science. They said, "I did a postdoc […] on atmospheric chemistry. And so, I sat in on my postdoc advisor's course on atmospheric chemistry." Many of the participants who explicitly included climate change in their course materials were able to do so because of their previous experience in the field (4 participants).

***Lack of Climate Change Knowledge*.**

Other instructors, while still viewing the topic as important to them as educators, often did not feel confident in the material to effectively incorporate it into their courses. For example, Participant #8 said “I think just my assumption is they will take an environmental chemistry, they don't need me, because I honestly...I feel like, I'm not as confident in all the data.” Instructors like Participant #8 were aware of their limitations on climate change content knowledge, which influenced them to not teach about climate change. Previous research reinforces the sentiment of Participant #8; not having enough previous knowledge of climate change leads to instructors being less likely to teach it themselves (M. Chowdhury et al., 2021; Seroussi et al., 2019). To bridge the gap between knowledge and comfort in teaching climate change, additional support is needed either through the institution, workshops, (Carson & Dawson, 2020), or other professional development opportunities (A. Anderson, 2012; Carson & Dawson, 2020; Kirk et al., 2014).

Instructor Autonomy and Agency to Enact Changes In Their Courses

The ability of the interview participants to make changes in their courses presented as reasons towards including climate change as well as reasons against including climate change in their instruction (Table 5.5).

Table 5.5

Instructor Autonomy and Agency to Enact Changes in Their Courses

Code	Definition	Example
Reason to include		
Instructor has agency over course content	Agency over course details is managed by the instructor as well as any decisions related to course structure and content	Over the years, the atmospheric chemistry is squished, the earth chemistry to be very small. And because I feel that the climate change was so important, I wanted to make sure they understood all the different parts (P7)
Depth over breadth	Content details of climate change are more important than a multitude of concepts	Because I care about depth rather than breadth (P15)
Guided by emotional toll of climate change	The emotional impact over the implications of climate change guide instructors to cover climate topics in their courses	I was like. Well, it's super depressing when we end the climate change unit. What can I do about that? And so last year, I added, all sort of the mitigation strategies (P15)
Reason to not include		
Class structure guided by someone else (coordinator, predecessor, previous notes, etc.)	Instructor does not manage details or direction around course content, limiting their choice flexibility.	I can't make changes to the topics that are covered (P6)
Content restrictions due to time or course expectations	Objectives of the course restrict the addition or inclusion of climate change	I think there's too much content in Gen Chem, if you think, particularly over the whole year, but each semester, the way it's traditionally laid out, there's too much content (P16)
Instructor avoids politics	Due to the political polarization of climate change, instructors choose to stay away from these topics	Unfortunately, climate change is a politicized issue. I want to be able to, I don't know, I want to be careful about how I approach climate science (P6)

Instructor Has Agency Over Course Content

Where some courses are restricted by the content expectations required of the course, other participants have more direct agency over the structure and delivery of their content. In one such case, Participant #14, found that the structure and manner of topic scaffolding allowed for easier by-in from other faculty members involved in teaching the same course. The organization of the material was what made the adoption and integration of topics to be the most successful within a teaching group.

> Participant #14 (General): I'm so familiar with the content of this class, because I've taught it so many times that it wasn't hard for me to go, oh, we could just put this and I mean, in a way, I put it in piecemeal into my lectures. But in order to get other people to do it, I did have to eventually integrate it with what we were doing throughout the course. And I did have to write it up in our electronic textbook, including, figures, homework problems, you name it, all sorts of stuff. Because as you can imagine that the general, this is like, if I asked you to teach gen chem, you're not going to go writing your own textbook, you're going to start with textbooks, figures, things, lecture notes from somebody else, everything. And that's the same here.

Disciplines, such as mathematics, have described the relationship of textbooks as a vehicle for educational reform (Gracin & Matić, 2021; Skinner & Howes, 2013). Chemistry instructors have a tendency to stick with traditional representations of chemical concepts in their textbooks (Vojír & Rusek, 2021). The use of an incremental approach has shown beneficial outcomes in STEM education (He, 2021) and could be used to address broader reform strategies at the institutional level (Dedeurwaerdere, 2013). However, the incremental approach at the instructor level may work best for instructors who teach the same class for multiple years.

Instructor agency increases their cognitive presence in the learning environment but also has impacts over how learners interact with their course content (Costley, 2016). Control over course content can extend to other instructors in the same teaching group, which can further benefit the organization and delivery of the course curriculum (Wild et al., 2018).

***Depth Over Breadth*.**

Where the amount of content to deliver among some of the participants was viewed as a limiting factor to their inclusion of climate change material, other participants structured their courses with a more detailed focus in mind. Participant #15 converted their course to cover less material and focus on climate change. They described their reasoning, saying:

> Participant #15 (Environmental): I had the person who taught the class before me, so I had what he did. But again, it wasn't enough depth for me, it was more breadth. But at least I had that baseline. And then it's just been an evolution over time of both the material but also how do I want to engage with students and what I want students to know.

Though the consequence of this style of teaching reduced the overall number of topics covered in the class, the trade-off might leave the students with a better understanding of the material in an area that will have the greatest implications for their future. A focus on more in-depth topics in high school science courses has been shown to correlate with greater success for those students in college (Schwartz et al., 2009). At the college level, Participant #15's perspective is shared with other chemistry professors who view the depth of a topic as essential for developing conceptual understanding (Holme et al., 2015). Tension still persists when chemistry instructors are asked about their views on depth versus breadth which were influenced by their personal and contextual factors (Kraft et al., 2023).

Additionally, Participant #15 outlined the order of the course content so that the most important topics in the course, climate change, were addressed first before students became fatigued towards the end of the term.

> Participant #15 (Environmental): What I want them to get out of the class is really about climate change, because it's the main thing that's going to affect their future. So now, I go through the textbook backwards during the semester. And that way, I get the students learning about climate change when they're going to be the most engaged in the class because it's earliest in the semester.

Backwards design involves first focusing on the learning outcomes when designing a course (Wiggins & McTighe, 2005). Backwards designed courses generally outperform more traditional course delivery structures (Kelting-Gibson, 2005; Martin et al., 2019). Particularly in undergraduate STEM courses, backwards course design has benefited both teachers and students in the course (Daugherty, 2006; Hills et al., 2020; Mertz & Neiles, 2020; Villalta-Cerdas & Yildiz, 2022) and in the lab (Neiles & Arnett, 2021).

Guided by the Emotional Toll of Climate Change

When teaching climate change, the future effect on the planet carries a negative emotional connotation. Emotions also served as a motivating influence over instructor’s choices as to why and/or how they include climate change in their instruction. For these instructors, the realities of climate change do not uplift a lot of positivity in their instruction. However, in order to combat the potential issues of apathy over the repercussions of climate change, some instructors sought to use hopeful messaging to extend their instruction to foster student engagement. For example, Participant #3 said, “I also have moved to a place where I'm trying to integrate something hopeful… guiding them to resources that might spark a little bit of hope.”

This instructor spoke of their decision to add hopeful components to their lessons to temper the depressive effects of teaching climate change. Additionally, by including more hopeful content, students will see helpful opportunities outside of the course.

Class Structure Guided by Someone Else

Two of the participants discussed how they inherited or were influenced by the previous instructor of their course or by another faculty member within their department. The use of the instructor's own undergraduate notes acted as the foundation of their teaching.

> Participant #9 (Physical chemistry): So practically speaking, the answer is I just went through my (undergraduate) notes, which are pretty nice. I took really good quality notes in that course, I never had the idea that I might teach it one day. But I was lucky that when I went when I arrived here, I mean, I had to teach a week after I got here. So, I was like, wow, so I just opened up my notes and started lecturing out of them… I figured out the timing a little bit and tried to just follow in his footsteps.

The influence of other instructors lays the foundation for how the subjects course content continue to be taught to future generations.

Content Restrictions Due to Time or Course Expectations

Many chemistry courses have specific content areas that need to be fulfilled while also facing the constraints of the time available to cover topics. This type of limitation was most often expressed by general chemistry instructors (3 total). For Participant #6, a general chemistry instructor, the amount of content they thought was expected to be covered placed restrictions on the agency they had for the topics they covered. They said, "I can't make changes to the topics that are covered… so the one thing that we can't change is that all these topics must be covered."

Course content restrictions have been one area targeted for curricular reform in chemical education (Cooper, 2010; Lloyd & Spencer, 1994; Petsko, 2004). Efforts in chemistry education reform through institutional support both from within the department and the college showed that changes can be successful (Cooper & Klymkowsky, 2013; Talanquer & Pollard, 2017). As a newer faculty member, Participant #6 may not be in a place to solicit the extensive support needed to enact any curricular reforms at this time.

Instructor Avoids Politics

The nature of climate change discussions in public discourse involves the intersection of many different ideological perspectives and viewpoints spanning not just the scientific but also political and economic implications. For example, Participant #15 used newspaper articles to bring in current events into their course but was careful in their selection of the materials to avoid inviting political connections. They said:

> Participant #15 (Environmental): we cover newspaper articles, students are up to date on current events, and this changed every year, of course…, I wasn't trying to include politics in the class. But it was inevitable because of the types of articles that I was bringing into the class. Right, because of what was going on in the world at that time. So now, I'm super careful about the newspaper articles that I bring in.

Instructors often avoid potentially controversial topics from either a lack of confidence or knowledge in the subject area along with concerns of reactions from students, parents, and other community members (Cassar et al., 2023; Garrett & Alvey, 2021). Participant #15 fits into what has been previously established of environmental instructors addressing the scientific areas of climate change while avoiding political connection to the topic (Bhattacharya et al., 2021; Kranz et al., 2022). Several chemists in their field have written calls to action to combat the politicization of science. However, as long as the scientific and political climates remain highly polarized then instructors will continue to seek to avoid inflaming the conflict.

Instructor Perspectives on Improving Climate Change Education

When instructors were asked about their thoughts on improving how climate change is taught in chemistry, they suggested expanding instruction, ways they could teach, and that small incremental changes can be productive (Table 5.6).

Table 5.6

Instructors' Suggestions on Improving Climate Change Education

Code Definition	Example
Climate change coverage in chemistry and interdisciplinary courses. Which courses are the best fit for climate change topics should be addressed.	In my opinion, it should be addressed immediately, in every gateway course. It should be foundational to the first-year seminar, it should be foundational to gen bio, to gen chem…not only should we have first year seminars built around, but it should be in every frontline, every first-year course. (P3)
Small incremental approaches to changes are worthwhile. Introducing small curricular reforms over time will have meaningful change.	I took the incremental approach to look for the openings. There are obvious, take those little steps. I think almost anyone can do that. And that's not a bad way to go[...]my advice definitely is incremental, come up with a single thing, one lecture or even half a lecture, but, a learning objective, it should be linked to what you're expecting already, like suddenly saying, well, we never even go into anything[…]We did a little bit here, a little bit there. And all sudden you start putting us together about that I got a lot. (P14)
Make explicit connections to climate change. Overt connections are the optimal way to instruct students about climate change.	I think, directly with just focusing on chemistry for climate change would be good […] I as an instructor can understand what's the big picture here, where's the connection here? But the students cannot see these different parts of the puzzle that they really fit in together, that the idea of energy crisis is really fitting together to what we are dealing with. (P11)

Climate Change Coverage in Chemistry and Interdisciplinary Courses

Instructors who were not currently teaching climate change, viewed other courses to be a better fit for the content.

Participant #1 (Allied Health): I think the best place for it is [...] analytical, because it's really about the detection of those things, which is more analytical type stuff.

Since the classes that participant #1 taught were specifically designed for pre-health majors, their perspective on teaching remained focused on content that aligns with health-related objectives. Their view remained consistent with climate change being an important topic that is better related to more explicit examples. For instructors already teaching climate change content, their viewpoint was from the perspective of where the largest group of students would be exposed to the topics.

> Participant #13 (Biochemistry): There's a lot of places where I think it's relevant. I think we have a large number of people taking first and second semester Gen Chem and a much smaller number of people taking analytical, physical, BioChem in the department. And so, I think from a point of view of getting students exposed to it, I think it makes sense to put in those big classes.

This instructor highlighted the importance of getting students exposed to the content early since most of the student’s taking chemistry tend to do so just in general chemistry. Many of the students who take chemistry courses tend to not be chemistry majors themselves, which has the consequence of locking them out of connections that might not be made until later classes. For this instructor it was important to structure earlier chemistry courses around making these meaningful connections so that the widest body of students will encounter it. Furthermore, among those currently teaching climate change, they also expressed suggestions for expanding climate content further outside of chemistry.

> Participant #3 (Biochemistry): in my opinion, it should be addressed immediately, in every gateway course. It should be foundational to the first-year seminar, it should be foundational to gen bio, to gen chem... Not only should we have first year seminars built around it, but it should be built in every frontline, every first-year course.

Similar to the views discussed by participant #13, participant #3 considered an interdisciplinary approach to be essential for students to receive exposure to climate change material. Previous research has shown benefits of interdisciplinary instruction for supporting students in learning about climate change (Davison et al., 2014; Pharo et al., 2012; Todd & O'Brien, 2016). By integrating climate change content across courses, students can experience a more rounded perspective and develop a deeper understanding of multiple aspects related to climate change.

Small Incremental Approaches to Changes Are Worthwhile

Some of the participants reflected on their method of including climate change in their courses. For several, taking small steps over a longer period was an effective strategy to develop climate change content in their chemistry instruction.

> Participant #14 (General): I took the incremental approach to look for the openings. There are obvious, take those little steps. I think almost anyone can do that. And that's not a bad way to go...my advice definitely is incremental, come up with a single thing, one lecture or even half a lecture, but, a learning objective, it should be linked to what you're expecting already, like suddenly saying, well, we never even go into anything…We did a

> little bit here, a little bit there. And all sudden you start putting us together about that I got a lot.

Participant #14 incrementally changed their course over many years. This was facilitated by the instructor's consistent course assignment. An incremental approach to learning has also been developed in other fields, such as agriculture, to aid in adaptation measures to address the impacts of climate change (Winarto & Stigter, 2016).

Make Explicit Connections to Climate Change

For the importance of climate change to be effectively communicated to their students, many of the participants mentioned the need to be direct about content associations to climate change.

> Participant #11 (General): I think, directly with just focusing on chemistry for climate change would be good […] I as an instructor can understand what's the big picture here, where's the connection here? But the students cannot see these different parts of the puzzle that they really fit in together, that the idea of energy crisis is really fitting together to what we are dealing with.

The connection of climate change to chemistry required these items to be pointed out to students. Gaps can form in student understanding if the instructor does not take the appropriate steps to lay out the information effectively. For Participant #11, the energy crisis was an area where students struggle seeing the greater perspective and how it relates to climate change. The instructor conveyed the idea that only through deliberate teaching would these barriers be adequately lowered. One instructor underlined the issue between qualities of the instructor and the materials available to them.

> Participant #7 (Non-Majors): You definitely need to be an instructor who seeks out information. […] I will also say that in general chemistry, you're not going to get somebody who's going to introduce a lot of climate change unless it's in the textbook, because you know, they have to march through a particular collection of material that is nationwide, recognized as being the curriculum, and they don't want to deviate.

Reform efforts in chemistry often conflict with the traditional design of how the content is historically laid out (Cooper & Klymkowsky, 2013; Vojír & Rusek, 2021). For this instructor textbooks have a degree of responsibility for providing instructors with examples to teach the chemistry of climate change.

Ways of Incorporating Climate Change Into Chemistry Instruction

The extent of climate change instruction varied throughout all interviews. These instructors either did not teach about climate change, taught about it tangentially, or taught about climate change in multiple ways. Three of the 16 participants did not teach about climate change. For example, Participant 8 said, “honestly, we don't really discuss climate change.” In the quote, “we” referred to the course. The “taught multiple ways” subcategory was found to be broad, including ten out of the sixteen participants. Additionally, this category spanned everywhere from two example problems of climate change to an entire unit dedicated to climate change. For example, Participant 15 explained, “climate change is the topic of about seven weeks of class of the environmental chemistry, it's the first seven weeks.” The final subcategory of extent pertains to the three interviewees that did not teach climate change directly but discussed it in passing.

Participant #16 created a literature reading assignment where students could opt to review an article about climate change. For example, this participant responded with the following after being asked if they teach about climate change in their course,

> Participant #16 (General): Very peripherally […] I did introduce some opportunities for students to connect to climate change kinds of things […,] one of a number of things they [the students] could latch on to in the journal […] probably a third of them had some sort of research agenda that was connected to climate.

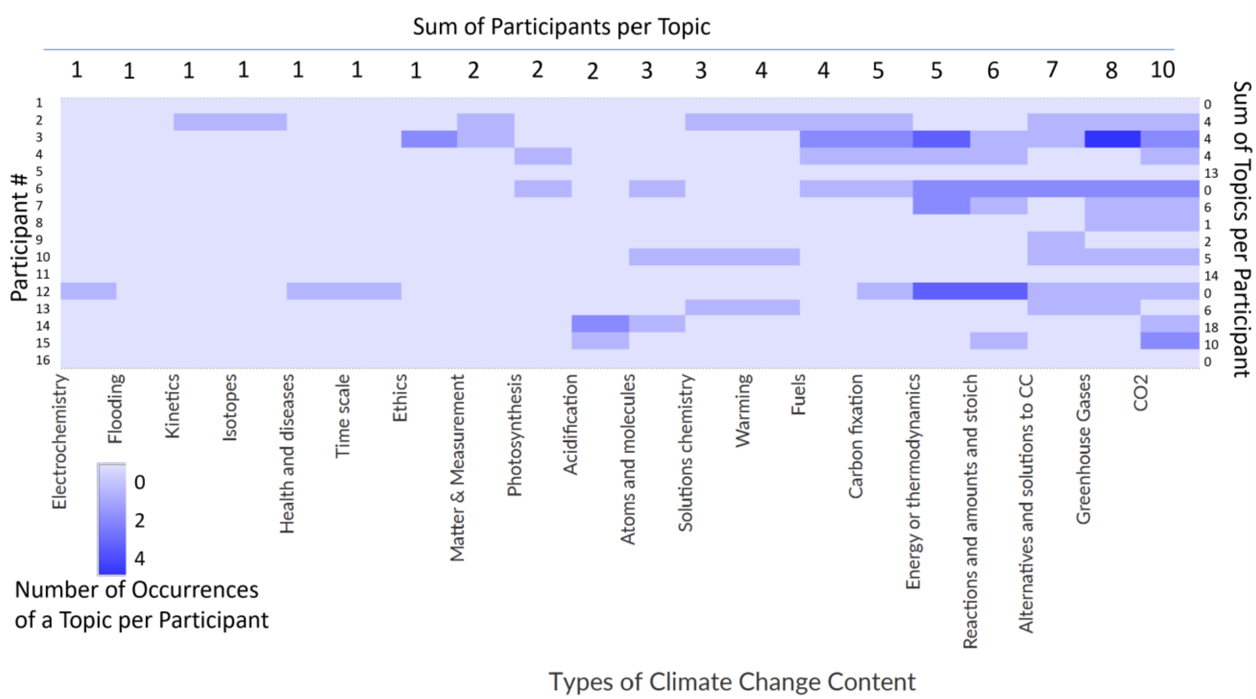
Since the students had the option to do the assignment without using an article related to climate change and the instructor described their climate change teaching as peripheral, we characterized this instructor as tangentially teaching about climate change.

For instructors who discussed climate change they did so in lectures, literature readings, assignments or exams, discussions, media, and textbooks. A highly coded location of climate change was lectures, (eight of the participants). To be coded under lectures, the participant needed to state a climate change topic that was explored in the course throughout the class but not as a part of a class discussion. Participant 14 said "I was covering [climate change] in lecture without the textbook backup for 10 years now." Five out of 16 participants used literature- research papers, articles, etc.- in their courses to teach climate change. Participant 3 said, "with the climate change course, the way we structure around that action learning is that we start with literature that kind of intertwines." This subcategory closely ties to media, which was distinguished as outside sources such as podcasts, videos, pictures, etc., to enhance learning. Media did not include research articles. Participant 7 explained their use of media as "using movie clips to teach chemistry, but also documentaries that you can use in your classroom […] So my students were very interested in the impacts of climate change." Six out of 16 participants used assignments for climate change content. For this section, any graded content was included, such as a worksheet, homework assignment, or exam. The most popular outlet for climate change topics was in class discussions (with nine out 16 participants) describing the use of in-class discussions. Participant 3 stated, “I am very overt about discussing [climate change] … looking at it as the center of the discussion.” The final outlet for climate change instruction was through the textbook. Only four out of sixteen participants claimed to discuss climate change through this outlet, and Participant 14 explained, “we've got [climate change] content written into our textbook, probably for at least three years now, maybe more." The outlet used to teach climate change might impact how much climate change is discussed and therefore, how much students could take away from that discussion.

The final subcategory of the first research question examined what type of climate change content was being taught (Figure 5.1). The types of climate change topics that these instructors discussed were similar to the organization outlined in the Visualizing the Chemistry of Climate Change (VC3) by Mahaffy et al. (2017). VC3 organizes key chemistry concepts, such as gas chemistry or chemical bonding, and relates it to climate change through connecting topics, like global warming potential and molecular energy absorption at different spectral regions. Carbon dioxide was the most coded type of climate change content (10 out of the 16 participants). An example of a code was when Participant 2 said, “we do talk about […] in the sense that carbon dioxide released carbon dioxide is the primary driver for climate change” Carbon dioxide was quickly followed by greenhouse gases (8 out of 16 participants). This made sense as CO_2 is an example of a greenhouse gas. However, greenhouse gases were a broader climate change topic. For example, Participant 4 stated, “I include the basic science of greenhouse gases." Alternatives and solutions were also highly coded (7 out of 16 participants). This topic included any current strategies to prevent or mitigate climate change which was evident when Participant 15 expressed, “last year, I added, all sort of the mitigation strategies. So, I had already had fossil fuels and renewable energy in the class.” Reactions and amounts were another example of content with many codes (6 out of 16 participants). Participant 11 stated, "I'm using some examples in my own classroom to talk about how certain reactions or certain processes impact the climate." An example of a topic with few codes is acidification, which was only coded in two interviews. Participant 2 explained their use of acidification in their course when they said, “we do talk about ocean acidification, which is related to climate change." It is important to note that there was a wide span of content being taught between the participants.

Figure 5.1

Heat Map of Participant’s Frequency of Climate Change Content Present in Their Interview



Limitations

The voluntary nature of the participants limited the scope of this study. The recruitment materials mentioned climate change. Thus, participants may have self-selected based on interest in the research topic which could narrow the perspectives provided in this study. A participant initially thought they should not participate because they did not connect climate change to chemistry in their courses. However, they did decide to participate in the study. The number of potential participants that self-selected out of the study cannot be fully known. Despite this issue, the data collected in this study demonstrated a variety of views that address the research questions and yield meaningful insight into the instruction of climate change by this set of instructors.

Conclusions and Future Directions

Though these undergraduate chemistry instructors viewed the topic of climate change as vitally important for their students, the extent of coverage of the topic often varied. This study examined how these instructors decided to include or exclude climate change and what they thought might be done to improve climate change content in chemistry in the future, and the topics they found important for teaching climate change.

These instructors either did not teach about climate change, taught about it tangentially, or taught about climate change in multiple ways. For instructors who discussed climate change they did so in lectures, literature readings, assignments or exams, discussions, media, and textbooks. The most frequent climate change content discussed by instructors was carbon dioxide, greenhouse gases, and alternatives and solutions, whereas topics like kinetics and isotopes were discussed less often. These connections between chemistry and climate change are reflective of the organization of the Visualizing the Chemistry of Climate change (VC3) by Mahaffy et al. (2017). VC3 organizes key chemistry concepts, such as gas chemistry or chemical bonding, and relates it to climate change through connecting topics, like global warming potential and molecular energy absorption at different spectral regions. Instructors' decision-making about climate change instruction included reasons why they did or did not make connections and limitations they experienced. The perspective that climate change is important and an essential topic that students need to understand was expressed by most of the participants. These instructors also indicated the interest that students had in climate change as a motivating influence to include climate change in their instruction. The participants who had previous knowledge about climate change along with the ability to make changes to their course and have access to resources allowed them to make connections with climate change. Real-world examples were the most common framing device used by instructors to relate their course topics to climate change. By using more socially relevant scientific topics, such as climate change, students are more likely to foster beliefs that promote scientific understanding (T. Chowdhury et al., 2020; Pelch & McConnell, 2017) and a present a greater compassion that motivates actions on those issues (Herman, 2018; Wang et al., 2018). As reflected by some of the participants, despite the ideological background of the students when they come to class, when presented with climate science issues, students often will conclude the connection between climate change and anthropogenic causes (Stevenson et al., 2016).

Instructors who had agency over their course content and also had previous knowledge about climate science spoke the most about incorporating these topics into their teaching. Additionally, these perspectives came with an understanding of educational resources that were available to them to connect climate change with chemistry. Instructors in this situation can experience hope about the impact they have on students (McNeal et al., 2017) and can support environmental citizenship (Ariza et al., 2021). Multiple forms of course engagement was mentioned by these instructors, such as assignments, in-class discussions, and lectures. Effective outcomes in student learning are benefitted by these multi-modal approaches to teaching and have shown to be effective for teaching climate change and other socio-scientific topics (Monroe et al., 2019; Nam & Ito, 2011).

The perceived value and importance of students understanding climate change was a common reason for these instructors to include the topic. Issues related to time were the primary reason for climate change to be excluded from their teaching. This most often took the form of time needed to develop their curriculum, access of integrable educational materials, or a lack of knowledge underlying the science behind climate change. According to the participants, small incremental additions were the most effective means of improving their teaching. Other research suggests that focusing on the core attitudes of adopting changes, like evidence-based practices for example, will have a greater opportunity for reform to occur (Gibbons et al., 2018). Participants also echoed the need for a cross disciplinary approach to reinforcing important climate topics. Where the literature also reinforces the importance of the interdisciplinary approach as essential for understanding the position of complex problems (Eastwood et al., 2011). An example of such changes implemented at the institutional level fostered a positive shift in climate change curriculum, professional development, and student-lead learning activities (Davison et al., 2014). Administrative support would also be critical for sustainable reforms across disciplines at their home institution. A multipronged approach is necessary to facilitate the possibility of long-term transformative reforms. Institution specific conditions could be a barrier to implementing broader systemic reforms and would need to be addressed according to the needs of each individual institution.

CHAPTER VI

NATIONAL SURVEY OF UNITED STATES COLLEGE CHEMISTRY INSTRUCTORS' PERSPECTIVES ON TEACHING CLIMATE CHANGE

Contributions of Authors and Co-authors

Manuscript in Chapter V

Author: Patrick Wilson

Contributions: Designed study. Conducted data collection and preparation. Conducted data analysis. Wrote first draft of this manuscript.

Co-Author: Tori Sayers

Contributions: Provided feedback on study design. Participated in survey development. Reviewed data during the pilot study.

Co-Author: Melissa Weinrich

Contributions: Designed study. Advised on data collection and analysis. Reviewed and provided feedback on drafts.

Abstract

Education about the chemistry of climate change will play an important role in combating the consequences of fossil fuels and aid in mitigation strategies. Chemistry instructors guide course content and will be essential in equipping students with the knowledge and skills to tackle the challenges of climate change. This study used a national survey in the United States examining the perspectives of undergraduate chemistry professors on how they include climate change topics in their teaching. Over 6400 instructors were contacted at 259 institutions across the United States resulting in a total response of 417 participants. Despite being a highly valued topic among survey participants, the majority of respondents taught climate change tangentially or not at all. Time constraints and standardization of their courses were communicated as the top reasons for this lack of inclusion. For instructors who did incorporate climate topics in multiple ways, they expressed more agency over their course content and interest from their students as key influences. The most common key chemistry topics that were connected to climate change were gases, solutions, and reaction chemistry. Examples of these topics include the characterization of greenhouse gases, equilibrium reactions of ocean acidification, and the stoichiometry of combustion reactions. The personal factors collected were not a discriminating factor in climate change inclusion. Development of accessible and integrable materials will be needed to bridge the gap between issues of time constraints and incorporation of climate change educational materials in undergraduate chemistry courses.

Introduction

Recent United Nations Climate Change Conference (COP26) meetings have stressed the importance of taking aggressive decarbonization efforts to avert a 1.5°C increase in the global temperature (Ming et al., 2021). Currently, the global efforts to combat these changes have fallen short of the IPCC's recommended guidelines (Lade et al., 2020; Pörtner et al., 2022). Aggressive decarbonization strategies will be needed to mitigate further environmental harm. To better meet the challenges of climate change, a multipronged approach will be necessary for humanity to plan and be prepared.

The consensus of the scientific community overwhelming states that the Earth's climate is being impacted by human activity (Oreskes, 2018). However, a majority of adults underestimate the perceived support for climate mitigation and concern among their peers (Sparkman et al., 2022). Education is one such area that will aid in informing and empowering current and future generations to prepare for the climate challenges ahead. A well-educated populace will play a pivotal role throughout every sector of our society to combat the effects of climate change.

Students overwhelmingly desire action on climate change (Ferragamo et al., 2020; Oliver & Adkins, 2020). Students who are educated about climate change make more informed decisions (Amanchukwu et al., 2015; Cordero et al., 2020; Obayelu et al., 2014). Instructors make decisions about the subject taught to their students and operate as facilitators of their learning journey. For students to be better equipped to engage with the impacts of climate change, instructors must provide them with the tools to succeed. A previous survey conducted by Vaille Dawson (2012) examining science teachers' perspectives on climate change, found that though the topic was important to them, it was often absent from their teaching.

A strong foundational understanding of chemistry principles is essential to developing clear representations of climate change's impacts in the world. There has been previous research focusing on misconceptions of climate change between students and teachers (Arslan et al., 2012; McCaffrey & Buhr, 2008; McCuin et al., 2014; A. N. Versprille & Towns, 2015). However, the extent to which climate change is being incorporated into courses has not been well characterized. This study sought to establish a baseline for how climate change content is being covered in undergraduate chemistry courses and provide insight into the decision-making process of these instructors.

Research Questions

Q6.1 In what ways do undergraduate chemistry instructors incorporate climate change into their courses?

Q6.2 How do post-secondary instructors make decisions about including climate change in their instruction?

Q6.3 How are these decisions influenced by teacher thinking, personal and contextual factors?

Theoretical Framework

The framework used in this study was the combination of the Teacher Centered Systemic Reform (TCSR) model as presented by Woodbury and Gess-Newsome (2002) and the Visualizing the Chemistry of Climate Change (VC3) by Mahaffy et al. (2017). The TCSR model acts to describe the influential role of instructors' courses and VC3 to establish core chemistry concepts connected to climate science.

As a conceptual change model, TCSR places the role of the instructor as the center of influence in courses, and a primary mechanism of educational reform (Woodbury & Gess-Newsome, 2002). Through the combination of course design and the instructor's pedagogical content knowledge, the instructor becomes the central figure in educational change. The TCSR development from the collaborations of Gess-Newsome et al. (2003) expands upon a teacher's thinking, interaction, and participation in the classroom toward educational reform. The model divides the influence of instructors into three categories: contextual factors, personal factors, and teacher thinking. Contextual factors relate to the instructor's relations to the course and institutional environment. Personal factors that connect with the instructor's previous experiences which include their training and demographics. Teacher thinking represents the perspectives held by the instructor on pedagogy, learning, and self-efficacy. The combination of all three pillars in the TSCR model provides insight into the link between the instructor's thinking with the ability or willingness to make changes in their own teaching.

VC3 examines the connection between core chemistry concepts and climate change. The foundations of VC3 were developed from contextual based learning from conceptual change frameworks, personal constructivism, and learning theories that include behaviorist and cognitive perspectives (Bodner, 1986; Bodner & Orgill, 2007; Parchmann et al., 2015). The structure and design of VC3 is based upon seven climate literacy principles from the U.S. Climate Change Science Program. Due to the complexity of climate science, systems approaches were needed to develop a robust framework (Shepardson et al., 2012). Competency in these literary principles is considered important for having the critical thinking skills necessary to be versed in climate science literacy. Examples of these principles involve: "2. Climate is regulated by complex interactions among components of the earth system" and "7. Climate change will have consequences for the earth system and human lives" (P. Mahaffy et al., 2017). From these principles, 17 core chemistry concepts were identified that relate to such chemistry topic categories as bonding, gases, and thermochemistry. Core chemistry concepts then were connected to ideas within climate topics. One example for the core chemistry concept of "Chemical Bonding" was connected to the key idea of "Absorption of energy by molecules in different spectral regions," as these concepts hold particular importance for the greenhouse effect. Each of the key connecting ideas operates as a starting point for climate principles to be integrated into chemistry education.

We combined these two frameworks in this study to understand the role of college chemistry instructors' thinking, personal, and contextual factors in influencing how they connect core chemistry concepts to climate change principles in their teaching practice.

Methods

Participants and Sampling Frame

Survey participants were sampled from departments organized according to the listing provided by The U.S. News & World Report 2023 ranking of chemistry departments (*The Best Chemistry Programs in America, Ranked*, 2023). Contact email information was gathered from the corresponding departmental websites at the listed universities and colleges in the United States. Data collection ceased after 259 schools were sampled resulting in 6459 undergraduate chemistry professors contacted. Both state and private schools were selected ranging from R1 to non-research institutions. A total of 417 participants fully completed the survey.

Recruitment for the survey study was carried out via email communications as identified according to their prospective departmental websites (Appendix B). Electronic consent forms were collected from all participants prior to involvement with the survey (Appendix G). We did not save identifiable information outside of the participant's basic demographics. No compensation was provided for participation in the survey.

Survey Development and Analysis

The survey design and questions were developed through responses to a previous interview study (Wilson, Sayers, et al., 2023) and a small pilot program. The pilot program sampled 35 undergraduate chemistry instructors from the state of Colorado and did not overlap with the final study. Changes made to the survey following completion of the pilot study were in forced answer questions and not in content related areas. This prevented key questions from being skipped by participants, such as their level of climate change inclusion in their teaching, ranked choice options for their decision making, and factors that influence their inclusion of climate topics. Qualtrics software was used as the delivery system. Electronic consent was acquired before access was given to the survey questions; a copy of the consent form can be found in Appendix G. To minimize potential participants from self-selecting out of the study, the language of the recruitment email focused on teaching topics rather than explicitly about climate change. The survey format, questions, recruitment, and consent materials were reviewed and approved by the University of Northern Colorado's Institutional Review Board (IRB).

After consent was received, the participants were first asked to select from a list of chemistry classes that they teach. Next, they selected a focus course which was applied to the remainder of the survey. The structure of the survey then focused on the level of inclusion, attitudes, and influences to how climate change was (or was not) included in their instruction. For example, the level of climate change inclusion was split into three options: "multiple ways," "in passing," or "not included." Instructors were shown a list of connected chemistry topics with climate change adapted from Mahaffy's Visualizing the Chemistry of Climate Change (VC3) (P. Mahaffy et al., 2017). For example, chemical reactions were a topic connected with climate change through the stoichiometry of combustion reactions as related to the greenhouse effect. The question of selecting the level of climate change inclusion was then reintroduced after the VC3 framework if participant who made inclusions and was not previously aware of connections that they may be making with climate change topics. Free response areas were opened following these items to allow participants the option to provide additional context. Reasons for whether climate change was taught or not were gathered using ranked choice design. The top rank indicated the highest reason for their decision to include (or not include) climate change in their teaching. Likert scale items were presented to assess participants' level as to how influential (or not) climate change was with their instruction. A value of 5 indicated an item that was not very influential for the participant to include climate change in their teaching and a value of 1 was very influential for the inclusion of climate change, and a 3 was a neutral position as being neither influential nor not influential for climate change inclusion. The last sections of the survey evaluated common personal factors related to the participants. Examples of some of these items included age, tenure status, and gender.

Statistical analysis and data plots were carried out using R 4.3.1(Team, 2021). Violin plots were created using the tidyverse R package (Wickham et al., 2019) from the ggplot2 geom_violin() function. Crosstab and stacked bar charts were converted based on the percentage of response for each of the corresponding categories and generated using Microsoft's Excel.

Validity and Reliability

The survey design and question content were first reviewed by a climate scientist and education expert to establish content validity. Next, a pilot study was also employed prior to the main survey being sent out to optimize the formatting of the survey and establish face validity. Following a six-week pilot collection period, the only changes made to the format of the survey were the addition of force checks for certain question and correcting the flow of the questions examining instructor's level of climate change content (directly, indirectly, or not at all) so that their ranked choice options matched the level of climate change inclusion.

Results and Discussion

Most survey participants (85.2%) reported that climate change was either taught tangentially or not at all in their focus course (Figure 6.1).

Figure 6.1

Extent of Climate Change Inclusion in Participant's Focus Course

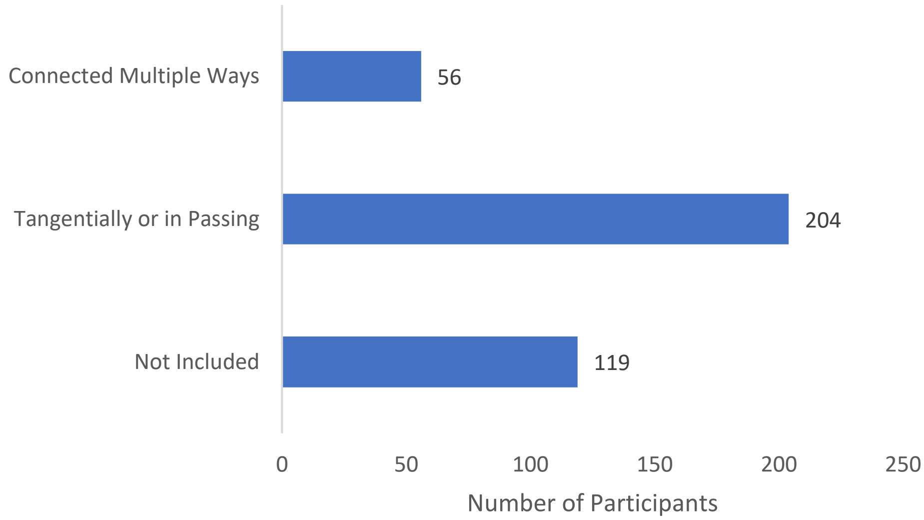


Table 6.1 gives a breakdown of the key chemistry concepts selected by the survey participants as the types of climate change content connected to their teaching. In total, 260 participants taught about the chemistry of climate change either tangentially or in multiple ways. Gases appeared as the most selected core chemistry topic taught by surveyed professors. This was consistent with the representation of climate change topics in undergraduate textbooks (Wilson, Duarte, et al., 2023). Within the key concept of gases, the way carbon dioxide and greenhouse gases are characterized was the most commonly occurring topic (145 counts out of 417). Descriptions of spectral absorptions and human contributions to global warming were equally represented (94 counts each). Areas within Matter and Measurement was the second highest selected core concept, specifically where chemistry can be used for solving global challenges was the most selected connecting topic (116 counts). The Solutions core concept was also highly selected among participants (113 counts) as the connecting topic was most related to equilibrium concepts between carbonic acid and carbon dioxide. The only other core concept that

had over 100 selections was chemical reactions with the connecting concept dealing with stoichiometry of combustion reactions as relating to greenhouse gases or carbon cycling (100 counts). Thermochemistry had below 100 counts but shared a similar topic relationship with the generation of greenhouse gases was seen with the Gases key concept (96 counts). The type of climate change was the lowest selected with only 58 counts for temperature rise as a type of climate change.

Table 6.1

Core Chemistry Concepts and Connecting Topics Selected by Survey Participants

Core Concept	Connecting Topic	Count (out of 417)
Gases		
	Characterization of carbon dioxide and other greenhouse gases	145
	Absorption of energy by molecules in different spectral regions related to global warming	94
	Human involvement in greenhouse gas production	94
	Global warming and the greenhouse effect	87
	Nature of light and electromagnetic spectrum as related to climate change	68
	Temperature and pressures as they relate to climate	46
	Kinetic molecular theory related to climate change	27
Matter and Measurement		
	Importance of chemistry in contributing solutions to global challenges	116
	Complexity of natural systems	75
	Data collection, analysis, and interpretation	39
	Nature of science and uncertainty	37
	Nature of models and modeling	23
	Hypothesis testing	10
Atoms, ions, and molecules		
	Speciation of carbon, nitrogen, oxygen, and phosphorous	23
	Isotope ratios in glacial ice cores to obtain temperature proxy data	14

(continued)

Table 6.1 (continued)

Core Chemistry Concepts and Connecting Topics Selected by Survey Participants

Core Concept	Connecting Topic	Count (out of 417)
Thermochemistry		
	Thermodynamics of the combustion of fossil fuels and production of atmospheric gases	96
	Alternative energy possibilities related to climate change	80
	Thermodynamics of photosynthesis related to climate change or carbon recycling	34
Solutions Chemistry		
	Equilibrium concepts of carbonic acid and carbon dioxide	113
	Acidification of oceans by carbon dioxide and speciation of carbon in oceans	81
	Phase changes involving water and the role of water in modulating climate	37
	Separation and analysis of characterizing species in seawater and detection of trace substances	25
Chemical Reactions		
	Stoichiometry of combustion reactions or photosynthesis, as related to greenhouse gases or carbon cycling	100
	Atom economy, atom efficiency, and green chemistry	77
Kinetics		
	Kinetic processes in the atmosphere, soil, and oceans	36
	Atmospheric lifetime of greenhouse gases	23
Electrochemistry		
	Role of chemistry in the production of modern materials and alternative energy sources	78
	Efficiency of electrochemical reactions to generate energy	49

Many of the participants' free responses tended to further elaborate on just how their instruction tangentially applied to climate change.

> Participant #164: When discussing nuclear reactions and calculations related to nuclear reactions, I discuss the energy density of various things (batteries vs. organic fuels vs.

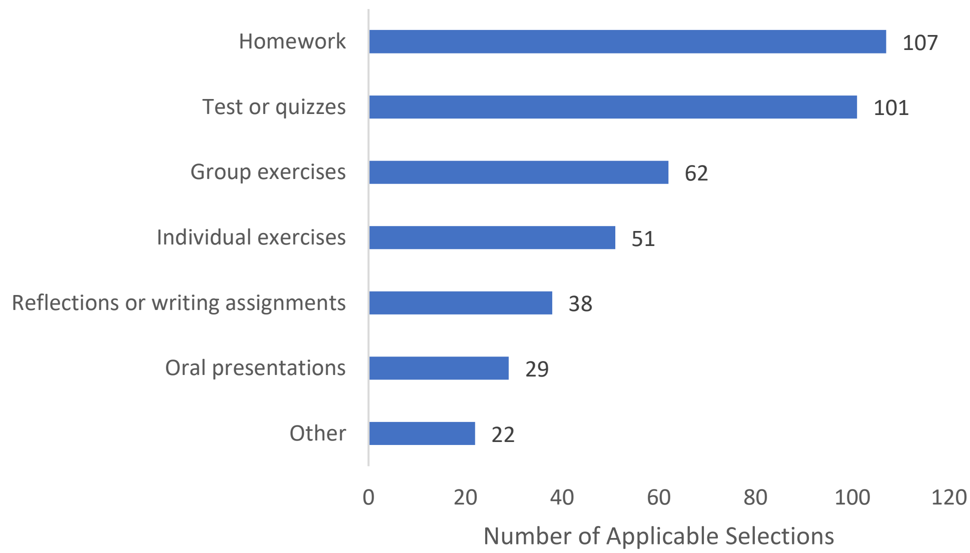
nuclear fission, etc.) Again, it's pretty tangential, but that is another area where I sort of bring in the topic.

This example, like several others presented by the survey participants, chose to look at climate issues through the lens of alternative energy. Other participants emphasized environmental topics that are not related to climate change. Participant #164 said, “I discuss chlorofluorocarbons and how they catalyze the destruction of ozone through a radicle mechanism.”   However, over half of the responses made some reference to how their focal course did not apply to or did not contain any climate change topics. Where several others happened to repeat items that were already provided in the concept inventory, such as ocean acidification.

Approximately a quarter of participants (25.7%) reported incorporating some form of assessment related to climate change (Figure 6.2). Homework assignments had the highest reported values (107) followed by tests or quizzes (101). The closeness of these two values is likely representative of how instructors provide homework assignments that are later reflected in their course’s tests or quizzes. Group and individual exercises were less common (62 and 51 counts respectively). The “other” option were items not typically related to the lecture room, such as laboratory activities.

Figure 6.2

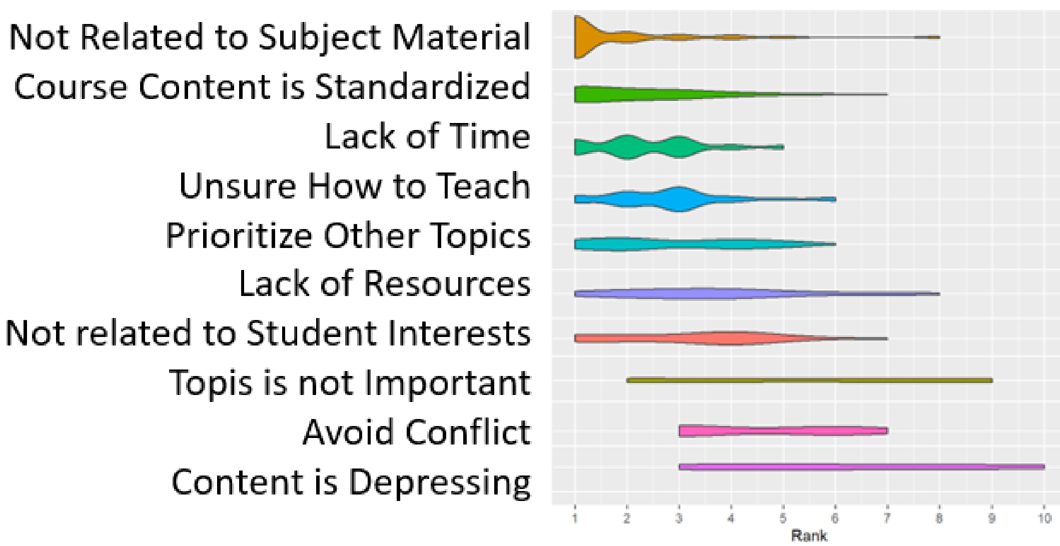
Types of Assessments Used by Instructors Who Teach Climate Change in Their Courses



Instructors are often faced with juggling a myriad of responsibilities in their roles at their institutions and these influence their decision-making. Participants ranked the highest that climate change was not related to their subject material (Figure 6.3). Time restrictions appeared as the second highest rank reason. Unsurprisingly, time is a frequent reason for restrictions to reform regardless of the underlying objective (Al Salami et al., 2017; Bagiati & Evangelou, 2015; Collinson & Fedoruk Cook, 2001; Dancy & Henderson, 2010; Hsu et al., 2011). Feeling unsure how to teach climate change was the third highest ranked reason for not teaching the topic. Previous research has shown a connection between instructor knowledge of climate change with their willingness to include the subject in their courses (Li et al., 2021; Seroussi et al., 2019). Course standardization was commonly ranked within participants' top 4 choices and had a similar distribution to wanting to prioritize other topics. Avoiding conflict and views of the content as being depressing only appeared at the 3rd rank or below, indicating that this was not a strong reason against including climate change in their teaching. This suggests that the categories most often selected for the reason climate change was not taught in their chemistry course related to either a structural limitation (lack of time and restrictive course design) or from their connection to the subject (climate change not related to their subject or the uncertainty of how to teach climate change).

Figure 6.3

Reasons Instructors Do Not Include Climate Change in Their Instruction Do Not Include It in Their Instruction

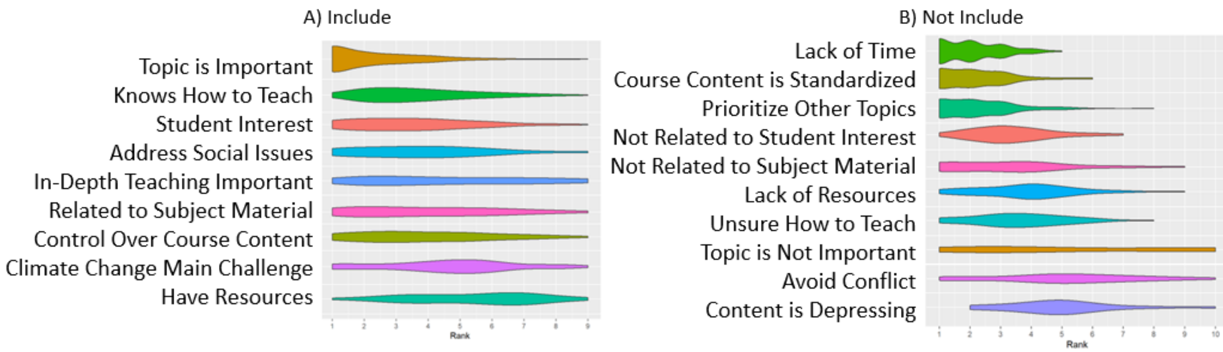


Note. “1” means participants selected this statement as their topic reason.

Instructors that reported teaching climate change tangentially provided their reason for and against incorporating the topic in their classes (Figure 6.4). Similar to those who did not include climate change in their teaching at all, the top reasons among those tangentially teaching climate change to not include the topic were also course standardization and lacking time to teach the content. Participants that taught climate change tangentially indicated their priority to teach other topics. They were also guided by uncertainty in how to teach climate change or lacking in educational resources. However, the top reason for including climate change was the perspective that the topic is important. Knowledge about how to teach climate change was also ranked highly among the 2nd and 3rd choice categories. Ranked choices for those teaching climate change were distributed more broadly than those who did not. than those who did not.

Figure 6.4

Ranked Reasons Climate Change Is Taught Tangentially or in Passing

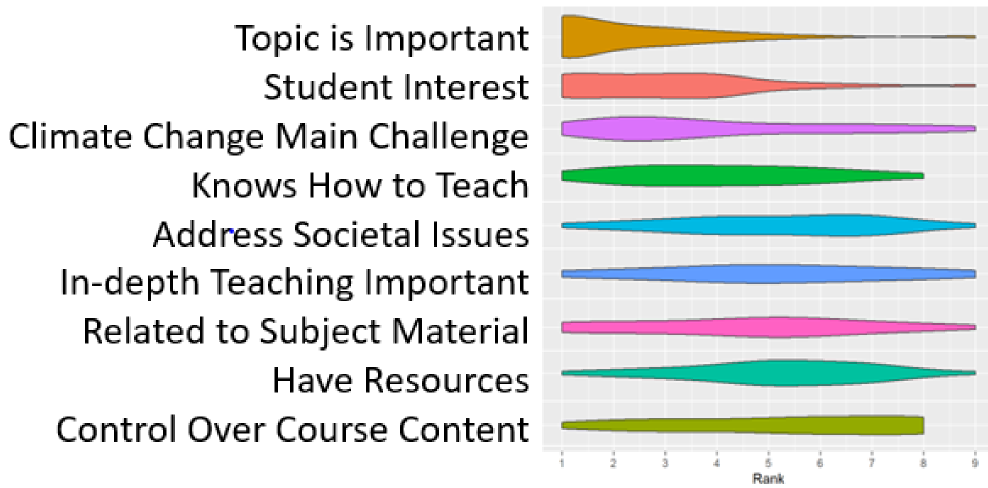


Note. A) Reasons for why climate change is included. B) Reasons for why climate change is not included. "1" means participants selected this statement as their topic reason.

Instructors who taught climate change in multiple ways also selected the importance of climate change as the top reason for content inclusion (Figure 6.5). Interest from their students was also highly ranked among the survey participants. The perceived importance of climate change combined with the curiosity of their students seems to be the biggest reasons for these instructors to include climate change topics in their teaching.

Figure 6.5

Ranked Reasons Climate Change Are Included by Participants Who Taught Climate Change in Multiple Ways



Note. “1” means participants selected this statement as their topic reason.

Some participants also provided additional context through their free response for their reasonings for including climate change in their teaching. One participant expanded on their reasons for including climate change in their course multiple ways:

> Participant #114: If I don’t teach this, many students may go through their entire college career and never learn the science of something that that will have much impact on their lives.

Most students don’t take chemistry beyond general chemistry and would not be exposed to the connections between chemistry and climate change. Environmental chemistry courses also are typically offered as electives, which leaves behind the bulk of chemistry students if their departments offer such a course at all. Some instructors commented on the structure of their general chemistry course to catch students on important socially relevant topics (such as climate change):

> Participant#74: I typically teach Gen Chem 2, which does not include a large amount of climate related topics - but our Gen Chem 1 classes include a full-fledged module on climate change. We chose Gen Chem 1 for this as a larger number of students takes Gen Chem 1 compared to Gen Chem 2.

For instructors that provided a less direct connection of their teaching to climate change, their reasoning still used chemistry as a means of explaining issues in the "real world." For example, one survey participant stated:

> Participant #113: The topic of climate change demonstrates the complexity of "real world chemistry" and chemistry solutions to problems. This issue of climate change connects several very important topics in chemistry. Once students have a fundamental knowledge of some of these topics, we can start to bring them together to provide a picture of how chemistry (and our actions) influence several aspects of climate.

The thoughts of bringing chemistry concepts into the real world showed how this instructor incorporated best practices into their teaching. By guiding students through the complex nature of chemical topics they can make deeper, more meaningful inferences about how humanity impacts the climate. Contrasted with participants who did not include climate change in their teaching at all, one participant expressed their views as teaching chemistry independent of the real-world context. Participant #190: "I teach my students how molecules are named, and how they react. I will not tell them how they must use this information, or what causes they should pursue relating to this information."

This instructor's perspective separates the applications that can be made with chemistry to focus more on fundamental topics. Also, this participant's comment on climate change as a cause, rather than a scientific phenomenon, may suggest other influences outside of scientific concepts that direct their teaching of chemistry.

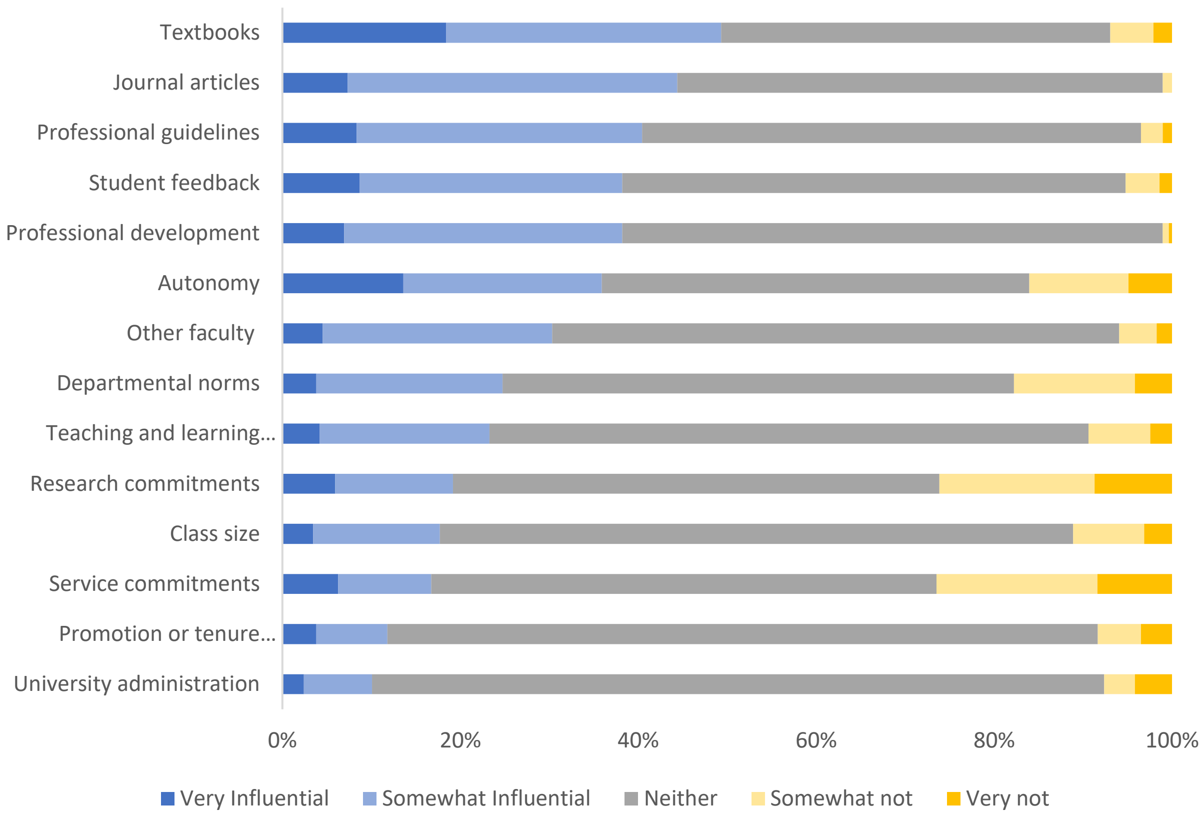
Influences on the Inclusions or Exclusion of Climate Change in Undergraduate Chemistry Courses

Educational resources, such as textbooks and open educational resources along with research and education journals involving climate change had the largest number of participants selecting these items as either very or somewhat influential (Figure 6.6). The use of any educational resource requires an instructor who is knowledgeable enough about the availability of these assets and who is also capable of extracting the components that would be the best for their course.

Professional organizational guidelines, professional development or conferences, and student feedback had the next highest distributions of participants. However, the majority of the sampled categories were reported has having neutral influence towards incorporating climate change in their teaching. Commitments related to research and service were among the least influential categories. Contrary to perspectives reported in the literature, the concern over the politicization of climate change was the most common category to be neither influential nor not influential in incorporating climate change (Nation & Feldman, 2022).

Figure 6.6

Likert Scaled Responses on Influences to Include Climate Change

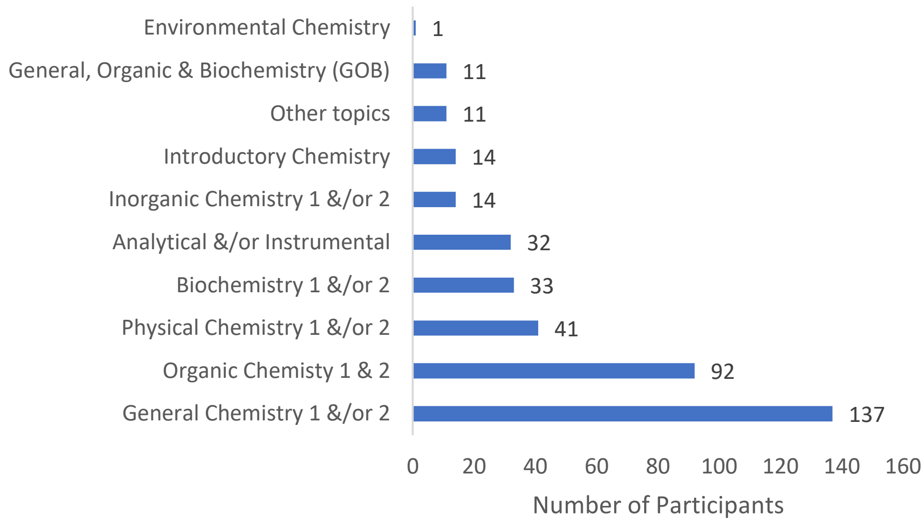


Chemistry Connections Most Frequently Associated With Climate Change

General chemistry 1 and or 2 appeared as the most frequently selected focus course with organic chemistry being second and a somewhat even proportion between physical, biochemistry, and analytical (Figure 6.7). The distribution of courses is unremarkable due to general and organic chemistry being the most common courses offered among the population sampled.

Figure 6.7

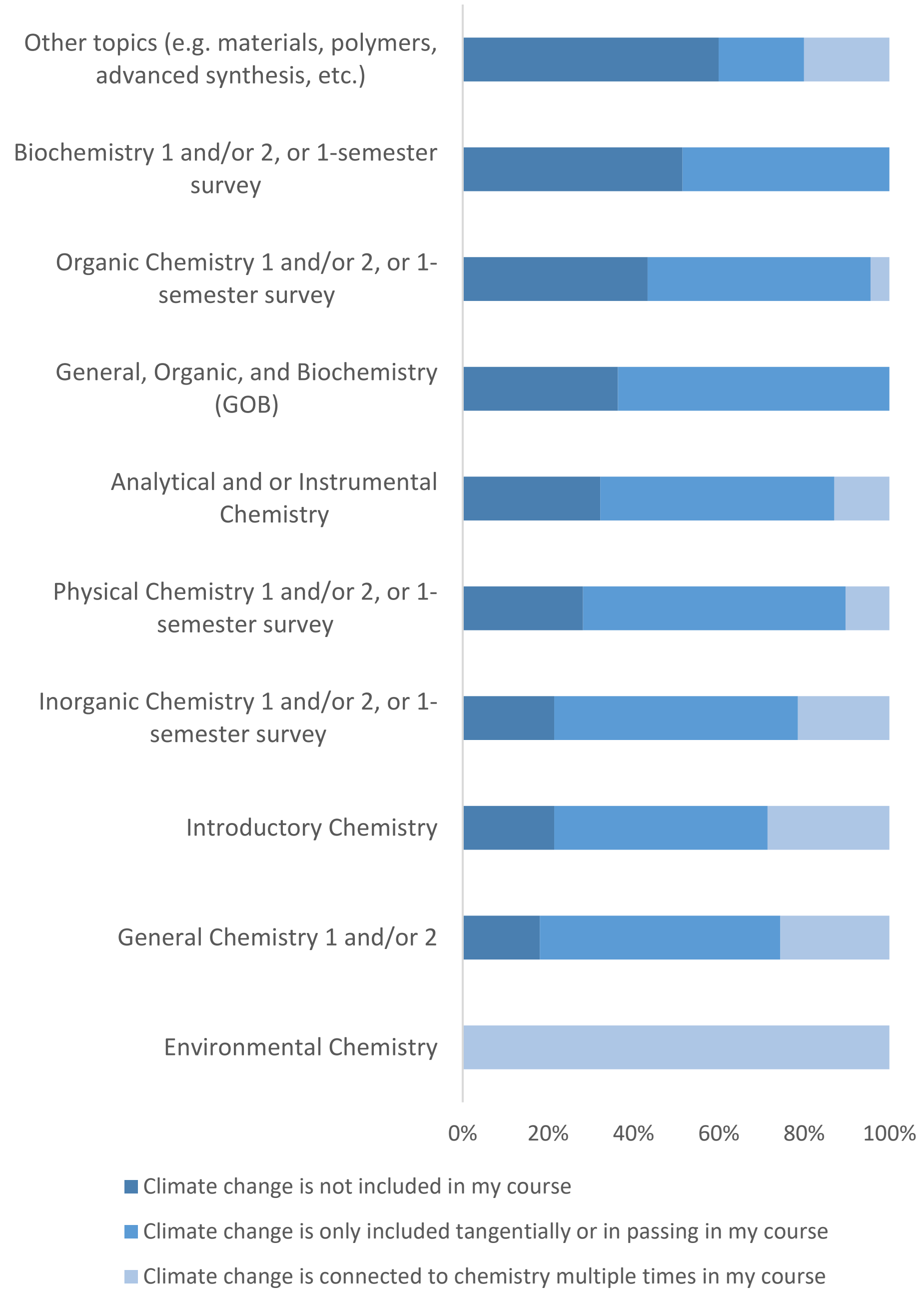
Selected Focus Course for Content Connections With Climate Change



A crosstabulation showed the extent of inclusion of climate change with the participant's chosen focal course (Figure 6.8). Apart from environmental chemistry and other topics, approximately 50% of the remaining courses included climate change tangentially. These participants most often selected general chemistry as their focal course (133 participants). Organic chemistry, biochemistry and other topics had proportionally more participants who did not include climate change than other chemistry courses (43%, 52%, and 60%, respectively.)

Figure 6.8

Crosstabulation of Selected Focus Course With Level of Climate Change Inclusion

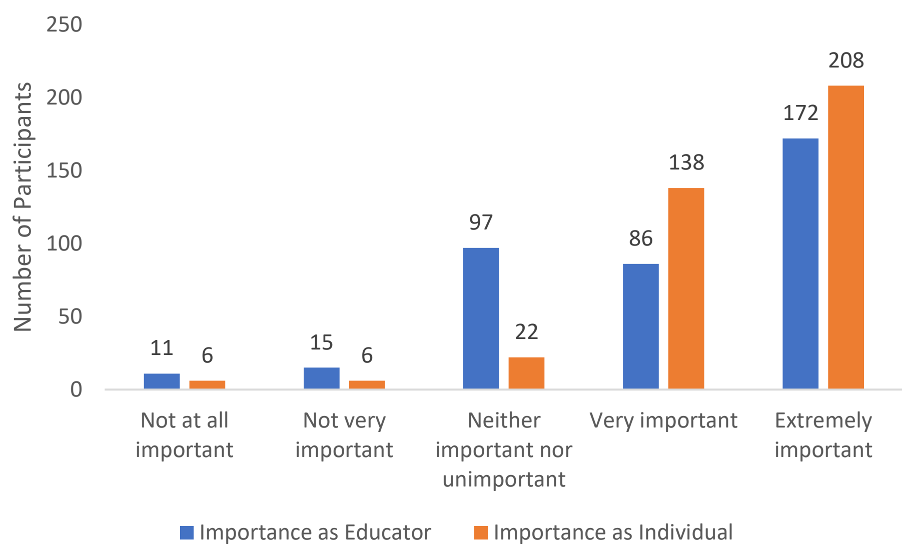


Importance of Climate Change

As individuals, instructors overwhelmingly valued the importance of climate change (83% of the total participants). However, when asked as educators, these perspectives shifted more toward a neutral position (Figure 6.9) Instructors indicated why this might be in the free response. For example, one instructor said, “I don’t really have the time to revise my notes to make climate change a major focus of my teaching, although I would love to include it.” Another instructor said, “It would be easier to incorporate if I had the teaching resources to use in class instead of having to create them myself.” These instructors’ comments related to limitations in resources and time to include climate change in their teaching. The high importance of climate change as individuals to these instructors and the difference presented as educators could be viewed more as a set of structural issues rather than a desire to not include it.

Figure 6.9

Undergraduate Chemistry Instructors Value Climate Change as Individuals and Educators.

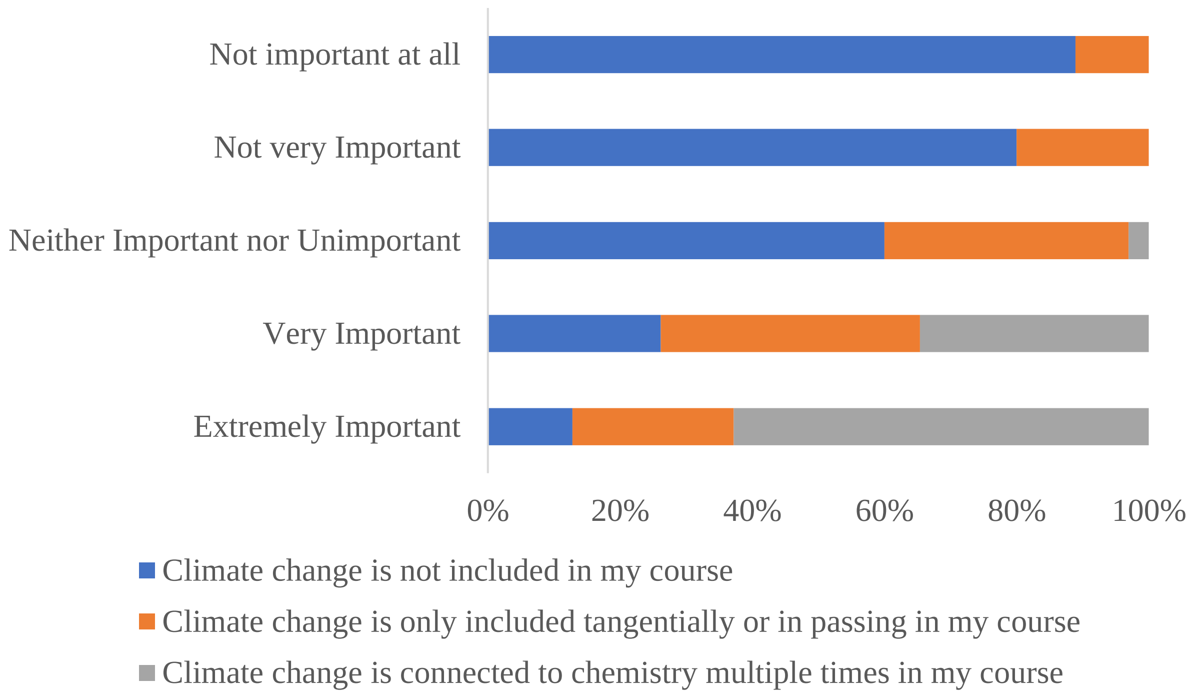


A crosstabulation showed the relationship between the level of climate change inclusion in the participant’s focal course with their views of climate change’s importance to them as educators (Figure 6.10). Instructors who connected climate change multiple ways in their course were almost exclusively those who also viewed the topic as either very or extremely important.

Those who viewed climate change either in the neutral or not important categories tended to not incorporate climate change in their teaching. Instructors who covered climate change tangentially, viewed climate change as a very important topic the highest and had a more even split between extremely important and the neutral position.

Figure 6.10

Crosstab of Importance of Climate Change as an Educator With the Level of Inclusion in Teaching



The personal factors of the participants were considered for the role they could play in influencing the level of climate change included in their teaching. The level of climate change inclusion did not appear to have any meaningful patterns when compared to the participant's first appointment year (Table 6.2). The tenure status of participants had a similar distribution across level of climate change inclusion (Table 6.3). However, there were no participants who were on the tenure track that also taught climate change in multiple ways. Instructors who are non-tenure track tend to hold views of being excluded or have their agency constrained (Drake et al., 2019; Haviland et al., 2017). Tenured faculty are more likely to be involved in forwarding climate change related issues such as university divestment from fossil fuels (Stephens et al., 2018). The incorporation of more interdisciplinary collaboration in tenure and promotion guidelines could act as a means of improving the broader climate perspectives into university courses.

Table 6.2

Crosstabulation Frequency of Level of Climate Change Inclusion With First Appointment Year

	1970-1975 (%)	1976-1980 (%)	1981-1985 (%)	1986-1990 (%)	1991-1995 (%)	1996-2000 (%)	2001-2005 (%)	2006-2010 (%)	2011-2015 (%)	2016-2020 (%)
Not included	1	2	1	5	11	10	10	19	20	21
Included tangentially	0	3	4	5	7	13	13	13	19	23
Multiple times	0	9	6	11	17	21	9	2	17	9

Table 6.3

Crosstabulation Frequency of Level of Climate Change Inclusion With Tenure Status

	Tenure (180 participants) (%)	Tenure track (41 participants) (%)	Non-tenure (67 participants) (%)	Total
Not included	61	15	24	93
Included tangentially	61	18	21	148
Multiple times	70	0	30	47

The majority of the participants had professor in their title (Table 6.4). Based on academic role, the distribution of participants was relatively close with one another. This suggests that the academic role of the participants does not have a connection to their instruction of climate change material. From a wider university perspective, institutions which are unclear in their organization values, as related to climate change, can create attitude gaps among faculty and staff (Hindley, 2022). To overcome these issues, universities must be more explicit in their promotion of interdisciplinary approaches to research, communication among departments, and work towards facilitating collective actions around climate change education (Leal Filho et al., 2018).

Table 6.4

Crosstabulation Frequency of Level of Climate Change Inclusion With Academic Role.

	Adjunct (1) (%)	Instructor (7) (%)	Lecturer (30) (%)	Assistant Professor (148) (%)	Associate Professor (58) (%)	Professor (135) (%)	Postdoc (1) (%)	Total
Not included	-	2	10	34	18	35	-	119
Included tangentially	0.5	1	6	44	14	33	0.5	203
Multiple times	-	3	9	29	14	45	-	58

Limitations

Convenience sampling was used for the collection purposes of this study and carries issues inherent with that form of data collection. Response rates are typically low for most surveys. This study concluded with a response rate of 6.2%. Self-reported areas of the survey, such as those involving gender and race/ethnicity, were left open for participants to respond freely, and many chose not to respond, lowering the overall response rate for those questions. Due to the reduced response for those categories, those data were excluded from the personal factors analysis.

Survey questions can be interpreted in several ways. For instance, questions involving what influences their decision-making on including climate change could be viewed as either from their professional or personal perspective depending on the participant. The format of the survey sought to separate some of these influences, such as the importance of climate change as an educator versus an individual, but variation among the interpretation of the participants cannot be fully avoided.

Conclusions and Implications

In this national survey of undergraduate chemistry instructors in the United States we uncovered the ways they incorporate climate change into their courses. Additionally, this survey provided insight into the influences on their decision-making process and the role instructor's thinking, personal and contextual factors played.

Most of survey participants reported that climate change was either taught tangentially or not at all in their focus course. For instructors who connected chemistry concepts to climate principles, gases and matter and measurement were the most common chemistry concepts selected, whereas kinetics and isotopes were less common. A quarter of participants reported incorporating some form of assessment related to climate change. Instructors' ranked statements related to their decision-making process. Time constraints, standardization and autonomy over their course were the top reasons for instructors to teach climate change tangentially or not at all. This result was consistent with other studies that have shown that instructors who value climate change and other socio-scientific issues also lack inclusion of such topics in their teaching (Dawson, 2012; Feierabend et al., 2011; Nida et al., 2020). None of the most frequently selected reasons had anything to do with avoiding creating conflict or that climate change itself was not an important topic. For instructors who did teach climate change, their decisions were guided by the importance of the topic and perceived student interest. These perspectives were also consistent with the instructors who taught climate change tangentially. Textbook and journals were somewhat influential for instructors incorporating climate change, whereas all other contextual factors surveyed were selected as not influential for either incorporating or not incorporating climate change. General Chemistry was the course where climate change was more common, whereas in Organic Chemistry it was less common. Overall, these instructors overwhelmingly valued the importance of climate change as individuals, but often saw it as less relevant to their specific course. None of the personal factors that were able to be collected correlated with instructors' level of climate change inclusion.

To better achieve these types of topical integration, instructors will need to be better educated and equipped with the materials to make these incorporations easily. Several organizations and resources already exist whose mission is focused on providing educators with the tools to better incorporate socio-scientifically relevant topics in their courses (Carson & Dawson, 2020; Flener-Lovitt, 2014; Macalalag et al., 2020; P. Mahaffy & Elgersma, 2022; Zeidler & Sadler, 2023). Future work could investigate the way instructors discover and use educational resources related to climate change to inform on ways these methods could be applied to the broader chemistry teaching population.

CHAPTER VII

CONCLUSIONS

The purpose of this dissertation was to examine the educational influence textbooks and undergraduate instructors have on their students.

Climate Change Content in Undergraduate General Chemistry Textbooks

Textbook chapters relating to gas concepts were the overwhelming most frequent source of connections made between chemistry and climate change. These topics were most often related through the description of carbon dioxide and other greenhouse gases. Fossil fuels and human activity were other links that were used to describe the greenhouse effect and describe these concepts according to their ability to warm the planet. Other connections emphasized in general chemistry textbooks was also how greenhouse gases were characterized but through different chemical perspectives. Outside of gas chemistry, matter, and measurement along with chemical bonding was the next most commonly appearing chemical concepts. Matter and measurement content detailed models of climate change and commented on the nature of scientific understanding. Chemical bonding highlighted the activity of greenhouse gases with absorption energies in different spectral regions.

The level of climate change content within the sampled undergraduate general chemistry textbooks varied extensively. The topic selection of each textbook was reflective of the importance of a given topic. Climate change concepts were distributed across four categories: the main body of text, margins (including additional essays), figures, and end-of-chapter assessments. Textbooks that discussed climate change were located outside of the main body of text. End-of-chapter assessments would often describe small connections to climate change that were frequently left outside of the main body of text. Anecdotes or short vignettes were the most common structure in these questions but would sometimes lack context for how it related to chemistry or climate change. Any content gaps left open by the use of such a textbook would leave the instructor to make up for the deficit if they desired to explain the connections between climate change and chemistry.

The presence of content gaps in the connecting topics between climate change and chemistry could also contribute to a lack of student understanding and further implicate misconceptions. Examples of these implications have been studied and most often involve the nature of carbon dioxide, other greenhouse gases, and the relationship between the carbon cycle and water (Jarrett & Takacs, 2020). Students are susceptible to these misconceptions due to not being given a proper context around climate change to have a comprehensive understanding of the topic (Shepardson et al., 2009). Though misconceptions can be hard to overcome, addressing these issues directly has shown progress in resolving these problems (McCuin et al., 2014). The presentation of climate change in textbooks could be related to how misconceptions continue to persist among students.

General chemistry is often the only sequence of chemistry many students take during their undergraduate experience. If socio-scientific topics, such as climate change, aren't presented in these entry level courses, students would be left without experiencing such content at all. Furthermore, due to a lack of content coordination across undergraduate STEM courses, non-science students may never come into contact with any form of climate change education.

With proper interdisciplinary coordination, students have a greater probability of developing clear scientific understanding of topics that are most likely to impact their lives in the future.

Due to the influence that textbooks have on course structure and curricular design, this study provides insight into how climate change content may be included in general chemistry courses. Textbooks that have a lack of climate change context then fall on the instructor to either make up the difference or omit such content from their teaching. However, further study is necessary to fully investigate the connection between climate change resources and use by chemistry instructors.

Interviews of Instructor Teaching of Climate Change in Undergraduate Chemistry

Undergraduate chemistry instructors interviewed in this study most often taught climate change topics in multiple ways. The degree to which climate change was taught was split between being explicit, tangential, or not at all in their course design. Climate change topics were facilitated in their courses through several levels of pedagogical choices, such lectures, in-class discussions, and homework (or other assessment items). Similar to the textbook analysis study, instructors related climate change by emphasizing carbon dioxide and greenhouse gases. However, these instructors focused more on human’s role in the development and responsibility for climate change.

The qualities of our sampled instructors who explicitly taught climate change had a clear understanding of the topic, maintained autonomy over their course, and were guided by the degree they valued the importance of teaching climate change to their students. Additionally, being able to access and use appropriate resources aided in integrating climate change concepts with their course design. Several interview participants expressed their desire for students to have a deeper understanding of socially relevant scientific topics and would structure their course to so that the most important topics were covered earlier in the semester, where students would be less affected by the end of term fatigue.

The expansion of climate change coverage in chemistry classes was conveyed by a majority of the interviewed participants. These views often further extended into commenting on a more interdisciplinary approach to teaching important scientific topics, like climate change. Their goals would have an alignment of several classes reinforcing these relevant topics throughout all STEM courses. They also emphasized the importance of laying the foundational knowledge for students earlier so that more meaningful connections can be made when they participate in other courses.

Other recommendations for including climate change in chemistry education detailed taking an incremental approach. Small additions of content could build upon itself over the course of several semesters culminating in larger change without having to resort to a new course design. However, this option would be limited to instructors that have the ability to teach the same course over several semesters and also have the autonomy to make changes to their course. Large universities with multiple sections of the same course, like what is often seen with general chemistry, could prove challenging to institute changes with this approach. The ability to reform greater educational structures also requires administrative support. In order for reforms to be long lasting and interdisciplinary, such engagement from department chairs, deans, and university presidents is needed to organize and facilitate these transformations.

National Survey of Chemistry Instructor Perspectives on Teaching Climate Change

Climate change was valued highly to survey respondents as individuals similarly as it was to the interview participants. However, survey participants' teaching of climate change was not reflective of their values which was consistent with other studies evaluating the inclusion of socio-scientific topics in secondary and undergraduate science teaching (Dawson, 2012; Feierabend et al., 2011; Nida et al., 2020). The main reasons provided for why climate change was not included were a lack of time and restrictions related to course standardization. Barriers from time restrictions are a common issue for education reforms and are not unique to chemistry. Some of the comments reflected in the free response sections for the participant's reasoning highlighted these structural constraints while also still communicating their views of climate change as an important topic that they were still interested in incorporating.

Chemistry instructors who did teach climate change multiple ways selected the interest from their students along with their own knowledge of the subject combined with their ability to make changes to their courses as the main reasons for content inclusion. Instructors who taught climate change tangentially also selected similar reasons for topic inclusion despite a different level of engagement with the material. Among the factors that could influence instructors' inclusion of climate change, only educational resources such as textbooks and journal articles were found to be somewhat influential. Every other category, ranging from institutional levels (like tenure promotion and administration) and student interactions (requests, feedback, and class size) were not influential.

Further studies will be needed to better assess what changes could be made to take a tangential teaching instructor into covering the topic in more ways. Climate change educational resources do exist for chemistry (such as those provided by VC3 for example) and have also been expanding over recent years (Belova et al., 2015; P. Mahaffy et al., 2017; Molthan-Hill et al., 2022; Rudd, 2021; A. Versprille et al., 2017). This study suggests that there may be a disconnect between instructors and their knowledge of or access to these educational resources. Additional research could examine this gap and provide understanding for how instructors can better use alternative educational resources to enhance their teaching and provide better socio-scientific coverage for their students.

Conclusions and Implications

The coverage of climate change in undergraduate general chemistry textbooks was similar to how instructors, from both the interviews and survey, covered the topics in their classes. Gas chemistry was the most common approach to connect climate change with chemistry. Topics ranged from describing the greenhouse effect to how molecules absorb energy in different spectral regions. Textbooks were also highly regarded as a strong influence on the ability to incorporate climate change with their teaching. Books, much like the instructors, that incorporated climate change in multiple ways would provide a clearer, more robust understanding of the topic. Instructors who were explicit in their inclusion of climate change had alignment of the topic through several layers in their course design. Exams, homework questions, and class discussions were some of the examples provided. Textbooks similarly aligned their climate change content through the presentation of material in the main text, figures/margins, and within end-of-chapter assessments. Future studies could examine how instructors choose their educational resources and make decisions on how these materials best serve learning.

Climate change was valued highly for all the interview participants and for the majority of survey participants. The value that instructors placed on climate change was not always reflected in their teaching. More for the survey participants than those of the interviews, climate change was often covered tangentially or not at all. Competition on their time to make reforms was a universal limitation to pursuing and developing reforms. The desire for more easily accessible educational materials was expressed in both survey and interview participants. To bridge the gap between instructors who teach climate change tangentially or not at all, access to educational resources needs to be more explicit and opportunities for professional development more easily available.

REFERENCES

Aksit, O., McNeal, K. S., Gold, A. U., Libarkin, J. C., & 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. https://doi.org/10.1002/tea.21430

Al Salami, M. K., Makela, C. J., & de Miranda, M. A. (2017). Assessing changes in teachers' attitudes toward interdisciplinary STEM teaching. *International Journal of Technology and Design Education*, *27*(1), 63–88. https://doi.org/10.1007/s10798-015-9341-0

Amanchukwu, R. N., Amadi-Ali, T. G., & Ololube, N. P. (2015). Climate change education in Nigeria: The role of curriculum review. *Education*, *5*(3), 71–79.

Anderson, A. (2012). Climate change education for mitigation and adaptation. *Journal of Education for Sustainable Development*, *6*(2), 191–206. https://doi.org/10.1177/0973408212475199

Anderson, R. D., & Helms, J. V. (2001). The ideal of standards and the reality of schools: Needed research. *Journal of Research in Science Teaching*, *38*(1), 3–16. https://doi.org/10.1002/1098-2736(200101)38:1<3::AID-TEA2>3.0.CO;2-V

Ariza, M. R., Christodoulou, A., van Harskamp, M., Knippels, M.-C. P. J., Kyza, E. A., Levinson, R., & Agesilaou, A. (2021). Socio-scientific inquiry-based learning as a means toward environmental citizenship. *Sustainability*, *13*(20), 11509. https://doi.org/10.3390/su132011509

Arrhenius, S. (1897). On the influence of carbonic acid in the air upon the temperature of the ground. *Publications of the Astronomical Society of the Pacific*, *9*(14), 22.

Arslan, H. O., Cigdemoglu, C., & Moseley, C. (2012). A three-tier diagnostic test to assess pre-service teachers' misconceptions about global warming, greenhouse effect, ozone layer depletion, and acid rain. *International Journal of Science Education*, *34*(11), 1667–1686. https://doi.org/10.1080/09500693.2012.680618

Aubrecht, K. B. (2018). Teaching relevant climate change topics in undergraduate chemistry courses: Motivations, student misconceptions, and resources. *Current Opinion in Green and Sustainable Chemistry*, *13*, 44–49. https://doi.org/10.1016/j.cogsc.2018.03.008

Bagiati, A., & Evangelou, D. (2015). Engineering curriculum in the preschool classroom: The teacher's experience. *European Early Childhood Education Research Journal*, *23*(1), 112–128. https://doi.org/10.1080/1350293X.2014.991099

Baskaran, A. (2016). UNESCO science report: Towards 2030. *Institutions and Economies*, 125–127.

Belova, N., Eilks, I., & Feierabend, T. (2015). The evaluation of role-playing in the context of teaching climate change. *International Journal of Science and Mathematics Education*, *13*(1), 165–190. https://doi.org/10.1007/s10763-013-9477-x

Berry, T., Cook, L., Hill, N., & Stevens, K. (2010). An exploratory analysis of textbook usage and study habits: Misperceptions and barriers to success. *College Teaching*, *59*(1), 31–39. https://doi.org/10.1080/87567555.2010.509376

The Best Chemistry Programs in America, Ranked. (2023). https://www.usnews.com/best-graduate-schools/top-science-schools/chemistry-rankings

Bhattacharya, D., Carroll Steward, K., & Forbes, C. T. (2021). Empirical research on k-16 climate education: A systematic review of the literature. *Journal of Geoscience Education*, *69*(3), 223–247. https://doi.org/10.1080/10899995.2020.1838848

Bodansky, D. (1993). The United Nations framework convention on climate change: A commentary. *Yale Journal of International Law*, *18*(2), 451–558.

Bodner, G. M. (1986). Constructivism: A theory of knowledge. *Journal of Chemical Education*, *63*(10), 873. https://doi.org/10.1021/ed063p873

Bodner, G. M., & Orgill, M. (2007). *Theoretical frameworks for research in chemistry/science education*. Pearson Prentice Hall.

Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health*, *11*(4), 589–597. https://doi.org/10.1080/2159676X.2019.1628806

Carson, K., & Dawson, V. (2020). A teacher professional development model for teaching socioscientific issues. *Teaching Science*, *62*(1), 28–35. https://doi.org/10.3316/informit.270511920952144

Cassar, C., Oosterheert, I., & Meijer, P. C. (2023). Why teachers address unplanned controversial issues in the classroom. *Theory & Research in Social Education*, *51*(2), 233–263. https://doi.org/10.1080/00933104.2022.2163948

Chowdhury, M., Ahmed, K. J., Ahmed, M. N. Q., Haq, S. & Md. A. (2021). How do teachers' perceptions of climate change vary in terms of importance, causes, impacts and mitigation? A comparative study in Bangladesh. *Sn Social Sciences*, *1*(7), 174. https://doi.org/10.1007/s43545-021-00194-7

Chowdhury, T., Holbrook, J., & Rannikmäe, M. (2020). Socioscientific issues within science education and their role in promoting the desired citizenry. *Science Education International*, *31*(2), 203–208.

Cohen, R. M. (2002). Schools our teachers deserve a proposal for teacher-centered reform. *Phi Delta Kappan*, *83*(7), 532–537. https://doi.org/10.1177/003172170208300713

Collinson, V., & Fedoruk Cook, T. (2001). "I don't have enough time" - Teachers' interpretations of time as a key to learning and school change. *Journal of Educational Administration*, *39*(3), 266–281. https://doi.org/10.1108/09578230110392884

Cooper, M. (2010). The case for reform of the undergraduate general chemistry curriculum. *Journal of Chemical Education*, *87*(3), 231–232. https://doi.org/10.1021/ed800096m

Cooper, M., & Klymkowsky, M. (2013). Chemistry, life, the universe, and everything: A new approach to general chemistry, and a model for curriculum reform. *Journal of Chemical Education*, *90*(9), 1116–1122. https://doi.org/10.1021/ed300456y

Cordero, E. C., Centeno, D., & Todd, A. M. (2020). The role of climate change education on individual lifetime carbon emissions. *PLOS ONE*, *15*(2), 23. https://doi.org/10.1371/journal.pone.0206266

Corner, A., Whitmarsh, L., & Xenias, D. (2012). Uncertainty, scepticism and attitudes towards climate change: Biased assimilation and attitude polarisation. *Climatic Change*, *114*(3), 463–478. https://doi.org/10.1007/s10584-012-0424-6

Costley, J. (2016). The effects of instructor control on critical thinking and social presence: Variations within three online asynchronous learning environments. *Journal of Educators Online*, *13*(1), 109–171.

Dancy, M., & Henderson, C. (2010). Pedagogical practices and instructional change of physics faculty. *American Journal of Physics*, *78*(10), 1056–1063. https://doi.org/10.1119/1.3446763

Daugherty, K. K. (2006). Backward course design: Making the end the beginning. *American Journal of Pharmaceutical Education*, *70*(6), 135.

Dávila, K., & Talanquer, V. (2010). Classifying end-of-chapter questions and problems for selected general chemistry textbooks used in the United States. *Journal of Chemical Education*, *87*(1), 97–101. https://doi.org/10.1021/ed8000232

Davis, K. S. (2003). "Change is hard": What science teachers are telling us about reform and teacher learning of innovative practices. *Science Education*, *87*(1), 3–30. https://doi.org/10.1002/sce.10037

Davison, A., Brown, P., Pharo, E., Warr, K., McGregor, H., Terkes, S., Boyd, D., & Abuodha, P. (2014). Distributed leadership: Building capacity for interdisciplinary climate change teaching at four universities. *International Journal of Sustainability in Higher Education*, *15*(1), 98–110. https://doi.org/10.1108/IJSHE-10-2012-0091

Dawson, V. (2012). Science teachers' perspectives about climate change. *Teaching Science*, *58*(3), 8–13. https://doi.org/10.3316/aeipt.195592

Dedeurwaerdere, T. (2013). Transdisciplinary sustainability science at higher education institutions: Science policy tools for incremental institutional change. *Sustainability*, *5*(9), 3783–3801. https://doi.org/10.3390/su5093783

Dewey, J. (1995). Science as subject-matter and as method. *Science & Education*, *4*(4), 391–398. https://doi.org/10.1007/BF00487760

Doherty, S. J., Bojinski, S., Henderson-Sellers, A., Noone, K., Goodrich, D., Bindoff, N. L., Church, J. A., Hibbard, K. A., Karl, T. R., Kajfez-Bogataj, L., Lynch, A. H., Parker, D. E., Prentice, I. C., Ramaswamy, V., Saunders, R. W., Smith, M. S., Steffen, K., Stocker, T. F., Thorne, P. W., … Zwiers, F. W. (2009). Lessons learned from IPCC AR4: Scientific developments needed to understand, predict, and respond to climate change. *Bulletin of the American Meteorological Society*, *90*(4), 497–514. https://doi.org/10.1175/2008BAMS2643.1

Drake, A., Struve, L., Meghani, S. A., & Bukoski, B. (2019). Invisible labor, visible change: Non-tenure-track faculty agency in a research university. *The Review of Higher Education*, *42*(4), 1635–1664.

Drewes, A., Henderson, J., & Mouza, C. (2018). Professional development design considerations in climate change education: Teacher enactment and student learning. *International Journal of Science Education*, *40*(1), 67–89. https://doi.org/10.1080/09500693.2017.1397798

Duit, R., Treagust, D., & Widodo, A. (2008). Teaching science for conceptual change: Theory and practice. *International Handbook of Research on Conceptual Change*, 629–646.

Eastwood, J. L., Schlegel, W. M., & Cook, K. L. (2011). Effects of an interdisciplinary program on students' reasoning with socioscientific issues and perceptions of their learning experiences. In T. D. Sadler (Ed.), *Socio-scientific Issues in the Classroom: Teaching, Learning and Research* (pp. 89–126). Springer Netherlands. https://doi.org/10.1007/978-94-007-1159-4_6

Eilks, I., Marks, R., & Stuckey, M. (2018). Socio-scientific issues as contexts for relevant education and a case on tattooing in chemistry teaching. *Educación Química*, *29*, 9. https://doi.org/10.22201/fq.18708404e.2018.1.63680

Feierabend, T., Jokmin, S., & Eilks, I. (2011). Chemistry teachers' views on teaching 'climate change'—An interview case study from research-oriented learning in teacher education. *Chem. Educ. Res. Pract.*, *12*(1), 85–91. https://doi.org/10.1039/C1RP90011K

Ferragamo, M., Larson, M., Brown, P., & McClenachan, L. (2020, April 3). Youth perceptions of climate change and climate action in Waterville, Maine. *The Maine Journal of Conservation and Sustainability*. https://umaine.edu/spire/2020/04/03/ferragamo/

Flener-Lovitt, C. (2014). Using the socioscientific context of climate change to teach chemical content and the nature of science. *Journal of Chemical Education*, *91*(10), 1587–1593. https://doi.org/10.1021/ed4006985

Folke, C., Polasky, S., Rockström, J., Galaz, V., Westley, F., Lamont, M., Scheffer, M., Österblom, H., Carpenter, S., Chapin III, F. S., Seto, K., Weber, E., Crona, B., Daily, G., Dasgupta, P., Gaffney, O., Gordon, L., Hoff, H., Levin, S., & Walker, B. (2021). Our future in the Anthropocene biosphere. *Ambio*, *50*. https://doi.org/10.1007/s13280-021-01544-8

Fosnot, C. T. (2013). *Constructivism: Theory, Perspectives, and Practice, Second Edition*. Teachers College Press.

Garrett, H. J., & Alvey, E. (2021). Exploring the emotional dynamics of a political discussion. *Theory & Research in Social Education*, *49*(1), 1–26. https://doi.org/10.1080/00933104.2020.1808550

Gess-Newsome, J., Southerland, S. A., Johnston, A., & Woodbury, S. (2003). Educational reform, personal practical theories, and dissatisfaction: The anatomy of change in college science teaching. *American Educational Research Journal*, *40*(3), 731–767. https://doi.org/10.3102/00028312040003731

Gibbons, R. E., Villafañe, S. M., Stains, M., Murphy, K. L., & Raker, J. R. (2018). Beliefs about learning and enacted instructional practices: An investigation in postsecondary chemistry education. *Journal of Research in Science Teaching*, *55*(8), 1111–1133. https://doi.org/10.1002/tea.21444

Gracin, D. G., & Matić, L. J. (2021). Use of textbooks and other resources in curriculum reform. A longitudinal case study. *ZDM – Mathematics Education*, *53*(6), 1373–1385. https://doi.org/10.1007/s11858-021-01271-0

Grooms, J., Sampson, V., & Golden, B. (2014). Comparing the effectiveness of verification and inquiry laboratories in supporting undergraduate science students in constructing arguments around socioscientific issues. *International Journal of Science Education*, *36*(9), 1412–1433. https://doi.org/10.1080/09500693.2014.891160

Grossman, P., & Thompson, C. (2008). Learning from curriculum materials: Scaffolds for new teachers? *Teaching and Teacher Education*, *24*(8), 2014–2026. https://doi.org/10.1016/j.tate.2008.05.002

Gulacar, O., Zowada, C., & Eilks, I. (2018). Bringing chemistry learning back to life and society. In *Building bridges across disciplines for transformative education and a sustainable future* (pp. 49–60). Aachen: Shaker.

Haviland, D., Alleman, N. F., & Cliburn Allen, C. (2017). ‘Separate but not quite equal’: Collegiality experiences of full-time non-tenure-track faculty members. *The Journal of Higher Education*, *88*(4), 505–528. https://doi.org/10.1080/00221546.2016.1272321

He, Y. (2021). STEM teaching reform: Incremental pathways. *Journal of College Science Teaching*, *51*(7), 2.

Herman, B. C. (2018). Students’ environmental NOS views, compassion, intent, and action: Impact of place-based socioscientific issues instruction. *Journal of Research in Science Teaching*, *55*(4), 600–638. https://doi.org/10.1002/tea.21433

Hills, M., Harcombe, K., & Bernstein, N. (2020). Using anticipated learning outcomes for backward design of a molecular cell biology course-based undergraduate research experience. *Biochemistry and Molecular Biology Education*, *48*(4), 311–319. https://doi.org/10.1002/bmb.21350

Hindley, A. (2022). Understanding the gap between university ambitions to teach and deliver climate change education. *Sustainability*, *14*(21), 13823. https://doi.org/10.3390/su142113823

Hoeft, M. (2012). Why university students don’t read: What professors can do to increase compliance. *International Journal for the Scholarship of Teaching and Learning*, *6*(2). https://doi.org/10.20429/ijsotl.2012.060212

Holme, T. A., Luxford, C. J., & Brandriet, A. (2015). Defining conceptual understanding in general chemistry. *Journal of Chemical Education*, *92*(9), 1477–1483. https://doi.org/10.1021/acs.jchemed.5b00218

Hsu, M.-C., Purzer, S., & Cardella, M. (2011). Elementary teachers' views about teaching design, engineering, and technology. *Journal of Pre-College Engineering Education Research (J-PEER)*, *1*(2). https://doi.org/10.5703/1288284314639

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

Johnson, C. C. (2006). Effective professional development and change in practice: Barriers science teachers encounter and implications for reform. *School Science and Mathematics*, *106*(3), 150–161. https://doi.org/10.1111/j.1949-8594.2006.tb18172.x

Johnstone, A. H. (1993). The development of chemistry teaching: A changing response to changing demand. *Journal of Chemical Education*, *70*(9), 701. https://doi.org/10.1021/ed070p701

Jordan, R. C., Sorensen, A. E., & Gray, S. A. (2023). What undergraduate students know and what they want to learn about in climate change education. *PLOS Sustainability and Transformation*, *2*(4), e0000055. https://doi.org/10.1371/journal.pstr.0000055

Kelting-Gibson, L. M. (2005). Comparison of curriculum development practices. *Educational Research Quarterly*, *29*(1), 26–36.

Kirk, K. B., Gold, A. U., Ledley, T. S., Sullivan, S. B., Manduca, C. A., Mogk, D. W., & Wiese, K. (2014). Undergraduate climate education: Motivations, strategies, successes, and support. *Journal of Geoscience Education*, *62*(4), 538–549. https://doi.org/10.5408/13-054

Klosterman, M. L., & Sadler, T. D. (2010). Multi-level assessment of scientific content knowledge gains associated with socioscientific issues-based instruction. *International Journal of Science Education*, *32*(8), 1017–1043. https://doi.org/10.1080/09500690902894512

Kraft, A., Popova, M., Erdmann, R. M., Harshman, J., & Stains, M. (2023). Tensions between depth and breadth: An exploratory investigation of chemistry assistant professors' perspectives on content coverage. *Chemistry Education Research and Practice*, *24*(2), 567–576. https://doi.org/10.1039/D2RP00299J

Kranz, J., Schwichow, M., Breitenmoser, P., & Niebert, K. (2022). The (un)political perspective on climate change in education—A systematic review. *Sustainability, 14*(7), 4194. https://doi.org/10.3390/su14074194

Kuhn, T. (2021). The structure of scientific revolutions. In *Philosophy after Darwin* (pp. 176–177). Princeton University Press. https://www.degruyter.com/document/doi/10.1515/9781400831296-024/html

Lade, S. J., Steffen, W., de Vries, W., Carpenter, S. R., Donges, J. F., Gerten, D., Hoff, H., Newbold, T., Richardson, K., & Rockström, J. (2020). Human impacts on planetary boundaries amplified by Earth system interactions. *Nature Sustainability*, *3*(2), 119–128. https://doi.org/10.1038/s41893-019-0454-4

Lau, K. H., Lam, T., Kam, B. H., Nkhoma, M., Richardson, J., & Thomas, S. (2018). The role of textbook learning resources in e-learning: A taxonomic study. *Computers & Education*, *118*, 10–24. https://doi.org/10.1016/j.compedu.2017.11.005

Leal Filho, W., Morgan, E. A., Godoy, E. S., Azeiteiro, U. M., Bacelar-Nicolau, P., Veiga Ávila, L., Mac-Lean, C., & Hugé, J. (2018). Implementing climate change research at universities: Barriers, potential and actions. *Journal of Cleaner Production*, *170*, 269–277. https://doi.org/10.1016/j.jclepro.2017.09.105

Ledley, T. S., Rooney-Varga, J., & Niepold, F. (2017). Addressing climate change through education. In *Oxford Research Encyclopedia of Environmental Science*. https://oxfordre.com/environmentalscience/display/10.1093/acrefore/9780199389414.001.0001/acrefore-9780199389414-e-56

Lee, H., Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P., Trisos, C., Romero, J., Aldunce, P., & Ruane, A. C. (2023). *Climate change 2023 synthesis report summary for policymakers*. https://ntrs.nasa.gov/citations/20230009518

Leslie, P. (2016). *Action for climate empowerment: Guidelines for accelerating solutions through education, training and public awareness*. UNESCO Publishing.

Lester, F. K. (2007). *Second handbook of research on mathematics teaching and learning: A project of the national council of teachers of mathematics*. IAP.

Li, C. J., Monroe, M. C., Oxarart, A., & Ritchie, T. (2021). Building teachers' self-efficacy in teaching about climate change through educative curriculum and professional development. *Applied Environmental Education & Communication*, *20*(1), 34–48. https://doi.org/10.1080/1533015X.2019.1617806

Little, J. W. (1993). Teachers' professional development in a climate of educational reform. *Educational Evaluation and Policy Analysis - EDUC EVAL POLICY ANAL*, *15*, 129–151. https://doi.org/10.2307/1164418

Lloyd, B. W., & Spencer, J. N. (1994). The forum: New directions for general chemistry: Recommendations of the task force on the general chemistry curriculum. *Journal of Chemical Education*, *71*(3), 206. https://doi.org/10.1021/ed071p206

Lund, T. J., & Stains, M. (2015). The importance of context: An exploration of factors influencing the adoption of student-centered teaching among chemistry, biology, and physics faculty. *International Journal of STEM Education*, *2*(1), 13. https://doi.org/10.1186/s40594-015-0026-8

Macalalag, A. Z., Johnson, J., & Lai, M. (2020). How do we do this: Learning how to teach socioscientific issues. *Cultural Studies of Science Education*, *15*(2), 389–413. https://doi.org/10.1007/s11422-019-09944-9

Mahaffy, P. (2006). Moving chemistry education into 3D: A tetrahedral metaphor for understanding chemistry. Union Carbide Award for Chemical Education. *Journal of Chemical Education*, *83*(1), 49. https://doi.org/10.1021/ed083p49

Mahaffy, P., & Elgersma, A. (2022). Systems thinking, the molecular basis of sustainability and the planetary boundaries framework: Complementary core competencies for chemistry education. *Current Opinion in Green and Sustainable Chemistry*, *37*, 100663. https://doi.org/10.1016/j.cogsc.2022.100663

Mahaffy, P., Holme, T. A., Martin-Visscher, L., Martin, B. E., Versprille, A., Kirchhoff, M., McKenzie, L., & Towns, M. (2017). Beyond "inert" ideas to teaching general chemistry from rich contexts: Visualizing the chemistry of climate change (VC3). *Journal of Chemical Education*, *94*(8), 1027–1035. https://doi.org/10.1021/acs.jchemed.6b01009

Marlon, J. R., Wang, X., Bergquist, P., Howe, P. D., Leiserowitz, A., Maibach, E., Mildenberger, M., & Rosenthal, S. (2022). Change in US state-level public opinion about climate change: 2008–2020. *Environmental Research Letters*, *17*(12), 124046. https://doi.org/10.1088/1748-9326/aca702

Martin, F., Ritzhaupt, A., Kumar, S., & Budhrani, K. (2019). Award-winning faculty online teaching practices: Course design, assessment and evaluation, and facilitation. *The Internet and Higher Education*, *42*, 34–43. https://doi.org/10.1016/j.iheduc.2019.04.001

Matić, L. J., & Gracin, D. G. (2016). The use of the textbook as an artefact in the classroom. *Journal Für Mathematik-Didaktik*, *37*(2), 349–374. https://doi.org/10.1007/s13138-016-0091-7

Matlin, S., Mehta, G., Hopf, H., & Krief, A. (2016). One-world chemistry and systems thinking. *Nature Chemistry*, *8*(5), 393–398. https://doi.org/10.1038/nchem.2498

McCaffrey, M. S., & Buhr, S. M. (2008). Clarifying climate confusion: Addressing systemic holes, cognitive gaps, and misconceptions through climate literacy. *Physical Geography*, *29*(6), 512–528. https://doi.org/10.2747/0272-3646.29.6.512

McCuin, J. L., Hayhoe, K., & Hayhoe, D. (2014). Comparing the effects of traditional vs. Misconceptions-based instruction on student understanding of the greenhouse effect. *Journal of Geoscience Education*, *62*(3), 445–459. https://doi.org/10.5408/13-068.1

McNeal, P., Petcovic, H., & Reeves, P. (2017). What is motivating middle-school science teachers to teach climate change? *International Journal of Science Education*, *39*(8), 1069–1088. https://doi.org/10.1080/09500693.2017.1315466

Meehan, C. R., Levy, B. L. M., & Collet-Gildard, L. (2018). Global climate change in U.S. high school curricula: Portrayals of the causes, consequences, and potential responses. *Science Education*, *102*(3), 498–528. https://doi.org/10.1002/sce.21338

Mertz, P. S., & Neiles, K. Y. (2020). Scaffolding career skills into the undergraduate curriculum utilizing a backward design approach. In *Integrating Professional Skills into Undergraduate Chemistry Curricula* (Vol. 1365, pp. 43–55). American Chemical Society. https://doi.org/10.1021/bk-2020-1365.ch004

Mesa, V., & Griffiths, B. (2012). Textbook mediation of teaching: An example from tertiary mathematics instructors. *Educational Studies in Mathematics*, *79*(1), 85–107. https://doi.org/10.1007/s10649-011-9339-9

Miguel, N. M. (2015). Textbook consumption in the classroom: Analyzing a classroom corpus. *Procedia - Social and Behavioral Sciences*, *198*, 309–319. https://doi.org/10.1016/j.sbspro.2015.07.449

Ming, A., Rowell, I., Lewin, S., Rouse, R., Aubry, T., & Boland, E. (2021). *Key messages from the IPCC AR6 climate science report*. https://doi.org/10.33774/coe-2021-fj53b

Molthan-Hill, P., Blaj-Ward, L., Mbah, M. F., & Ledley, T. S. (2022). Climate change education at universities: Relevance and strategies for every discipline. In M. Lackner, B. Sajjadi, & W.-Y. Chen (Eds.), *Handbook of Climate Change Mitigation and Adaptation* (pp. 3395–3457). Springer International Publishing. https://doi.org/10.1007/978-3-030-72579-2_153

Monroe, M. C., Plate, R. R., Oxarart, A., Bowers, A., & Chaves, W. A. (2019). Identifying effective climate change education strategies: A systematic review of the research. *Environmental Education Research*, *25*(6), 791–812. https://doi.org/10.1080/13504622.2017.1360842

Morin, J., Cohen, B., Harder, N., & Thompson, S. (2022). Nurse educators' perceptions of ecoliteracy in undergraduate nursing education. *Quality Advancement in Nursing Education - Avancées En Formation Infirmière*, *8*(1). https://doi.org/10.17483/2368-6669.1287

Nadeem, R. (2021, May 26). Gen Z, millennials stand out for climate change activism, social media engagement with issue. *Pew Research Center Science & Society*. https://www.pewresearch.org/science/2021/05/26/gen-z-millennials-stand-out-for-climate-change-activism-social-media-engagement-with-issue/

Nam, Y., & Ito, E. (2011). A climate change course for undergraduate students. *Journal of Geoscience Education*, *59*(4), 229–241. https://doi.org/10.5408/1.3651405

Nation, M. T., & Feldman, A. (2022). Climate change and political controversy in the science classroom. *Science & Education*, *31*(6), 1567–1583. https://doi.org/10.1007/s11191-022-00330-6

Neiles, K. Y., & Arnett, K. (2021). Backward design of chemistry laboratories: A primer. *Journal of Chemical Education*, *98*(9), 2829–2839. https://doi.org/10.1021/acs.jchemed.1c00443

Nida, S., Rahayu, S., & Eilks, I. (2020). A survey of Indonesian science teachers' experience and perceptions toward socio-scientific issues-based science education. *Education Sciences*, *10*(2), 39. https://doi.org/10.3390/educsci10020039

Nuangchalerm, P. (2010). Engaging students to perceive nature of science through socioscientific issues-based instruction. In *Online Submission* (Vol. 13, Issue 1, pp. 34–37). https://eric.ed.gov/?id=ED508531

Obayelu, O. A., Adepoju, A. O., & Idowu, T. (2014). Factors influencing farmers' choices of adaptation to climate change in Ekiti State, Nigeria. *Journal of Agriculture and Environment for International Development (JAEID), 108*(1), 3–16. https://doi.org/10.12895/jaeid.20141.140

Oliver, M. C., & Adkins, M. J. (2020). "Hot-headed" students? Scientific literacy, perceptions and awareness of climate change in 15-year olds across 54 countries. *Energy Research & Social Science, 70*, 101641. https://doi.org/10.1016/j.erss.2020.101641

Oreskes, N. (2004). The scientific consensus on climate change. *Science, 306*(5702), 1686–1686. https://doi.org/10.1126/science.1103618

Oreskes, N. (2018). The scientific consensus on climate change: How do we know we're not wrong? In E. A. Lloyd & E. Winsberg (Eds.), *Climate Modelling: Philosophical and Conceptual Issues* (pp. 31–64). Springer International Publishing. https://doi.org/10.1007/978-3-319-65058-6_2

Parchmann, I., Broman, K., Busker, M., & Rudnik, J. (2015). Context-based teaching and learning on school and university level. In *Chemistry Education* (pp. 259–278). John Wiley & Sons, Ltd. https://doi.org/10.1002/9783527679300.ch10

Pelch, M. A., & McConnell, D. A. (2017). How does adding an emphasis on socioscientific issues influence student attitudes about science, its relevance, and their interpretations of sustainability? *Journal of Geoscience Education*, *65*(2), 203–214. https://doi.org/10.5408/16-173.1

Petsko, G. A. (2004). Bad chemistry. *Genome Biology*, *5*(2), 102. https://doi.org/10.1186/gb-2004-5-2-102

Pharo, E. J., Davison, A., Warr, K., Nursey-Bray, M., Beswick, K., Wapstra, E., & Jones, C. (2012). Can teacher collaboration overcome barriers to interdisciplinary learning in a disciplinary university? A case study using climate change. *Teaching in Higher Education*, *17*(5), 497–507. https://doi.org/10.1080/13562517.2012.658560

Popova, M., Shi, L., Harshman, J., Kraft, A., & Stains, M. (2020). Untangling a complex relationship: Teaching beliefs and instructional practices of assistant chemistry faculty at research-intensive institutions. *Chemistry Education Research and Practice*, *21*(2), 513–527. https://doi.org/10.1039/C9RP00217K

Pörtner, H.-O., Roberts, D. C., Tignor, M. M. B., Poloczanska, E. S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A., & Rama, B. (Eds.). (2022). *Climate change 2022: Impacts, adaptation and vulnerability. Contribution of working group ii to the sixth assessment report of the intergovernmental panel on climate change*.

Rahayu, S. (2021). *Chemistry for life: How to analyze and construct socioscientific cases for chemistry instruction?* 9. https://doi.org/10.1063/5.0043177

Raker, J. R., Dood, A. J., Srinivasan, S., & Murphy, K. L. (2021). Pedagogies of engagement use in postsecondary chemistry education in the United States: Results from a national survey. *Chemistry Education Research and Practice*, *22*(1), 30–42. https://doi.org/10.1039/D0RP00125B

Ravishankara, A. R., Rudich, Y., & Wuebbles, D. J. (2015). Physical chemistry of climate metrics. *Chemical Reviews*, *115*(10), 3682–3703. https://doi.org/10.1021/acs.chemrev.5b00010

Reid, A. (2019). Climate change education and research: Possibilities and potentials versus problems and perils? *Environmental Education Research*, *25*(6), 767–790. https://doi.org/10.1080/13504622.2019.1664075

Rezat, S., Fan, L., & Pepin, B. (2021). Mathematics textbooks and curriculum resources as instruments for change. *ZDM – Mathematics Education*, *53*(6), 1189–1206. https://doi.org/10.1007/s11858-021-01309-3

Rezat, S., & Sträßer, R. (2012). From the didactical triangle to the socio-didactical tetrahedron: Artifacts as fundamental constituents of the didactical situation. *ZDM*, *44*(5), 641–651. https://doi.org/10.1007/s11858-012-0448-4

Rhoton, J., & Bowers, P. (2001). *Professional development: Planning and design*. NSTA Press.

Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S. E., Donges, J. F., Drüke, M., Fetzer, I., Bala, G., von Bloh, W., Feulner, G., Fiedler, S., Gerten, D., Gleeson, T., Hofmann, M., Huiskamp, W., Kummu, M., Mohan, C., Nogués-Bravo, D., … Rockström, J. (2023). Earth beyond six of nine planetary boundaries. *Science Advances*, *9*(37), eadh2458. https://doi.org/10.1126/sciadv.adh2458

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., de Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., … Foley, J. A. (2009). A safe operating space for humanity. *Nature*, *461*(7263), 472–475. https://doi.org/10.1038/461472a

Rosa, W. (Ed.). (2017). Transforming our world: The 2030 agenda for sustainable development. In *A New Era in Global Health*. Springer Publishing Company. https://doi.org/10.1891/9780826190123.ap02

Rudd, J. A. (2021). From climate change ignorant to climate change educator. *Chemistry – A European Journal*, *27*(20), 6107–6111. https://doi.org/10.1002/chem.202004414

Sadler, T. (Ed.). (2011). *Socio-scientific issues in the classroom: Teaching, learning and research*. Springer Netherlands. https://doi.org/10.1007/978-94-007-1159-4

Schmidt, W., Houang, R., & Cogan, L. (2002). A coherent curriculum: The case of mathematics. *American Educator*, *26*(2), 10.

Schwartz, M. S., Sadler, P. M., Sonnert, G., & Tai, R. H. (2009). Depth versus breadth: How content coverage in high school science courses relates to later success in college science coursework. *Science Education*, *93*(5), 798–826. https://doi.org/10.1002/sce.20328

Serin, H. (2018). A comparison of teacher-centered and student-centered approaches in educational settings. *International Journal of Social Sciences & Educational Studies*, *5*(1), 164–167.

Seroussi, D.-E., Rothschild, N., Kurzbaum, E., Yaffe, Y., & Hemo, T. (2019). Teachers' knowledge, beliefs, and attitudes about climate change. *International Education Studies*, *12*(8), 33–45.

Shea, N., Mouza, C., & Drewes, A. (2016). Climate change professional development: Design, implementation, and initial outcomes on teacher learning, practice, and student beliefs. *Journal of Science Teacher Education*, *27*, 235–258. https://doi.org/10.1007/s10972-016-9456-5

Shepardson, D. P., Niyogi, D., Choi, S., & Charusombat, U. (2009). Seventh grade students' conceptions of global warming and climate change. *Environmental Education Research*, *15*(5), 549–570. https://doi.org/10.1080/13504620903114592

Shepardson, D. P., Niyogi, D., Roychoudhury, A., & Hirsch, A. (2012). Conceptualizing climate change in the context of a climate system: Implications for climate and environmental education. *Environmental Education Research, 18*(3), 323–352. https://doi.org/10.1080/13504622.2011.622839

Shi, L., Chu, E., & Debats, J. (2015). Explaining progress in climate adaptation planning across 156 U.S. municipalities. *Journal of the American Planning Association*, *81*(3), 191–202. https://doi.org/10.1080/01944363.2015.1074526

Skinner, D., & Howes, B. (2013). The required textbook friend or foe? Dealing with the dilemma. *Journal of College Teaching & Learning (TLC)*, *10*(2), 133–142. https://doi.org/10.19030/tlc.v10i2.7753

Smith, B. D., & Jacobs, D. C. (2003). TextRev: A window into how general and organic chemistry students use textbook resources. *Journal of Chemical Education*, *80*(1), 99. https://doi.org/10.1021/ed080p99

Sparkman, G., Geiger, N., & Weber, E. U. (2022). Americans experience a false social reality by underestimating popular climate policy support by nearly half. *Nature Communications*, *13*(1), 4779. https://doi.org/10.1038/s41467-022-32412-y

Stephens, J. C., Frumhoff, P. C., & Yona, L. (2018). The role of college and university faculty in the fossil fuel divestment movement. *Elementa: Science of the Anthropocene*, *6*, 41. https://doi.org/10.1525/elementa.297

Stevenson, K. T., Peterson, M. N., & Bradshaw, A. (2016). How climate change beliefs among U.S. teachers do and do not translate to students. *PLOS ONE*, *11*(9), 11. https://doi.org/10.1371/journal.pone.0161462

Stolz, M., Witteck, T., Marks, R., & Eilks, I. (2013). Reflecting socio-scientific issues for science education coming from the case of curriculum development on doping in chemistry education. *Eurasia Journal of Mathematics, Science and Technology Education*, *9*(4), 361–370. https://doi.org/10.12973/eurasia.2014.945a

Szozda, A. R., Mahaffy, P. G., & Flynn, A. B. (2023). Identifying chemistry students' baseline systems thinking skills when constructing system maps for a topic on climate change. *Journal of Chemical Education*, *100*(5), 1763–1776. https://doi.org/10.1021/acs.jchemed.2c00955

Talanquer, V., & Pollard, J. (2017). Reforming a large foundational course: Successes and challenges. *Journal of Chemical Education*, *94*(12), 1844–1851. https://doi.org/10.1021/acs.jchemed.7b00397

Team, R. C. (2021). R: A language and environment for statistical computing. Vienna: R foundation for statistical computing. *R Foundation for Statistical Computing*. https://cir.nii.ac.jp/crid/1370576118723163397

Todd, C., & O'Brien, K. J. (2016). Teaching anthropogenic climate change through interdisciplinary collaboration: Helping students think critically about science and ethics in dialogue. *Journal of Geoscience Education*, *64*(1), 52–59. https://doi.org/10.5408/12-331.1

Tolppanen, S., Kang, J., & Riuttanen, L. (2022). Changes in students' knowledge, values, worldview, and willingness to take mitigative climate action after attending a course on holistic climate change education. *Journal of Cleaner Production*, *373*, 133865. https://doi.org/10.1016/j.jclepro.2022.133865

Valverde, G. A., Bianchi, L. J., Wolfe, R. G., Schmidt, W. H., & Houang, R. T. (2002). *According to the book: Using TIMSS to investigate the translation of policy into practice through the world of textbooks*. Springer Science & Business Media.

van den Ham, A.-K., & Heinze, A. (2018). Does the textbook matter? Longitudinal effects of textbook choice on primary school students' achievement in mathematics. *Studies in Educational Evaluation*, *59*, 133–140. https://doi.org/10.1016/j.stueduc.2018.07.005

Versprille, A. N., & Towns, M. H. (2015). General chemistry students' understanding of climate change and the chemistry related to climate change. *Journal of Chemical Education*, *92*(4), 603–609. https://doi.org/10.1021/ed500589g

Versprille, A., Zabih, A., Holme, T. A., McKenzie, L., Mahaffy, P., Martin, B., & Towns, M. (2017). Assessing student knowledge of chemistry and climate science concepts associated with climate change: Resources to inform teaching and learning. *Journal of Chemical Education*, *94*(4), 407–417. https://doi.org/10.1021/acs.jchemed.6b00759

Villalta-Cerdas, A., & Yildiz, F. (2022). Creating significant learning experiences in an engineering technology bridge course: A backward design approach. *2022 ASEE Virtual Annual Conference Content Access*. https://par.nsf.gov/biblio/10352624-creating-significant-learning-experiences-engineering-technology-bridge-course-backward-design-approach

Vojír, K., & Rusek, M. (2021). Preferred chemistry curriculum perspective: Teachers' perception of lower-secondary school textbooks. *Journal of Baltic Science Education*, *20*(2), 316–331.

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

Wang, H.-H., Hong, Z.-R., Liu, S.-C., & Lin, H.-S. (2018). The impact of socio-scientific issue discussions on student environmentalism. *Eurasia Journal of Mathematics, Science and Technology Education*, *14*(12), em1624. https://doi.org/10.29333/ejmste/95134

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L. D., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T. L., Miller, E., Bache, S. M., Müller, K., Ooms, J., Robinson, D., Seidel, D. P., Spinu, V., … Yutani, H. (2019). Welcome to the Tidyverse. *Journal of Open Source Software*, *4*(43), 1686. https://doi.org/10.21105/joss.01686

Wiggins, G. P., & McTighe, J. (2005). *Understanding by design*. ASCD.

Wild, A., Galosy, J., Kagle, M., Gillespie, N., & Rozelle, J. (2018). Teacher agency over curriculum and professional learning: Lock-step. *Journal of Professional Capital and Community*, *3*(4), 306–320. https://doi.org/10.1108/JPCC-12-2017-0034

Wilson, P., Duarte, N., Harris, T., Sayers, T., & Weinrich, M. (2023). *Analysis of climate change in general chemistry textbooks* [Manuscript Under Review].

Wilson, P., Sayers, T., & Weinrich, M. (2023). *Undergraduate instructors' approach to the teaching of climate change in chemistry* [Manuscript Under Review].

Winarto, Y. T., & Stigter, K. J. (2016). Incremental learning and gradual changes: "Science Field Shops" as an educational approach to coping better with climate change in agriculture. In *Promoting Climate Change Awareness through Environmental Education* (pp. 60–95). IGI Global. https://doi.org/10.4018/978-1-4666-8764-6.ch004

Woodbury, S., & Gess-Newsome, J. (2002). Overcoming the paradox of change without difference: A model of change in the arena of fundamental school reform. *Educational Policy*, *16*(5), 763–782. https://doi.org/10.1177/089590402237312

Wuebbles, D., Fahey, D., Hibbard, K., Arnold, J., Kunkel, K., DeAngelo, B., LeGrande, A., Doherty, S. J., Leung, L. R., Easterling, D., Malsowski, W., Edmonds, J., Mears, C., Perlwitz, J., Hall, T., Romanou, A., Hayhoe, K., Sanderson, B., Hoffman, F., … West, T. (2017). *Climate science special report: Fourth national climate assessment, volume I* (pp. 1–470). U.S. Global Change Research Program, Washington, DC. https://doi.org/10.7930/J0J964J6

Yoho, R. A., & Rittmann, B. (2018). Climate change and energy technologies in undergraduate introductory science textbooks. *Environmental Communication*, *12*(6), 731–743. https://doi.org/10.1080/17524032.2018.1454337

York, S., & Orgill, M. (2020). ChEMIST table: A tool for designing or modifying instruction for a systems thinking approach in chemistry education. *Journal of Chemical Education*, *97*(8), 2114–2129. https://doi.org/10.1021/acs.jchemed.0c00382

You, J., Lee, H., & Craig, C. J. (2019). Remaking textbook policy: Analysis of national curriculum alignment in Korean school textbooks. *Asia Pacific Journal of Education*, *39*(1), 14–30. https://doi.org/10.1080/02188791.2019.1572591

Zeidler, D., & Sadler, T. (2023). Exploring and expanding the frontiers of socioscientific issues. In *Handbook of Research on Science Education* (p. 31). Routledge.

Zowada, C., Eilks, I., & Gulacar, O. (2019). Innovating undergraduate general chemistry by integrating sustainability-related socio-scientific issues. *Action Research and Innovation in Science Education*, *1*, 3–8. https://doi.org/10.12973/arise/100433

APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL LETTER FOR INTERVIEW STUDY

UNIVERSITY OF
NORTHERN COLORADO

Institutional Review Board

Date: 07/01/2021

Principal Investigator: Patrick Wilson

Committee Action: **IRB EXEMPT DETERMINATION – New Protocol**

Action Date: 07/01/2021

Protocol Number: 2106026945

Protocol Title: Chemistry instructor's perspectives in incorporating climate change instruction in undergraduate chemistry courses.

Expiration Date:

The University of Northern Colorado Institutional Review Board has reviewed your protocol and determined your project to be exempt under 45 CFR 46.104(d)(702) for research involving

Category 2 (2018): EDUCATIONAL TESTS, SURVEYS, INTERVIEWS, OR OBSERVATIONS OF PUBLIC BEHAVIOR. Research that only includes interactions involving educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior (including visual or auditory recording) if at least one of the following criteria is met: (i) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects; (ii) Any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation; or (iii) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a limited IRB review to make the determination required by 45 CFR 46.111(a)(7).

You may begin conducting your research as outlined in your protocol. Your study does not require further review from the IRB, unless changes need to be made to your approved protocol.

As the Principal Investigator (PI), you are still responsible for contacting the UNC IRB office if and when:

UNIVERSITY OF
NORTHERN COLORADO

Institutional Review Board

- You wish to deviate from the described protocol and would like to formally submit a modification request. Prior IRB approval must be obtained before any changes can be implemented (except to eliminate an immediate hazard to research participants).
- You make changes to the research personnel working on this study (add or drop research staff on this protocol).
- At the end of the study or before you leave The University of Northern Colorado and are no longer a student or employee, to request your protocol be closed. *You cannot continue to reference UNC on any documents (including the informed consent form) or conduct the study under the auspices of UNC if you are no longer a student/employee of this university.
- You have received or have been made aware of any complaints, problems, or adverse events that are related or possibly related to participation in the research.

If you have any questions, please contact the Research Compliance Manager, Nicole Morse, at 970-351-1910 or via e-mail at nicole.morse@unco.edu. Additional information concerning the requirements for the protection of human subjects may be found at the Office of Human Research Protection website - http://hhs.gov/ohrp/ and https://www.unco.edu/research/research-integrity-and compliance/institutional-review-board/.

Sincerely,

Nicole Morse
Research Compliance Manager

University of Northern Colorado: FWA00000784

APPENDIX B

INTERVIEW STUDY RECRUITMENT EMAIL

Dear Dr. [name inserted here],

My name is Patrick Wilson and I am a graduate student from the Chemistry and Biochemistry Department at the University of Northern Colorado. I am writing to invite you to participate in my research study about climate change instruction in your undergraduate chemistry courses. I would like to speak with you even if you do not discuss or teach climate change in your chemistry courses. I obtained your contact information from your department's faculty page.

If you decide to participate in this study, you will be interviewed over the course of 30 minutes to 1 hour. I would like to audio/video record the interview. The information obtained from the interview will be used to examine the extent of climate change related topics and their incorporation into undergraduate level chemistry courses.

This request for an interview is completely voluntary. You can choose whether you'd like to participate in this study. If you would like to be involved with this study, you can schedule a time to do the interview here, or by phone at 970-238-0405.
Thank you very much for your time.

Sincerely,

Patrick Wilson M.S.
Pronouns: his/him/he
Graduate Teaching Assistant
Department of Chemistry and Biochemistry
University of Northern Colorado

APPENDIX C

INTERVIEW STUDY CONSENT FORM

CONSENT FORM FOR HUMAN PARTICIPANTS IN RESEARCH
UNIVERSITY OF NORTHERN COLORADO

Project Title: Chemistry instructor's perspectives in incorporating climate change instruction in undergraduate chemistry courses.

Researcher: Patrick Wilson
Email: patrick.wilson@unco.edu

Research Advisors: Melissa Weinrich, PhD
phone number: (970)351-1172 email: melissa.weinrich@unco.edu

The goal of this project is to understanding undergraduate chemistry instructor's perspectives on incorporation and teaching of climate change related topics in their courses. As a participant in this study, you will be asked to be interviewed. The interview will last approximately 30 minutes to 1 hour. The interview will be recorded and later transcribed.

Steps will be taken to provide maximal confidentiality during the data acquisition process and analysis. Consent forms signed will be stored separately from the data as to not provide any link between the participant and data collected. Each participant will be assigned an alias associated with your answers to interview questions and basic demographic information. Voice recordings will be stored on a password protected electronic device. Any future publications will include alias's and only de-identified data.

While participating in this study, there is no expectation that you will encounter a level of risk different from any normal typical day. Your time is extremely valuable and is expected to cover 30 minutes to 1 hour to conduct your interview with me. There will be no other forms of compensation for this time beyond my gratitude.

Participation is voluntary. You may decide not to participate in this study and if you begin participation you may still decide to stop and withdraw at any time. Your decision will be respected and will not result in loss of benefits to which you are otherwise entitled. Having read the above and having had an opportunity to ask any questions, please sign below if you would like to participate in this research. A copy of this form will be given to you to retain for future reference. If you have any concerns about your selection or treatment as a research participant, please contact Nicole Morse, IRB Administrator, Office of Research, Kepner Hall, University of Northern Colorado Greeley, CO 80639; 970-351-1910.

____________________________ ____________________________

Participant's Signature Date Researcher's Signature Date

APPENDIX D

INSTRUCTOR STUDY INTERVIEW PROTOCOL

- How important is climate change to you as an educator?
- Briefly, what is your teaching philosophy? What courses do you teach?
- Do you discuss climate change (including any related subtopics) in your chemistry courses?
    - If so how? Can you give an example? How (did) do you make decisions about how to include instruction about climate change in your course?

- If not, why not? What are the reasons why you don't discuss climate change?
- How would you make decisions about how to include or not include instruction about climate change in your course?
- If you are not incorporating climate change instruction in your chemistry courses, could you give an example of how you could do this? Where could this occur in your course?
- Here is an example of an activity that could be used in general chemistry. The example examines a comparison in carbon dioxide output from the combustion of ethanol versus octane. Would you be interested in incorporating this type of activity in your chemistry courses?

- What benefits do/would your students get from this activity?
- What barriers do/would you experience in using this activity?

- Have you had informal conversations with students about climate change?
- Do you have any recollection of students asking questions in class about topics related to climate change?
- In your own undergraduate education, did/how did your instructors talk about climate change?
- Which courses should address climate change related topics?
- What suggestions do you have for improving instruction about the chemistry of climate change in chemistry courses?

Demographic information
Please select your age range:

- 18-24 25-34 35-44 45-54 55-64 65+
    - What is your gender?
    - How do you identify your ethnicity?
    - What is your highest level of education?
    - What position do you hold at your university?

APPENDIX E

INSTITUTIONAL REVIEW BOARD APPROVAL LETTER FOR SURVEY STUDY

UNIVERSITY OF
NORTHERN COLORADO

Institutional Review Board

Date: 11/11/2022

Principal Investigator: Patrick Wilson

Committee Action: **IRB EXEMPT DETERMINATION – New Protocol** Action
Date: 11/11/2022

Protocol Number: 2210045499

Protocol Title: Undergraduate Chemistry Professor's Perspectives on Content Selection in Chemistry Courses

Expiration Date:

The University of Northern Colorado Institutional Review Board has reviewed your protocol and determined your project to be exempt under 45 CFR 46.104(d)(702) for research involving

Category 2 (2018): EDUCATIONAL TESTS, SURVEYS, INTERVIEWS, OR OBSERVATIONS OF PUBLIC BEHAVIOR. Research that only includes interactions involving educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior (including visual or auditory recording) if at least one of the following criteria is met: (i) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects; (ii) Any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation; or (iii) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a limited IRB review to make the determination required by 45 CFR 46.111(a)(7).

You may begin conducting your research as outlined in your protocol. Your study does not require further review from the IRB, unless changes need to be made to your approved protocol.

As the Principal Investigator (PI), you are still responsible for contacting the UNC IRB office if and when:

Carter Hall 2008 | Campus Box 143 | Greeley, CO 80639 | Office 970-351-1910

UNIVERSITY OF NORTHERN COLORADO

Institutional Review Board

- You wish to deviate from the described protocol and would like to formally submit a modification request. Prior IRB approval must be obtained before any changes can be implemented (except to eliminate an immediate hazard to research participants).
- You make changes to the research personnel working on this study (add or drop research staff on this protocol).
- At the end of the study or before you leave The University of Northern Colorado and are no longer a student or employee, to request your protocol be closed. *You cannot continue to reference UNC on any documents (including the informed consent form) or conduct the study under the auspices of UNC if you are no longer a student/employee of this university.
- You have received or have been made aware of any complaints, problems, or adverse events that are related or possibly related to participation in the research.

If you have any questions, please contact the Research Compliance Manager, Nicole Morse, at 970-351-1910 or via e-mail at nicole.morse@unco.edu. Additional information concerning the requirements for the protection of human subjects may be found at the Office of Human Research Protection website - http://hhs.gov/ohrp/ and https://www.unco.edu/research/research-integrity-and compliance/institutional-review-board/.

Sincerely,

Nicole Morse
Research Compliance Manager

University of Northern Colorado: FWA00000784

Carter Hall 2008 | Campus Box 143 | Greeley, CO 80639 | Office 970-351-1910

APPENDIX F

SURVEY RECRUITMENT EMAIL

Dear Chemistry Professor,

My name is Patrick Wilson and I am a graduate student from the Chemistry and Biochemistry Department at the University of Northern Colorado. I am writing to invite you to participate in my research study about how content is selected regarding the instruction in your undergraduate chemistry courses. I obtained your contact information from your department's faculty page.

If you decide to participate in this study, you will be taking a survey that is projected to take between 10 and 20 minutes. The information gathered from this survey seeks to provide insight as to the selection of topics in your undergraduate chemistry course(s).

This request for this survey is completely voluntary. You can choose whether you'd like to participate in this study. If you would like to be involved with this study, please click the following link below:

Follow this link to the Survey:
${l://SurveyLink?d=Take the Survey}
Or copy and paste the URL below into your internet browser:
${l://SurveyURL}
Follow the link to opt out of future emails:
${l://OptOutLink?d=Click here to unsubscribe}

Thank you very much for your time.

Sincerely,

Patrick Wilson M.S.
Pronouns: his/him/he
Doctoral Candidate
Department of Chemistry and Biochemistry
University of Northern Colorado

APPENDIX G

SURVEY STUDY QUESTIONS

This research project seeks to describe the extent to which climate change topics are included in undergraduate chemistry instruction. We also hope to understand the contextual, personal, and decision-making processes in your instructional practices. As a participant in this study, you will be asked to take a brief survey. The survey is expected to take between 10 to 20 minutes. This data collection and analysis process will be anonymous. No personal identifiable information will be collected outside of demographic details. All data will be stored on a password protected electronic device.

If you have any questions about this research project, please contact Patrick Wilson at patrick.wilson@unco.edu. If you have any concerns about your selection or treatment as a research participant, please contact Nicole Morse, IRB Administrator, Office of Research, Kepner Hall, University of Northern Colorado Greeley, CO 80638; 970-351-1910.

Thank you for agreeing to participate in our research. Before you begin, please note that the data you provide may be collected and used by Qualtrics as per its privacy agreement. Additionally, this research is for residents of the United States over the age of 18; if you are not a resident of the United States and/or under the age of 18, please do not complete this survey.

Qualtrics has specific privacy policies of their own. You should be aware that these web services may be able to link your responses to your ID in ways that are not bound by this consent form and the data confidentiality procedures used in this study. If you have concerns, you should consult these services directly.

Participation is voluntary. While participating in this survey, there is no expectation that you will encounter any level of risk different from any normal typical day. Your time is extremely valuable, and the survey is expected to take 10 to 20 minutes to complete. There will be no other form of compensation for participation outside of my gratitude. Having read the above, please indicate your acceptance to participate in this research below:
Yes: continues survey
No: ends survey

[Contextual Factors]

Which undergraduate chemistry courses have you taught or currently teach? Please select all of the following that apply:

- Introductory Chemistry
- General, Organic, and Biochemistry (GOB)-
- General Chemistry 1 and/or 2
- Organic Chemistry 1 and/or 2, or 1-semester survey
- Analytical and/or Instrumental Chemistry
- Physical Chemistry 1 and/or 2, or 1-semester survey
- Biochemistry Chemistry 1 and/or 2, or 1-semester survey
- Inorganic Chemistry 1 and/or 2, or 1-semester survey
- Environmental Chemistry
- Other topics (e.g. materials, polymers, advanced synthesis, etc.)

Please select one course to focus on in this survey. Which course will you focus on for this survey?

1. Introductory
1. GOB
2. General 1 and/or 2
3. Organic 1 and/or 2, or 1-semester survey
4. Analytical and or Instrumental
5. Physical 1 and/or 2, or 1-semester survey
1. Biochemistry 1 and/or 2, or 1-semester survey
2. Inorganic 1 and/or 2, or 1-semester survey
3. Environmental
4. Other topics (e.g. materials, polymers, advanced synthesis, etc.)

What textbook (title, author, and edition) is used in this course?

____

[Teacher Thinking]

Rate the importance of the following statements:

Climate change is important to me as an educator

- Extremely Important
- Very important
- Neither important no unimportant
- Not very important
- Not at all important

Climate change is important to me as an individual

- Extremely Important
- Very important
- Neither important nor unimportant
- Not very important
- Not at all important

- Instructor Decisions about Climate Change

Indicate which of the following topics are covered in your focus course, as they relate to climate change:

- Gases
  - Characterization of carbon dioxide and other greenhouse gases
  - Temperature and pressure as they relate to climate
  - Kinetic molecular theory related to climate change
  - Nature of light and electromagnetic spectrum, as related to climate change
  - Absorption of energy by molecules in different spectral regions related to global warming
  - Global warming and the greenhouse effect
  - Human involvement in greenhouse gas production
- Matter and Measurement
  - Data collection, analysis, and interpretation (related to climate change)
  - Hypothesis testing (related to climate change)
  - Nature of models and modeling (related to climate change)

  - Nature of science and uncertainty (related to climate change)
  - Complexity of natural systems
  - Importance of chemistry in contributing solutions to global challenges (e.g. sequestration of carbon, alternative energy opportunities)
- Atoms, ions & molecules
  - Isotope ratios in glacial ice cores to obtain temperature proxy data
  - Speciation of carbon, nitrogen, oxygen & phosphorus as connected to climate change
- Thermochemistry
  - Thermodynamics of photosynthesis related to climate change or carbon cycling
  - Thermodynamics of the combustion of fossil fuels & production of atmospheric gases, related to climate change
  - Alternative energy possibilities related to climate change
- Solutions
  - Separation and analysis in characterizing species in seawater and detection of trace substances
  - Acidification of oceans by CO_2 and speciation of carbon in the oceans
  - Equilibrium concepts of carbonic acid and carbon dioxide
  - Phase changes involving water & the role of water in modulating climate
- Chemical Reactions
  - Stoichiometry of combustion reactions or photosynthesis, as related to greenhouse gases or carbon cycling
  - Atom economy, atom efficiency & green chemistry
- Kinetics
  - Atmospheric lifetime of greenhouse gasses
  - Kinetic process in the atmosphere, soils & oceans
- Electrochemistry
  - Role of chemistry in the production of modern materials & alternative energy sources which include biofuels, batteries, solar, wind power, etc.
  - Efficiency of electrochemical reactions to generate energy
- Climate Change Outcomes
  - Increase in atmospheric temperature
  - Increase in ocean temperature
  - Rise in sea level
  - Ecosystem changes
  - Human health, societal changes, and/or water resources
  - Timing of the impacts of climate change

Check box for inventory items: check indicates yes, blank indicates no

Is there a topic related to climate change that is not above that you teach in your course?

Are any of the previous concept items assessed? Yes/No

Which of the following assessment tools are used in your instruction of climate change (checkbox):

a. Individual exercises
b. Group exercises
c. Oral presentations
d. Tests or quizzes
e. Homework
f. Oral examinations
g. Other (please specify) [open space to specify]

Which of the following describes your coverage of climate change in your course?

- Climate change is not included in my course.
- Climate change is only included tangentially or in passing in my course.
- Climate change is connected to chemistry multiple times in my course.

[One of the next three questions is given based on response to previous question.]

Climate change is not included in my course because:

- It's not related to my subject material.
- It's not related to my students' majors or interests.
- The course content is standardized, and I cannot change it.
- I want to teach about other topics and context, and I don't have space in the curriculum
- I am not knowledgeable enough about how chemistry is connected to climate change to teach about it.
- I lack resources on how to connect chemistry to climate change.
- I want to avoid creating conflict.
- The content is depressing to teach.
- Other

Free Response: Please list any additional reasons why you do not include climate change in your chemistry course.

Climate change is included tangentially or in passing in my course because:

- There is interest from students.
- The topic is important.
- The course content is standardized, and I can only make so many changes or additions.
- There is not enough time to get through material.
- I think it is important, but I also want to teach about other topics and context.
- I do not have enough knowledge about how chemistry is connected to climate change to fully connect with class material.
- I lack resources on how to connect chemistry to climate change.
- The content is depressing to teach.
- I want to avoid creating conflict.
- Other

Free Response: Please list any additional reasons why you include climate change tangentially or in passing in your chemistry course.

Climate change is connected multiple times in my course because:

- There is interest from students.
- The topic is important.
- It allows me to connect class content with relevant examples.
- It is important to teach in-depth rather than cover a lot of content.
- Climate change is the main challenge students will face and they need resources to understand it.
- Other

Free Response: Please list any additional reasons why you connect climate change to chemistry multiple times in your chemistry course.

[Contextual Factors]

Select how influential the below resources are for your decision to incorporate or not incorporate climate change topics in your course.
[Options for each]

- Extremely influential to me incorporating climate change
- Very influential to me incorporating climate change
- Not influential
- Very influential to me not incorporating climate change
- Extremely influential to me not incorporating climate change

- Textbooks or open educational resources
- Professional development and/or conferences
- Research and education journals involving climate change topics
- Professional organization guidelines (e.g. ACS)
- Departmental chair
- Faculty within your department
- Faculty outside your department at your institution
- Faculty at other institutions
- Your Ph.D. and/or postdoc advisor
- Teaching and learning center
- A K-12 teacher
- Student request or feedback
- Promotion and tenure guidelines
- Class size
- Time constraints due to research commitments
- Time constraints due to service commitments
- Online resources (please specify): ____________
- Other (please specify): ____________

[Personal Factors]

Please select your age range

- 18-24
- 25-34
- 45-54
- 55-64
- 65+

What is your gender: _______________
What is your race/ethnicity? __________________
What is your teaching experience? (Check all that apply)
I have K-12 teaching experience.
I was a laboratory TA in graduate school.
I was a recitation TA in graduate school.
While in graduate school, I taught lectures when the lecturer/professor was absent.
I have taught at a community college.
I have taught at a 4-year college or university.
I have taught at a PhD-level, research intensive institution.
Other (please specify) _____________________

Please select the year that you received your first faculty appointment. Drop down menu starting at Prior to 1970 (in 5 year increments)
What is your academic role? (i.e. Professor, Lecturer, Associate Professor of Practice)
What is your tenure status at your institution?

Approximately what is the distribution of your appointment? (Total should add to 100%) If a field is Not Applicable, please enter 0. Teaching (%) ____ Research (%) ____ Service (%) ____

How many courses are you expected to teach per semester?

- 1
- 2
- 3
- 4 or more