Incorporation of Climate Change Topics in High School Chemistry: Teacher Practices, Beliefs, and Barriers to Implementation

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List of Tables

Abstract

Climate change is an ongoing and drastic problem that the world will have to address very soon. A basic knowledge of the processes that drive climate change is essential for making informed decisions (e.g. voting). Therefore, to ensure the general population has a foundational understanding of the chemical processes involved with climate change is crucial. Highschool chemistry teachers reportedly teach climate change at the lowest rates among STEM teachers. This study investigates if and how high school chemistry teachers incorporate climate change topics in their chemistry courses, and what attributes help or hinder them doing so. This study identified that chemistry teachers are overwhelmingly motivated to improve and update their curricula to include more climate change topics. They do commonly incorporate climate change topics into their courses, but the nature and depth of this varies greatly depending on the barriers and supports they face, which are highly dependent on the context of their individual school. Promising avenues for removing barriers and better supporting teachers in these aims are discussed.

Introduction

Motivation

Climate change will have lasting and irreversible effects on the world. Climate change is already leaving impacts across the globe. Small island nations will be the first and most heavily impacted by climate change. Some are predicted to be underwater, while most of them will have vastly different climates due to increasing global temperatures.[1] Extreme weather conditions such as record-breaking heat waves on the west coast of the United States and flooding on the east coast during 2020 can be traced back to the increasing average global temperature.[2,3] Put simply, anthropogenic emissions are trapping greenhouse gases in our atmosphere leading to an increase in temperature. The increase in global temperature disrupts the natural ecosystems and causes a general increase in extreme weather conditions that we have been seeing across

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[1] Lazrus, H. Sea Change: Island Communities and Climate Change. *Annual Review of Anthropology* **2012**, *41*, 285–301.

[2] 2020 western wildfire season climate change links https://www.climatesignals.org/events/western-wildfire-season-2020 (accessed 2022 -02 -15).

[3] Climate Change and Wildland Fire - Climate Change (U.S. National Park Service) https://www.nps.gov/subjects/climatechange/ccandfire.htm (accessed 2022 -02 -15).

the world in recent years.[4] These disasters are bound to increase and will be irreversible by 2050 unless drastic change is made.[5]

The largest issue that society faces in combatting climate change is the reluctance to accept the mitigation strategies that are needed to stop the temperature from rising. Climate change deniers, climate ambivalence, and large corporations' economic interests are major barriers to enacting mitigation strategies. Here I argue that if we let these problems go without addressing them, a business-as-usual model, they will keep compounding and the climate which we are a part of will become inhospitable.

There are many issues that stem from the rising global temperature, this makes agreeing on how to enact change can be extremely complicated and difficult.[6] For instance, there is a focus on the effect of transportation emissions on atmospheric composition, but this can be traced back to burning fossil fuels in general. A broad solution would be to use an alternate clean fuel source. Yet that can be hotly contested as well. Common alternatives are solar, wind, and nuclear power. These sources are cleaner than fossil fuel combustion but are also

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[4] US Department of Commerce, N. Global Monitoring Laboratory - Carbon Cycle Greenhouse Gases https://gml.noaa.gov/ccgg/trends/ (accessed 2022 -04 -26).

[5]IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

[6]Sayed, E. T.; Wilberforce, T.; Elsaid, K.; Rabaia, M. K. H.; Abdelkareem, M. A.; Chae, K.-J.; Olabi, A. G. A Critical Review on Environmental Impacts of Renewable Energy Systems and Mitigation Strategies: Wind, Hydro, Biomass and Geothermal. *Science of The Total Environment* **2021**, *766*, 144505. https://doi.org/10.1016/j.scitotenv.2020.144505.

associated with environmental impacts. There is no simple, single solution that satisfies everyone.

Another climate change issue that experiences vigorous debate is land/resource distribution and restoration.[7] Mining, fracking, lumber, and agriculture all contribute to habitat loss. The easiest solution here would be to transition using more sustainable materials or practices. For example, the lumber industry has attempted this by replanting the trees they cut down. This is not enough for a lot of environmental groups because it still destroys the old growth forests that many species have laid claim to, and the younger forests do not sequester carbon at the same rates. Yet another mitigation strategy is to geoengineer the planet so that the atmosphere cools. This is one of the most heavily debated proposals for fixing climate change. Proponents say that it would be able to fix some of the problems within weeks. However, the opposition grapples with the ethics and repercussions that geoengineering would bring.[8] Identifying and enacting real solutions to climate change requires having a scientifically literature population who are informed on these interdisciplinary issues and can debate and agree on climate change action. However, there is a lack of cohesion in the way that curricula are taught in

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[7] Sayed, E. T.; Wilberforce, T.; Elsaid, K.; Rabaia, M. K. H.; Abdelkareem, M. A.; Chae, K.-J.; Olabi, A. G. A Critical Review on Environmental Impacts of Renewable Energy Systems and Mitigation Strategies: Wind, Hydro, Biomass and Geothermal. *Science of The Total Environment* **2021**, *766*, 144505. https://doi.org/10.1016/j.scitotenv.2020.144505.

[8] Preston, C. J. Ethics and Geoengineering: Reviewing the Moral Issues Raised by Solar Radiation Management and Carbon Dioxide Removal. *WIREs Climate Change* **2013**, *4* (1), 23–37. https://doi.org/10.1002/wcc.198.

schools very broadly, and this applies to climate change subjects as well.[9]Here I argue it is important to teach students about climate change science so they can better understand the world around them as it continues to change dramatically, and to be informed while voting and making decisions about the future. A significant barrier to this is that chemistry and physics teachers are less likely than any other high school STEM teachers to incorporate climate change science into their courses.[10]

There is a lot of literature about the impacts that these groups have on the environmental movement. However, there is relatively little known about what factors have caused such low rates of climate change science education in high school classrooms. The literature does an excellent job finding a lack of education in this field, it rarely discusses the explanation for the lack of climate change science education. Understanding high school chemistry teachers' thoughts, beliefs, and/or barriers to teaching climate change science in their classrooms will show how teachers think about their roles in teaching climate change science. This is pivotal to understanding why it is taught at such low rates amidst a global crisis.

In this thesis, I aim to elucidate if and how high school chemistry teachers incorporate climate change science in their courses, and what contextual factors and structure enable or prevent them from doing so. . The ultimate aim of this work is to illustrate opportunities to better empower and enable highschool teachers to incorporate climate change science into their courses.

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[9]Plutzer, E.; McCaffrey, M.; Hannah, A. L.; Rosenau, J.; Berbeco, M.; Reid, A. H. Climate Confusion among U.S. Teachers. *Science* **2016**, *351* (6274), 664–665. https://doi.org/10.1126/science.aab3907.

[10]Hannah, A. L.; Rhubart, D. C. Teacher Perceptions of State Standards and Climate Change Pedagogy: Opportunities and Barriers for Implementing Consensus-Informed Instruction on Climate Change. Climatic Change 2020, 158 (3–4), 377–392. https://doi.org/10.1007/s10584-019-02590-8.

Literature Review

Existing literature quantitatively analyzes the way that climate change is taught in classes currently. A survey of 5000 randomly selected Swiss adults explored the relationship between environmental knowledge and conservation behavior.[11] This study found that educational campaigns should be designed with a profound understanding of the target population's underlying knowledge structure. This indicating that a base knowledge and understanding of the systems at play are important for interpreting and acting upon climate-related topics. As Frick et al. summarize: "It is important to ascertain how much people already know and what type of knowledge is essential to promote the target behavior. "[12]

Additionally, insight has been gathered as to which pedagogical best practices for climate change is taught. There is much discussion about the "both sides" approach, where climate change is discussed from why one would or would not believe it. This has met some criticism,[13,14] One paper is an article

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[11] Frick, J.; Kaiser, F. G.; Wilson, M. Environmental Knowledge and Conservation Behavior: Exploring Prevalence and Structure in a Representative Sample. *Personality and Individual Differences* **2004**, *37* (8), 1597–1613. https://doi.org/10.1016/j.paid.2004.02.015.

[12] Frick, J.; Kaiser, F. G.; Wilson, M. Environmental Knowledge and Conservation Behavior: Exploring Prevalence and Structure in a Representative Sample. *Personality and Individual Differences* **2004**, *37* (8), 1597–1613. https://doi.org/10.1016/j.paid.2004.02.015.

[13] McGinnis, P. Tackling the Complex Issue of Climate Change. *Science Scope* **2017**, *41* (2), 1–2.

[14] Plutzer, E.; Hannah, A. L. Teaching Climate Change in Middle Schools and High Schools: Investigating STEM Education's Deficit Model. *Climatic Change* **2018**, *149* (3–4), 305–317. https://doi.org/10.1007/s10584-018-2253-8.

written by a teacher explaining the dangers of teaching both sides when there is such broad agreement on climate change. The other paper takes a sample of 1,500 middle and high school teachers to answer if more science classes in college inspire the teachers to teach climate change science at higher rates. They found that it has a small impact, but that political orientation has a much stronger effect on their teaching strategies. Teachers' personal beliefs are found to correlate to how they teach climate change in their classrooms.[15] The same survey of 1,500 science teachers was analyzed to find that "the median teacher devotes only 1 to 2 hours to the topic." [16] The consensus among the literature is that it is irresponsible to encourage students to debate and question the scientific consensus that contributes to the Intergovernmental Panel on Climate Change.

Other insight into this field comes from the methodological approach and analysis of the teaching practices themselves. One popular way to do this is to promote pro environmental behaviors in classrooms.[17] Papers in this style are extremely helpful in identifying what students focus on and seeing how they engage with the topic. However, they fail to take the teachers' job into account. These papers suggest to teachers how they should teach but developing a new curriculum for their classes is extremely difficult due to time and other barriers. Other papers encourage teachers to use unique or technical teaching models in

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[15] Plutzer, E.; Hannah, A. L. Teaching Climate Change in Middle Schools and High Schools: Investigating STEM Education's Deficit Model. Climatic Change 2018, 149 (3–4), 305–317. https://doi.org/10.1007/s10584-018-2253-8

[16] Plutzer, E.; McCaffrey, M.; Hannah, A. L.; Rosenau, J.; Berbeco, M.; Reid, A. H. Climate Confusion among U.S. Teachers. *Science* **2016**, *351* (6274), 664–665. https://doi.org/10.1126/science.aab3907.

[17] Sieg, A.-K.; Dreesmann, D. Promoting Pro-environmental Beehavior in School. Factors Leading to Eco-friendly Student Action. *Sustainability (Switzerland)* **2021**, *13* (12). https://doi.org/10.3390/su13126598.

their classes.[18] The issue here is that this is not accessible for most teachers due to the wealth of their school districts or knowledge of unique teaching techniques like game design.

In summary, the literature largely quantitatively analysis what is taught in classes and characterizes pedagogical best-practice approaches. However, there is little to no work about what supports are needed to help teachers incorporate climate change topics, or what barriers they face when trying to teach this topic. Additionally, the literature tends to implicitly or explicitly blame instructors for shortcomings in teaching the content, without examining the full context of the teacher's circumstances and the barriers they encounter. Thus, there is a deep need to characterize what teachers are doing and what they want to be doing in their classrooms, taking into consideration the structural and interpersonal supports and challenges they face.

Research Question

Climate change is an omnipresent crisis put onto future generations. High-quality education on these issues is essential to prepare informed voters and pioneer effective climate initiatives. Thus, this project investigates the following research questions:

1) How do high school chemistry teachers address climate change in their classrooms?
2) What factors influence why and how they teach it?

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[18] Puttick, G.; Tucker-Raymond, E. Building Systems from Scratch: An Exploratory Study of Students Learning About Climate Change. *Journal of Science Education and Technology* **2018**, *27* (4), 306–321.

Methods

Study design

To address research questions (1) and (2) we conducted semi-structured interviews[19] with high school chemistry teachers in Western Oregon, asking about their teaching practices, experiences, and beliefs about climate change. To address research question (1) we aimed to triangulate teachers' self-reported teaching practices with course artifacts such as syllabi and assignments. We hypothesize that these findings will elucidate mechanisms that promote or inhibit the teaching of climate science in high school chemistry curricula.

This project had 3 stages: developing and testing an interview script, conducting the interviews, and analyzing the interview transcripts. Institutional Review Board (IRB) approval from Reed College (IRB No. 2021-F13) was received for all data collected within this study and appropriate consent was obtained from participants as required by the IRB.

Positionality Statement

This study was designed and conducted by author Kieran Wharton with the mentorship of Dr. Nicole James. In education research, the author's epistemic and ontological lenses inform the nature of the study design and consequently the data collected, the analytical methods used, and the interpretations derived from that data. Thus, awareness of intrinsic bias and mitigation of that bias is

[19] Saldaña, Jonny; Mathew B. Miles; A. Michael Huberman. *Qualitative Data Analysis: A Methods Sourcebook*, 3rd ed.; SAGE publications.

essential. Reflexivity[20] is a key practice for doing so. This positionality statement is meant to make this reflexivity transparent to the reader.[21]

Kieran Wharton is an undergraduate student at Reed College, majoring in environmental studies and chemistry. Wharton's position on climate change is as follows. Climate change is an unchangeable fact of the world brought upon us primarily by anthropogenic effects. Active climate denial and misinformation is a large contributor to our lack of climate change mitigation and action taken to fight its effects. At this stage, our world will be vastly altered during our lifetimes, thus it is of the utmost importance that the public is well informed and scientifically literate on the subject. Scientific literacy is a pivotal baseline for understanding the broader issues surrounding climate change and voting on climate initiatives. Education is the best way to inform society and reach people at an age in which they are starting to be able to make decisions as a part of our society. The world we are expecting is about to change and young people need to understand the options for mitigating the climate disasters to come. These beliefs influenced the design of the study. For example, by centering the experiences of high school teachers due to their role in building a scientifically literature population.

Interview script

Development

The interview script development started by first conducting a brief literature review to understand the gap between education research and teaching practices, also known as the research-practice gap. This was followed by a

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[20] Cohen, L.; Manion, L.; Marrison, K. R. B. Research Methods in Education; Routledge: New York, NY, 2011.

[21] Gary, A.; Holmes, D. Researcher Positionality-A Consideration of Its Influence and Place in Qualitative Research-A New Researcher Guide. Int. J. Educ. 2020, 8 (4), 1–10.

discussion with my advisor, Nicole James, about what type of data would be best to collect. We decided that the questions would be asked in a semi-structured format. A semi structured format follows a scripted list of questions but allows for scripted or unscripted follow-up questions to gain more specific information from the participant. To address our research questions, we designed four main lines of questioning, which target:

1) Participant background and teaching experience
2) Existing incorporation of climate science in their chemistry classes
3) The supports and barriers they have faced
4) Their own personal attitudes towards climate change.

This resulted in an initial draft of the Interview Protocol (Appendix A). This script went through four rounds of pilot testing and revision.

Pilot Testing

The initial interview protocol went through four rounds of pilot testing via mock interviews. Mock interviews were conducted over Zoom with individuals in education that had current or prior experience teaching high school level chemistry. The first interview was with a current post-doctoral scholar who had previously taught in high schools and whose research focuses on high school teachers. In this mock interview, the participant had to ask several clarifying questions before they answered most questions. This indicated that our initial questions were too broad in scope. In response to the first mock interview, substantial changes were made in the way the questions were asked, while remaining open form. This prevents the question from leading the participant to a particular answer, but still allows the participant to think more deeply about the topic and to share their thoughts with the interviewer.

The second mock interview was with a current high school chemistry teacher. She provided valuable insights into existing barriers at her institution, which led to changes in the questions to better capture barriers and supports. It was valuable to learn the way that current teachers think of the questions up to this point. Questions were rephrased so that they would better elicit teachers' thinking.

The third mock interview was with a professor in higher education who researches education and had previously taught high school science. The primary revision resulting from this mock interview was in terms of implementing the existing script. It was clear that I needed to work on the process of the interview itself so there were no awkward pauses, but while still giving the participants ample time to think about their answers and respond. The questions began to stabilize at this point.

The fourth mock interview conducted was with a tenured professor of chemistry who had previously taught at the high school level. The goal of this interview was to practice and solidify the interview protocol so that the process would go smoothly, and the participants would feel comfortable sharing their thoughts and beliefs. The primary feedback after this interview regarded building rapport before the interview began, to make the participant feel more comfortable, and to reiterate questions and allow time to prevent the participant from feeling rushed. The lack of revisions needed on the questions themselves showed saturation of the pilot testing process, and this yielded the final version of the interview protocol (Appendix B).

Participant Recruitment

To be eligible, participants must have taught chemistry at a high school in western Oregon within the last five years. Participants were recruited through invitation emails sent directly to high schools (Appendix F). Interested participants were directed to fill out a consent form (Appendix C), after which I reached out by email to schedule the interview. Participants were compensated for their time with a $30 Amazon gift card.

Participants of this study have all taught at multiple schools before the school they are currently teaching at. Teacher's personal backgrounds and identities likely influence their experiences. Table 1 lists participant demographic information and teaching experience, as one way of providing context to their accounts.

Participant information

Table 1: Demographics and teaching experience of study participants. F = female, M = male; nonbinary and self-describe gender options were available. ES = environmental science, IS= Integrated Science. *Participants were assigned pseudonyms (see section: Interview Processing)

Participant*	Gender	Race	Region	Experience	Courses Taught
Andrea	F	White	Urban	3-5 years	Chem, Bio, ES
Bruno	M	White	Urban	>5 years	Chem, Physics
Kris	M	White	Rural	>5 years	Chem, ES, IS, Bio
Michael	M	White	Rural	>5 years	Chem, Physics
Natalie	F	White	Suburban	>5 years	Chem, ES, Physics, IB/AP Bio, Botany

Interview protocol

All interviews were conducted over Zoom by the same interviewer (Author Kieran Wharton) between November 10th and December 15th of 2021 and March of 2022. All interviews lasted roughly 30 minutes. Kieran Wharton was the primary interviewer for all interviews; Nicole James was present as a secondary interviewer for two of the five interviews.

Interviews started with a brief introduction. Participants were asked for their consent to record. Recording was then initiated, and the lead interviewer read through the study description and the consent document (Appendix D). Once participants consented to the study, the interviewer proceeded through the interview questions as denoted in the interview protocol (Appendix B).

The first question set has to do with the participant's thoughts on climate change discussions in high school and how they engage with the topic in their classroom. The second set of questions explores supports and barriers that the participant faced incorporating climate change into their classrooms. The third and final set of questions discuss the teachers' beliefs and attitudes towards climate change. At the conclusion of the interview, participants were asked if there was anything we did not cover that they would like to add.

As part of the analytical process, the lead interviewer took notes during the interview, and wrote a detailed analytical memo [22] about the interview immediately afterwards. The purpose of the analytical memo is to write an account of the interview, summarize and explain the responses and describe the lead interviewer's thoughts during the interview. In many ways, this is the first stage of data analysis and can influence follow-up questions in subsequent interviews. Analytical memos must be completed immediately following the interview so that the thoughts are fresh in the mind.

Interview Processing

Interview recordings were saved in an encrypted file in a password protected computer, transcribed by TranscribeMe! (transcribeme.com) and used for coding.

Participants are assigned pseudonyms to maintain their confidentiality. Assigning pseudonyms can be a delicate matter. Removing a person's name from their personal beliefs, accounts, or responses can take away from their identity, and can cause the reader to make assumptions about the participant based on associations they have with the selected name. For this reason, I wanted to use a random name generator to select pseudonyms and keep an impartial name selection. To prevent distancing participants from their gender identity, I decided to use names that were typically viewed as either masculine or feminine, in alignment with their declared gender. The pseudonyms I selected therefore maintain as much of the participants' identity as possible while sustaining confidentiality and respecting that they are sharing their personal beliefs and thoughts.[23] Participants were assigned randomly generated pseudonyms using an online random name generator, behindthename.com.

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[22] Saldaña, Jonny; Mathew B. Miles; A. Michael Huberman. *Qualitative Data Analysis: A Methods Sourcebook*, 3rd ed.; SAGE publications.

[23] Heaton, Janet. "*Pseudonyms Are Used Throughout": A Footnote, Unpacked https://journals.sagepub.com/doi/10.1177/10778004211048379.

Coding Process

Transcripts were loaded into MaxQDA for analysis. The interviews for Andrea and Kris were open coded.[24] Author Kieran Wharton and advisor Nicole James read the interview transcripts and discussed the attributes and topics that the participants focused on during these interviews, to generate the initial codebook (Appendix E). The codebook was developed using the interview transcript from Andrea and Kris's interviews. I then tested the codebook by coding the interview with Andrea, however the codebook did not fully capture the themes that Andrea discussed. Specifically, she mentioned several different ways that she incorporates climate change into her lessons and her personal beliefs on climate change that the codebook did not capture. Edits were made to the codebook to better incapsulate themes from the interviews and the definitions were specified to make future coding more reliable and repeatable (Appendix F). All the interviews were then coded with this codebook. Professor Nicole James served as the interrater (IR). IRs are secondary coders who code a portion of the data set, which is then compared to how the primary researcher codes the data. The purpose of this step is to establish reliability and repeatability of the coding process on the data. Nicole James IR coded interview 5 to confirm that the codebook had captured everything we intended to gain from the interviews. However, this identified necessary additions to the codebook. Specifically, there were ways in which Michael's beliefs about climate change, how to handle parental and student pushback, and the context of his lesson plans that were not captured in the original codebook. New codes were added to the codebook and Kieran Wharton recoded all interviews. The fact that the codebook required additions after each interview indicates that we have not yet reached data saturation. That is, we are learning substantive, essential new information

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[24] Jonny Saldaña; Mathew B. Milez; A. Michael Huberman. *Qualitative Data Analysis: A Methods Sourcebook*, 3rd ed.; SAGE publications.

with each additional interview, indicating that more interviews need to be conducted (see Future Work).

Limitations

In human subjects' research, there are always uncaptured variables that can influence the data collected and the interpretation of that data. Thus, awareness of study limitations, and how these limitations may affect the data, is essential.

Participation in this study was completely voluntary. Because of this, there is a self-selection bias. Self-selection bias means the participants have agreed to discussing these topics. Participants less willing to think about or discuss these topics may have substantially different experiences or practices, which are not captured here. This means that this study is possibly less likely to get participation from teachers who do not believe in climate change, and possibly the teachers who were willing to speak with me are more likely to have some sort of climate change curricula for their classrooms.

This project involved teachers self-reporting their teaching beliefs, goals, and practices about climate change in their classrooms. It has been established that instructors do not always hold an accurate view of their actual classroom practices, [25] and sole reliance on instructor self-reported data has been criticized. [26] This study did collect classroom artifacts (copies of climate change-related lesson plans or activity materials) with the intention to characterize and compare

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[25] Speer, N. M. Issues of Methods and Theory in the Study of Mathematics Teachers' Professed and Attributed Beliefs. Educ. Stud. Math. 2005, 58, 361–391.

[26] Gaete, A.; Gómez, V.; Benavides, P. The Overuse of Self-Report in the Study of Beliefs in Education: Epistemological Considerations. *International Journal of Research & Method in Education* **2018**, *41* (3), 241–256. https://doi.org/10.1080/1743727X.2017.1288205.

the artifacts to teacher self-reported practices. Characterizing these classroom artifacts could be completed with future work.

All participants identified as white and cisgendered. Educators who come from marginalized backgrounds may face different barriers, or barriers with varying degrees of difficulty to overcome. For example, educators from marginalized racial groups or who hold marginalized gender identities may encounter different treatment from students and parents and may have different experiences interacting with administration than their white cisgendered peers. This study however cannot speak to the experiences of individuals who hold such identities.

Despite these limitations, this study sought to gather information about how teachers perceive their roles as educators during the climate crisis we face. This seeks to provide insight into plausible pathways and supports systems that enable educators to teach climate change in their classrooms, and the barriers that undermine or limit this aim.

Results & Discussion

The codebook was sufficient to capture a significant amount of data from the interviews resulting in a total of 191 codes across all five interviews. These codes are an analysis tool for identifying and interpreting the themes that emerge from the data.

In my discussion of the results, I will be analyzing the themes that were the most prominent across all interviews to help describe some of the larger issues identified by the participants. I will then go into further detail on the themes that did not transcend across all the interviews but that remain pivotal to the participant's beliefs and/or struggles with teaching climate change concepts in their classrooms.

Climate Change Beliefs

In our interviews, we aimed to capture the participants' personal beliefs on climate change, which we hypothesized would influence their classroom practices. We aimed to identify if the participants acknowledge the scientific consensus on climate change and that it is an anthropogenically driven phenomenon. Unanimously, all participants readily identified these attributes when prompted with "Separate from being a teacher, can you tell me a bit about your thoughts on climate change in general?" For example:

> Climate change is a documented fact, and it is caused by human activities based on models. And the production of greenhouse gases is the driving force behind climate change (Kris).

Additionally, participants commonly displayed climate anxiety, which varied in intensity. To illustrate this variation, Natalie hints that he has some pessimistic views due to concern that climate change action is not being taken seriously:

> I think there's a huge issue [with how we handle climate change] and we need to fix a lot of stuff that we're doing. And

> it's pretty much impossible at the individual level, and it sucks that everything must be so political… we can't ignore it. (Natalie)

In contrast, Andrea shows substantial concern about existing and continuing repercussions:

> I just have very little faith right now that governments and people are going to get it together […] we're not going to stop climate change from happening, we really need to start figuring out how we're going to deal with it. People are already being displaced […] I'm just worried that it needs to get worse before we can really start to make it get better. (Andrea)

At the extreme end of climate anxiety, Michael says:

> I fear for civilization itself I think it's not likely, but it's very possible that civilization will fall due to climate change […] and I think it's gonna be in our lifetime […] and that's what's terrifying to me. (Michael)

These data are used to contextualize teachers' underlying beliefs that motivate their classroom practices and how they responded to my questions. None of the participants expressed that they deny climate change. They all recognized the severity of the situation and that they teach climate change chemistry topics in some form. This indicates that the battle to be fought in teaching climate topics is not with teachers. These teachers all already acknowledge the scientific consensus on climate change and value educating their students about it. It is extremely influential to have teachers on board.

Motivations for Teaching Climate Change

One of the strongest driving factors teachers identify as motivating them to incorporate climate change topics is their desire to provide their students with the tools they may need to live in a world with a quickly changing environment. As Andrea states:

> I think providing them with the opportunity to explore and become interested in that will encourage them to go into those careers or pursue the post-secondary education that they're going to need. So, I want to make sure that I'm providing them those opportunities to be curious and inquisitive and maybe decide, "That's actually something I really want to go on to do." Or they end up working in a job or an industry that's related. Everything should be more interconnected than it is, too that even if you're not going to pursue a career in climate change, you still should have a basic understanding of what's going wrong here. Like financial, even insurance companies, they're going to have to start adjusting their formulas for people who lost their house to fire and floods. We're all going to be affected by this no matter what you think you're going to do. (Andrea)

Andrea very specifically discusses how part of her reasoning for including climate change topics in her chemistry classes is to prepare her students for any job they may want in the future. She and other teachers are motivated to include climate change topics in their chemistry courses so the students can better understand how climate change is scientifically altering our environment because it is a problem that every aspect of society will have to face in one way or another. Andrea conveys that there is value in understanding the basic chemistry behind these future problems.

Participants all expressed goals and aspirations to change how climate change is taught within their classrooms. Bruno explained some of his motivations are to focus on:

> What [the students] can personally do, what they and their household, or what they can do as an adult. Because they don't really have the advantage of voting or purchasing power or a lot of their day-to-day or even dietary considerations. They don't get to make a lot of those choices. But then saying, "Okay, when you are an adult or if you are on your own, then how would things change?" And then what would be the best thing systematically? So, for either as a community or a government to look at some solutions. (Bruno)

There was some discussion that climate change topics might be better served as a dedicated course, separate from the standard chemistry sequence, *"I would love it to be taught as a standalone, so you get a comprehensive view "* (Michael). All of the participants expressed a desire to have some form of a stand-alone

environmental studies or climate topics class that high school students should be required to take. A related goal for the teachers is to completely redesign the existing overarching highschooler curricula: *"I mean, the whole curriculum of the school could be revisited and updated"* (Kris). The idea of having a separate dedicated class or updated curricula all emerged during participants' discussion of their motivation to do more to support their students.

In summary, each of the participants expressed a strong desire to provide a foundational education in climate change, whether that be dedicating a class to environmental topics or redesigning existing chemistry curricula. They express this being driven by care about the students' futures, and the hope to impact how they engage with climate change decisions in their personal life and broader political choices.

Existing Mechanisms for Climate Change and Chemistry Connections

Participants readily identified existing ways they already incorporate climate change topics into their courses. Almost all the participants at different points mentioned that they try to integrate climate change topics into their already existing curricula. Andrea stated:

> I think we can use climate change as an example to teach the principles of chemistry, the principles of biology, and reference what [our environment should look like], and then how we're altering it. And it's still acknowledging the problem but helping people to get that educational foundation as to what is going on. (Andrea)

Other participants shared similar views. Michael said:

> I use climate change as an example when we are studying related principles. [In] liquid vapor equilibrium, I point out equilibrium's a really centric concept in a lot of sciences, so I talk about equilibrium of energy flow into and out of the Earth with climate change as the example. (Michael)

Overall, chemistry teachers have found ways to incorporate climate change topics in their classrooms, primarily using climate change topics as examples,

references, or insights into how their core chemistry content can be applied in the real world. The particular chemical content topics that teachers identified linking to climate change are summarized in Table 2.

Table 2: Chemistry and climate change topic connections.

Chemistry Topic	Climate Change connections
Gases	Greenhouse gas (GHG) behavior
Equilibrium	Ocean acidification, GHG reactions
Combustion reactions	Emissions chemistry
Solutions/solubility	Acid rain, ocean acidification, drought
Bonding	GHGs, pollution chemistry
Phases of matter	Seas level rise
Conservation of energy	Global warming, sea level rise

Some of the more popular existing climate change-chemistry curriculum connections include discussing greenhouse gases:

> We kind of start at the level like, what is our atmosphere made of? These are all the gases. Of the foremost prevalent gases, none of them are considered greenhouse gases, and talking about why. (Bruno)

> I kind of like to just start with, what are greenhouse gases and why do they trap heat? Like, what is the actual chemistry behind that? And then the percentage of them in the atmosphere to the breakdown, and why are some worse than others, even though they're in a smaller amount? (Andrea)

phases of matter,

> So, some of them did [a unit on] sea level rise, so they just looked at [phase changes] a little more in depth. So, we did a couple labs with melting ice cubes. […] the heating curve, when things melt, the temperature, and then just how they expand. Just a little demo where there's a sealed container that you heat up, and then you see that the water has nowhere else to go because the space is occupied, so it rises up. So just the fundamental principles of there's a lot of water on the planet. And eventually do the calculation of how much water is on the planet when it expands. What is that impact going to be for coasts? (Andrea)

and bonding,

> We start looking at what the structure of those compounds are, they can already kind of have a sense of how they behave in their properties, contribute to the regular greenhouse effect and the runaway greenhouse effect that we're currently seeing. And then what's happening with extreme weather? (Andrea).

> I think in the bonding unit, we can do a little bit better on talking about the difference between a greenhouse gas and a non-greenhouse gas in the atmosphere. (Bruno)

Gases, phases of matter, and bonding were areas all or nearly all participants identified incorporating climate change discussions. In addition to these, teachers also identified incorporating discussions of climate change alongside course content involving the nature of science, combustion reactions, and solutions/solubility. Michael talks about how he brings up the nature of science into his classes:

> Then incorporating some of the elements of the nature of science and start talking about how science is never certain. That's why can't wait until the science is done. Science is tentative and incremental. Science gives error bars. Science makes mistakes. (Michael)

This is one way that he expressed how he wants to create a more scientifically literate community. He describes that if his students can understand how science operates then they can begin to dispel the climate change denial ideas they encounter in their daily lives. Michael discusses this particular strategy as being reactive to a barrier that he encounters in teaching climate change, namely parental pushback (See section “How Teachers Address Barriers”. To avoid direct conflict, he implements lesson plans wherein the context of the problems is discussed alongisde the scientific process. He explains his motivations for teaching climate change through the lens of the nature of science:

> If the parents says, "Well, look, back in the '70s science said the world was gonna cool. Now, they say-- they state it's gonna warm. They're full of shit." it could be an occasion to say, "No, that's the process of science. Our answers now, if they're different from what they were previously, that's because they're better because we've done more study and done more inquiry into it." So, I think it fits in the nature of science… what

> makes one inference more solid than another inference. For instance, climate change has multiple different lines of evidence from different directions all pointing to the same conclusion. And that's stronger than one line of evidence pointing to it. So, I think it can be incorporated as examples on the nature of science as well because it is such a public it is one of the few scientific debates that has such a public front to it. (Michael).

Michael expressed that he must first explain how science works to get the students on board with his lessons. This helps preface any further discussion on why the consensus surrounding climate change has varied so much over the years.

Combustion reactions were another frequently discussed chemistry context. Combustion reactions can be used to explain how greenhouse gases are produced, as well as many other pollutants. Additionally, Natalie and Andrea discuss solutions and solubility as opportunities to discuss how our water systems will be impacted by climate change.

These are all manifestations of the underlying mechanisms that teachers are using to work climate change topics into their existing curricula. In contrast to this strategy of using climate change as an illustrative example of chemistry topics, Kris discussed similar activities but frames them as a diversion from the chemistry curriculum:

> So I have these asides to climate change ideas. When we talk about combustion reactions, we talk about climate change briefly because of the production of carbon dioxide and combustion reactions. But like I say, I haven't taught any kind of extended unit on climate change. (Kris)

Kris reports he found that, because of other curricular obligations, he was forced to avoid climate change as a topic of discussion and instead would divert from his lesson plans occasionally to discuss climate change topics.

How Teachers Address Barriers

I define barriers as being any sort of obstacle in place that makes desired teaching practices harder or impossible for the educators. Teachers face several barriers to including the curriculum that they wish to be teaching in their

classrooms. All the participants expressed barriers of some kind, even while still integrating climate change topics into their classes. Some barriers discussed were easier for the teacher to work around than others, but all teachers discussed their attempts to navigate existing barriers. While most teachers in this study have managed to overcome some barriers, remaining barriers prevent them from fully realizing their goals.

Time and Resources

Teachers identify having paid time dedicated to developing a specific climate change curriculum to be extremely important. Andrea said that teachers are overworked and need (paid) time away from class to update their curricula:

> I think [where] we're struggling right now is just planning time. Like having some time to really sit down, and paid time, […] [to] sit down and really figure out how to include this into existing units. (Andrea)

This is a straightforward barrier: Teachers simply do not have enough hours in their days to adjust their lesson plans to incorporate climate change.

Teachers also face a shortage of resources and supplies, particularly to construct meaningful labs and lessons. While we were wrapping up our conversation, Natalie says:

> It would be nice if there were more attention on [climate change being taught in classrooms]. Teachers do need help. And access to resources would be cool, not everyone knows about having Metro come in [to visit the class and discuss climate change] (Natalie)

The way she explains that teachers need help is very striking. She indicates that there are not enough resources out there for teachers and the resources that are available are not well known. In addition to physical lab and lesson resources, some of the participants expressed that there are not enough funds for the curricula that they would prefer to teach. Andrea explains when asked what barriers she faces in teaching climate change, *"Access to materials. Just being able to do labs."* She articulates a desire to include a lab that focuses on how plastic is not conventionally biodegradable, but there are enzymes in mushroom mycelium

that can degrade it. However, she is not able to purchase the materials needed to do this lab activity.

Complicated Climate

Multiple participants expressed that climate change is such a large, interdisciplinary problem that it can be extremely hard to create one unit that truly encapsulates the problems, solutions, and chemistry behind everything. A commonly discussed barrier across interviews was that climate change is multifaceted and hard to encapsulate:

> So it is hard to focus in on the broader climate change aspects or chemistry aspects of climate change. I feel like I can explain both…I can teach both things really well, but its just hard to get them to connect to one another. (Natalie)

She explains that she feels capable to teach climate change or chemistry but that the two combined is a more difficult endeavor. The chemistry of climate change is a difficult concept to digest let alone teach the two together as Natalie explained.

As discussed, a mitigation strategy that some participants have come up with is to integrate climate change discussions into already existing curricula as examples or problems. However, participants identify that this does not fully solve the problem; they expressed that ideally there would be a separate class to teach climate change in and that all STEM classes would incorporate some climate change topics. Consensus among these participants was that integration of climate change topics as examples in chemistry courses will not do enough to teach the students what they need to know about climate change.

Obligations

Kris and Bruno ran into the barrier of curricular obligations more frequently than other teachers. Curricular obligations are any course elements the participant is required to teach throughout their class. This can take the form of having to work through all the AP curriculum before the test, fulfill district

standard requirements (such as NGSS), or feeling the need to prepare students for subsequent classes by setting a holistic baseline set of knowledge. At the end of our interview, I asked Bruno if there was anything he would like to discuss that we had not yet talked about, and he responded:

> I think in general; the more and more districts tell you what to teach, the less freedom you have to teach. And I think chemistry is one of those classes where things just get so specific. These learning targets get so specific. And when they become so specific, teachers feel like they can't deviate off that and talk about some things that are much more important. (Bruno)

Bruno explains that he feels constricted by the school district telling him what lessons he should teach, which prevents him from dedicating class time to topics not directly articulated in the targets.

Kris, who had previously framed his course discussing climate change topics as an "aside" to the "real" chemistry topics, explains this barrier in manifesting through the obligations he feels to prepare students for subsequent courses:

> I think one thing that influences me is teaching AP Chemistry […] my college prep chemistry class, I always have in my mind preparing them for that course and that exam. And to actually master the foundations of chemistry, it takes two years' time for a digression into climate science in the chemistry class. (Kris)

Kris also discusses dedicating a short amount of time late in the term to discuss teach climate change, to make sure he gets through all the "standard chemistry" concepts first.

Both Kris and Bruno discuss an intrinsic tension that students first need to understand basic chemistry concepts, which can then be applied to climate change. However, to fulfil their job requirements, they must get through the curriculum they are assigned, and this limits the time they can dedicate to supporting students in exploring those applications.

Pushback

A barrier that Kris and Michael faced was general pushback at the topic of climate change. This pushback took the form of students and parents complaining about the subject matter being taught. Parents would complain to the administration that the teachers are teaching the "hoax of climate change." Kris explains how parents got upset with him for teaching aspects of climate change:

> I wanted to demonstrate to my kids the correlation between political ideology and acceptance or denial of climate change without specifying any individual. But that was kind of a hot topic that got me into trouble with some parents (Kris)

Parental pushback is a severe barrier that can dissuade teachers from discussing climate change. Both Kris and Michael faced parental pushback. Michael says, *"I think it's made it easier by not teaching, 'Here's our unit on climate change,' cause that sets off parental red flags"* (Michael). He explains that it is not worth effort expended to engage in direct conflict with parental pushback, so he was forced to find another way to incorporate climate change into his classroom that avoid or mitigate parental pushback.

Proxy Wars

Michael has also had to debate climate change with other teachers or parents through the proxy of a student:

> I tell the kid one thing, they go share it with their soccer coach, and the soccer coach says, "That's a bunch of BS. Here's some articles from the internet. Give these to your teacher. "He gives it to me, I see that the guy clearly didn't read the articles, he just put together a bunch of papers and then, I was like, you know, it's not fair for him and I to be debating each other through a kid. (Michael)

This is a difficult situation for Michael because it undermines his credibility and creates tension among colleagues within the school community. This is also a difficult situation for the student, who receives misinformation from an authority figure, which may result in confusion about the subject or who

they should believe. Michael states that he does not feel this environment supports student learning.

Supports that Enable Teaching Climate Change

While there were substantial barriers faced in teaching these concepts, the teachers were also supported in various ways. The most frequent examples of support for teaching climate change topics were admin backing and external supports, followed by support from other teachers and curricular independence.

Supportive Administration

The participants all expressed that their administration had allowed them to teach climate change concepts in their classrooms mostly through including district initiatives that provided some degree of curricular freedom, or simply by supporting the teachers in making their own lesson plans. Most administrations have recently implemented the new Next Generation Science Standards (NGSS) which does include climate change concepts. While this is considered a support, Andrea and Natalie mention that they do not find the curriculum substantial enough. Regardless, they describe that having any kind of climate education standards is a step in the right direction.

Support When Faced with Backlash

As I discussed before, backlash or pushback to teaching climate change was a barrier that several teachers experienced. Michael, Natalie, and Kris seem to have faced the most backlash. Natalie talks about how, *"there is a lot of pushback from students. The minute they hear climate change…it just becomes political." (Natalie).* Kris identified administration support as being key when he asked a question on a test about political ideology to show the correlation between believing in climate change and political leanings, which received significant parental pushback:

> "I was supported by my administration. They said, "Oh, maybe that question on political persuasion could have been introduced differently," because I didn't give the students much background and they just had a-- some had an adverse reaction to it." (Kris)

Thus, this parental pushback barrier was mitigated somewhat by having a supportive administration.

Additionally, one of the most discussed forms of support was administrations not obstructing teachers. Kris, Michael, Natalie, and Bruno mention that their administrations have allowed them the curricular independence to make modifications to their classes. Natalie explains that the teachers are viewed as the experts, *"I am pretty autonomous the, the district has invested in me being the expert"* (Natalie). They are required to meet the district standards, but they have the freedom to teach without their administration prescribing or approving every change that is made to their curriculum, allowing the teachers to be more flexible in integrating climate change topics in their classes.

Community

Having a teacher community emerged as a very powerful support. Educators can benefit from having other teachers in their schools or communities that are there to support them. Kris explains how having weekly meetings with teachers helped in their curriculum design and coordination:

> The science teachers had weekly meetings and discussed where to cut up the curriculum and who's going to teach what. So, the kids there got a more coherent curriculum. (Kris)

Teachers can be a fantastic support network for each other because they understand the school system, they can advocate for each other, and other educators can offer new ideas for lesson plans, or sharing lesson plans. Bruno relayed that he has adapted lesson plans directly from teachers in other school districts. The community that is made through these teacher networks can be used to relay information, new ideas, and curricular plans.

Outside Help

Another very common support that emerged was participants utilizing external resources that are not a part of their school or district. In part because of the barriers discussed above, some teachers looked outside of their schools for resources or supports. There are a lot of open-access resources to give teachers new ideas or lesson plans to help incorporate climate change. Natalie brought this up in response to a discussion on the curricular obligations and lack of time she has:

> We have over 200 kids that we teach every day. So where is the time to look into how to incorporate more stuff in? That's why I look at having people [in Portland Metro] to help me do it. (Natalie)

Natalie uses the local government programs to help teach her kids because she has so many students to teach that she does not have time to develop new materials. Andrea's school also uses curricula that are brought in from the Metro STEM partnership. Andrea also is part of an organization called Beyond Benign:

>]They're an organization that has this green chemistry initiative. It's a bit of a movement within industry [and] academia that's […] trying to build a hub for the Pacific Northwest, […] which is creating some go to resources of who's in the community that's already doing some of this that we can expose the kids to. (Andrea)

Andrea describes that she knows there are a lot of resources available, but teachers often don't know where to look or what will work best for them. She joined with this group in the hope to create a broad regional network of teachers and resources to help teach climate education in schools. Each of the other teachers also mentioned that they have looked for external support. However, Michael indicates that a lot of these resources are not very helpful for the way that he feels he teaches climate change:

> Every time some government agency does some research, they gotta put some percentage towards outreach. And often the quality is very mixed. But if I had sort of modular, "Hey, here's how to teach equilibrium with climate as the example. Here's

> how to teach conservation energy with climate as an example. Here's how to teach…etc." (Michael)

Michael's experience emphasizes the importance of the school context in the design of the curricula. Based on the nature of his school, he expresses a desire curricula that teaches chemistry through subtler climate change examples, but he describes most materials as centering climate change in a way that would be met with great resistance at his school

In summary, many teachers have sought outside help to overcome barriers they face in their schools, particular barriers that limit the time and resources they have to develop new curricular materials. However, the school context plays a strong role in how effective curricula must be designed, and not all teachers were able to find suitable materials for their purposes.

Conclusion

Future Work

Throughout my interviews with the participants, I continued to gain new insight and ideas from the teachers during each interview. Therefore, I did not reach data saturation, which is reached when there are no new codes for the codebook being developed. More interviews with teachers, using the same interview protocol, would provide more data and may alter our current conclusions. Thus, future work on this project involves conducting more interviews with high school chemistry teachers.

As part of their participation, the teachers I interviewed provided me with class artifacts (class syllabi, lesson plans, activity sheets, etc.). Due to time constraints, analyzing these documents was outside of the scope of this thesis. Future work on this project would involve analyzing these artifacts to further clarify the existing teaching practices in use when incorporating climate change topics. This analysis would reduce self-reporting bias, and more directly capture participants' pedagogical approach to teaching climate change.

Emerging Conclusions

This study gained insight into how teachers view their roles in educating their students on climate change. A major takeaway is that teachers recognize the scientific consensus on climate change and are motivated to teach climate education. However, they face several different kinds of barriers that prevent them from achieving their pedagogical goals. Some of these barriers come from institutional issues such as feeling pressure from curricular obligations. They can also come societal issues, such as climate change discussions eliciting oppositional pushback from students or parents.

The teachers in this study all indicated that they would prefer to teach climate topics differently if they had the time and resources to do so, although some teachers are able to work around this barrier by using outside resources. A limitation to these resources is they are not designed in a way amenable to all school contexts, and teachers often have broader goals for overarching curricular redesign re.

This study identified existing ways these participants diminish or avoid the barriers they encounter One common way teachers avoided barriers related to lack of time and resources, or existing curricular obligations, was to incorporate climate change as an example to illustrate foundational chemistry topics such as gases, phases of matter, and bonding. When parental pushback did occur, having administration support was essential.

These findings can inform how researchers approach investigating and developing improved environmental science education. Emerging insights into how to further support high school chemistry teachers in teaching climate change topics would be to support efforts to recognize high school teachers as experts, provide time for curricular planning, incentivize the development of collaborate teacher communities, increase awareness of existing external resources, and work with teachers to tailor existing resources to their school context.

Appendix A: Initial Interview Protocol

Interview Script

Recording Consent

Hello! My name is Kieran Wharton, I'm a senior at Reed College. I am going to start by telling you a little bit about this study and ask if you still consent to participate. First: Is it okay with you if I record this, so we have your oral consent on the recording?

[*Start Recording*]

Informed Consent

Read Oral Consent Script

Warm-up questions

Great! Thank you again for being here. We can get right into it if you are ready. My first question for you is:

1. What classes have you taught recently?
2. How would you identify yourself in STEM? For example, as a chemist, biologist, etc...

Main Question Set 1: Climate change in the classroom

3. Do you think the science of climate change should be taught in high schools?
    a. Why / why not?
    b. If yes: In your ideal world, where does climate change science belong in the HS curriculum?
    c. If no: How do you think people should learn about climate science?

4. Have you ever considered incorporating climate change science into your chemistry content?
    d. Can you tell me more about that?
    e. How did/might you go about that?

Main Question set 2: Supports and barriers to teaching climate change

If incorporate climate change topics

5. What structures or factors helped you to incorporate climate change science?
    f. Are there factors that made or make those instructional practices difficult?
6. Are you happy with how you handle climate change science in your chemistry course?
    g. How would you want to improve or change it?
    h. What are the barriers stopping you from being able to do that?

<u>If do not incorporate climate change topics, but do think it should be taught</u>

7. What factors have made it difficult to incorporate climate change science in your classroom?

8. What support would make it more feasible to incorporate climate change science?

Main Question set 3: Teacher attitudes towards climate change

9. Separate from being a teacher, how do you think about climate change in your daily life?
    i. Do you think human emissions are causing climate change?
    j. Are people doing enough to mitigate its effects?

<u>Conclusion</u>

This is the last question I have for you today: Is there anything you would like to add about your experience with climate change in your classroom that has not been sufficiently covered yet in our conversation?

<u>Wrap-Up</u>

That concludes our conversation. Thank you so much for being a part of this research. I will be able to send you your compensation shortly.

Appendix B: Final Interview Protocol

Interview Script

Recording Consent

Hello! My name is Kieran Wharton, I'm a senior at Reed College. I am going to start by telling you a little bit about this study and ask if you still consent to participate. First: Is it okay with you if I record this, so we have your oral consent on the recording?

[*Start Recording*]

Informed Consent

Read Oral Consent Script

Warm-up questions

Great! Thank you again for being here. Just again, there are no "right or wrong" answers to any of these questions, we are just interested in your thoughts on these topics. We can get right into it if you are ready. My first question for you is:

1. What classes have you taught recently?
    a. What class years are a part of those courses?
    b. What's the general range of class sizes in those courses?
2. How would you describe your specialization in STEM? For example, would you consider your training to be more in chemistry, biology, physics, etc?

Main Question Set 1: Climate change in the classroom

3. Tell me a bit about how you think that climate change science should be taught in high schools? a. In an ideal world, what types of courses do you think should incorporate climate science topics?
4. Could you tell me your thoughts about incorporating climate change science into high school chemistry courses specifically?

a. Can you give me a specific example of how you have or how you would incorporate climate change topics into your chemistry courses?

b. What other units or content modules do you think would be promising places to incorporate climate change science into? How would you go about that?

Main Question set 2: Supports and barriers to teaching climate change

5. What has helped OR would help you incorporate climate change science in your teaching?

6. In general, are you happy with how you handle climate change science in your chemistry courses?

a. What has made it difficult to incorporate climate change science in your classroom?

7. What support would make it more feasible to incorporate climate change science? (what would make it easier)

Main Question set 3: Teacher attitudes towards climate change

8. Separate from being a teacher, can you tell me a bit about your thoughts on climate change in general? To what extent do you think human emissions are responsible for climate change? b. Do you think people are doing enough to mitigate its effects?

Conclusion

This is the last question I have for you today: Is there anything you would like to add about your experience with climate change in your classroom that has not been sufficiently covered yet in our conversation?

Wrap-Up

That concludes our conversation. Thank you so much for being a part of this research. I will be able to send you your compensation shortly.

Appendix C: Recruitment Form

Participant Recruitment Form

Digitized as a Qualtrics study, linked to the in the Participant Recruitment Email.

Key Information

- This is a voluntary research study about your teaching practices, beliefs, and experiences.
- Your participation in this study is confidential.
- Your participation in this study will be compensated with a $30 Amazon gift card.

Description of the Study

The purpose of the study is to explore topics incorporated in high school chemistry classrooms, particularly climate science topics. We are interested in your thoughts, feelings, beliefs, and any factors that inform if you do or do not incorporate climate science topics in your chemistry classroom.

Procedures

If you agree to be in this study, you will participate in one 20-30 minute interview (via Zoom) about your experiences and teaching practices. Your time will be compensated with a $30 Amazon gift card at the end of the interview. You are not required to answer any individual question. You are also free to withdraw your participation at any time. The interview will be video-recorded, but the recording will not be shared. The recording will be transcribed, and you will be assigned an anonymous pseudonym in the transcription.

Following the interview, you will be asked to share an example course syllabus, and any example class assignments relevant to the discussion that you are comfortable sharing. Identifying information will be removed. Excerpts of these documents may be quoted in presentations or publications, but no materials will be fully reproduced.

Risks and Benefits

The risks are minimal and include the possibility of discomfort during the conversation. To prevent this, you are never required to comment, and can cease your participation at any time. The benefits of participation in this study are to contribute to researchers' and teachers' understanding of the factors contributing to if and how teachers incorporate topics such as climate change in their chemistry courses.

Confidentiality

The data in this study will be kept confidential. Any records of your involvement will be kept strictly confidential. Research records will be kept in a locked file and all electronic information will be coded and secured using a password protected file. We will not include any information in any report we may publish that would make it possible to identify you.

Compensation

You will receive a $30 Amazon gift card to compensate you for your time (approximately 30 minutes).

Your Rights

The decision to participate in this study is entirely up to you. You may refuse to take part in the study at any time. You have the right to skip any question or research activity, as well as to withdraw completely from participation at any point. Doing so will not result in loss of the $30 compensation or any other benefits to which you are entitled.

If you have any questions or concerns about the study, at any time feel free to contact Dr. Nicole James (njames@reed.edu, 503-777-7228), or to the Reed College Institutional Review Board Co-Chairs, Professor Michael Pitts (mpitts@reed.edu, 503-517-7721) or Professor Sameer ud Dowla Khan (skhan@reed.edu, 503-517-7261).

Future Use of the Research Data

With your additional consent, your de-identified data from this study could be used for future research studies or distributed to another investigator for future research studies without additional informed consent from you

Please complete the form below to indicate your interest in participating in the study. This does not guarantee or obligate your participation. If you indicate interest, you will be sent a follow-up email with further details.

By checking one of the boxes below I confirm that I:

- ❑ Am interested in participating in this study
- ❑ Am not interested in participating in this study

I confirm that I am:

- ❑ 18 years old or older
- ❑ Under 18 years old

Please provide your contact information below:

Name: _____

Email: _____

Your responses to the following questions will not prevent you from participating in the study, but may be used to ensure a diverse set of voices are heard.

Which of the following Science subjects (of any level, e.g. Introductory, Honors, AP, IB, etc.) have you taught?

- ❑ Biology
- ❑ Chemistry
- ❑ Earth Sciences
- ❑ Environmental Sciences
- ❑ Health-related subjects (e.g. Health, nutrition)
- ❑ Integrated Science
- ❑ Physics
- ❑ Other, please specify: _____

How long have you been teaching chemistry?

- ❑ Less than 1 year
- ❑ 1-2 years
- ❑ 2-5 years
- ❑ More than 5 years

What subject would you say your science training was primarily in? Select all that apply

- ❑ Biology
- ❑ Chemistry
- ❑ Environmental Science

- ❑ Geology or Earth Sciences
- ❑ Physics
- ❑ Other, please specify: _____

How would you describe the school you currently teach at?

- ❑ Urban
- ❑ Suburban
- ❑ Rural
- ❑ Other, please specify: _____

What is your gender? [Optional]

- ❑ Female
- ❑ Male
- ❑ Non-binary
- ❑ Prefer to self-describe: _____

What is your ethnicity? Select all that apply [Optional]

- ❑ Black or African American
- ❑ Hispanic, Latinx, or Spanish
- ❑ Asian or Asian American
- ❑ Native American or Alaska Native
- ❑ Middle Eastern or North African
- ❑ Pacific Islander or Native Hawaiian
- ❑ Other

Appendix D: Consent Form

Reed College

Consent to Participate in a Research Study

Investigators

Name: Dr. Nicole James **Email:** njames@reed.edu

Name: Kieran Wharton **Email:** kiwharton@reed.edu

Key Information

- This is a voluntary research study about your teaching practices, beliefs, and experiences.
- Your participation in this study is confidential.
- Your participation in this study will be compensated with a $30 Amazon gift card.

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The purpose of the study is to explore topics incorporated in high school chemistry classrooms, particularly climate science topics. We are interested in your thoughts, feelings, beliefs, and any factors that inform if you do or do not incorporate climate science topics in your chemistry classroom.

Procedures

If you agree to be in this study, you will participate in one 20-30 minute interview (via Zoom) about your experiences and teaching practices. Your time will be compensated with a $30 Amazon gift card at the end of the interview. You are not required to answer any individual question. You are also free to withdraw your participation at any time. The interview will be video-recorded, but the recording will not be shared. The recording will be transcribed, and you will be assigned an anonymous pseudonym in the transcription. Following the interview, you will be asked to share an example course syllabus, and any example class assignments relevant to the discussion that you are comfortable sharing. Identifying information will be removed. Excerpts of these documents may be quoted in presentations or publications, but no materials will be fully reproduced.

Risks and Benefits

The risks are minimal and include the possibility of discomfort during the conversation. To prevent this, you are never required to comment, and can cease your participation at any time. The benefits of

participation in this study are to contribute to researchers' and teachers' understanding of the factors contributing to if and how teachers incorporate topics such as climate change in their chemistry courses.

Confidentiality

The data in this study will be kept confidential. Any records of your involvement will be kept strictly confidential. Research records will be kept in a locked file and all electronic information will be coded and secured using a password protected file. We will not include any information in any report we may publish that would make it possible to identify you.

Compensation

You will receive a $30 Amazon gift card to compensate you for your time (approximately 30 minutes).

Your Rights

The decision to participate in this study is entirely up to you. You may refuse to take part in the study at any time. You have the right to skip any question or research activity, as well as to withdraw completely from participation at any point. Doing so will not result in loss of the $30 compensation or any other benefits to which you are entitled.

If you have any questions or concerns about the study, at any time feel free to contact Dr. Nicole James (njames@reed.edu, 503-777-7228), or to the Reed College Institutional Review Board Co-Chairs, Professor Michael Pitts (mpitts@reed.edu, 503-517-7721) or Professor Sameer ud Dowla Khan (skhan@reed.edu, 503-517-7261).

Future Use of the Research Data

With your additional consent, your de-identified data from this study could be used for future research studies or distributed to another investigator for future research studies without additional informed consent from you

Appendix E: Initial Codebook

Axial Codes/categories	Code	Definition	examples
Existing climate change-chemistry curriculum connections	Sea level rise	discussing sea-level rise in the context of chemistry in their class.	"it's not just that water is melting...they do a project on sea level rise"
	Greenhouse gases	Greenhouse gases and a discussion on their effect on climate change and how they are formed	"I just start with, what are greenhouse gases and why do they trap heat?" Also if the teacher mentions how CO2 is involved in the process since it is a greenhouse gas. "the regular greenhouse effect versus the runaway greenhouse effect we are currently seeing."
	Droughts	How are droughts chemically involved in climate change and how will it help the students understand climate change	"we have an increased amount of drought, how is that affecting soil chemistry?"
	Phase of matter	discussion on how climate change is impacting the phases of matter, how ice and permafrost are melting, generally the physical science behind climate change	"what happens with the thermal expansion... we look at the heating curve, when things melt, the temperature, and how they expand..."
	Gases	Any discussion of gases in the environment, specifically on how gases are involved in climate change	Greenhouse Gases, "the production of carbon dioxide and Combustion reactions"

Existing climate change-chemistry curriculum connections	Bonding	How molecules bond, their structure and how they interact	"particle theory... (in our) bonding unit we actually start looking at what the structure of those compounds [greenhouse gases] are and they behave in their properties."
	Solutions, solubility	a unit that can be used to discuss climate change, topics of solutions and solubility	"we look at farming with the impact of irrigation we can look at the dissolved solvents and water"
	Combustion reactions	teaching combustion and how it can be integrated into a discussion of how it impacts climate change	"When we talk about combustion reactions we talk about climate change briefly [greenhouse gases]"
Existing mechanisms for climate chance-chemistry connections	Digressions/asides	bringing up climate change as an aside to the class. Specifically in terms of how it is not incorporated into the curriculum.	"I have these asides to climate change ideas" "I havent taught an extended unit on climate change, or more than just kind of digressions..."
	climate change examples	climate change can be used as an example to teach specific units such as bonding, combustion, reactions,	"I think we can use climate change as the example to teach the principles of chemistry."
	Chemistry as a tool	teaches students how chemistry can be used as a tool to fight climate change, either overtly or not.	"How could we use chemistry to combat some of those effects that we are going to see." "People are trying to make bricks out of plastic.. and other resins can be a useful structure... take some of those pollutants that we cant easily dispose of and change them."

Barriers	Curricular obligations	Pressure to teach everything within a curriculum or teach content because of specific obligations, usually in the context of not being able to teach their ideal curriculum because they feel they obligated to teach their specific curriculum	"I teach straight chemistry." "[climate change topic] was a break from that standard curriculum." "half a year on chem... I always have in my mind preparing [students] for the [college prep] course and the AP Exam"
	Lack of (paid) time	Participant discusses a lack of time to prepare for their classes, paid time because teachers should be paid for their work but this does not need to be referenced specifically	"we're struggling right now is just planning time. like having time to sit down, paid time...to figure out how really to include this [climate change topics] into existing units"
	Lack of resources	The participant mentions they do not have the resources they would like in order to teach more climate change in their classroom	"access to materials [is a barrier]. just being able to do labs... but we do not have the money to do that.
	Hard to focus	Climate change is a very broad topic and it can be very hard to focus on what aspects of it are important to teach or for students to grasp/learn about. This is a barrier because it makes it hard for teachers to make a comprehensive plan for teaching climate change in their classrooms.	"I find it a little bit challenging sometimes to kind of focus on what is climate change...and what are some of the problems that we want to address?"

Barriers	Lack of teacher community	conversation about how there is not a community for the participant at their school. This is a barrier because there is no communication on what is taught, as well as the fact that the teacher may not feel supported in what they are teaching. Teacher communities can also be a resource for curricular information and class structure.	"the person who teaches climate change here does not really address climate change, the whole curriculum of the school needs to be revisited and updated."
Supports	Admin backing	Any point in which the participant mentions support from admin specifically, can be in the form of independence, initiatives from the school, verbal support, or other support as well	"no institutional barriers, I have a lot of independence here so I am happy with that" "...I was supported by my administration
	Independent initiatives	that take place outside of the classroom that the teacher is involved in, specifically geared towards climate change or education.	"this is through, Beyond Benign, they're an organization that has this green chemistry initiative. Its a movement within the industry... we are trying to build a hub in the pacific northwest."
	Teacher Collaboration/Community	The opposite of the lack of collaboration mentioned above. The participant explains that there is coordination between teachers to better address the curriculum and standards	"The science teachers had weekly meetings and discussed how to cut up the curriculum and who's going to teach what."

Motivations	Desire to do better/improve	the participant expresses a desire to do more for their students or in the effort to teach climate change	"sometimes I struggle..." "yeah, I always want to do more. I will always want to do more no matter what the topic is for any subject.
	Societal education	Society needs to be educated on Climate Change topics, specifically so that we can navigate the changing future. People should have a general understanding of chemistry and climate knowledge in order to support arguments on climate change and mitigate denial and in general accept the science on climate change	Topics such as general climate knowledge, chemistry knowledge, or things the participant thinks everyone should know
	Climate anxiety	The failings of society to combat climate change and worry for how things will be in the future with regard to how climate is going to change for the worse before it gets better.	any discussion about climate change disasters like droughts and floods and fires. "I'm worried it needs to get worse before we can really start to make it get better." "We are all going to be affected by it whether you like it or not"
Climate Change beliefs	trust in science	They trust the science of climate change	CO2 increasing. Climate Change is caused mostly by human influences. Climate denial is a problem. Little government action
	Climate change denial	They discuss the problems of climate change denial in society	
	Chemistry as a tool	how chemistry can be used as a tool to fight climate change	

Climate Change beliefs	little government action	They believe that the government is not doing enough to mitigate climate change	
	exasperated by the pandemic	climate change has gotten worse because of the pandemic and how we had to pause fighting climate change to fight covid.	
Goals/ aspirations	Overarching curriculum redesign	The desire to redesign the current curriculum	"If I were to redesign the curriculum I would like to start from step one and do something like that [the Big History Project]"
	Interconnected reality	Climate change is interconnected with everything within and without STEM. Any discussion on how climate change topics should be taught with the interconectodness in mind.	"everything should be more interconnected than it is already taught". "Even insurance companies, they're going to need to start adjusting their formulas to account for climate change".
	support students	Students need support for the future in dealing with climate change, this code is to identify any support for the students or how they would like to help students in the future. this can be in the form of promoting curiosity for the students to be interested in climate change matters as well.	student empowerment in their knowledge of climate change. Student walkouts to protest climate change or other student-led organizations/initiatives.

Appendix F: Final Codebook

Axial Codes/categories	Code	Definition	examples
Existing climate change-chemistry curriculum connections	Greenhouse gases	discussing the formation/behavior/ structure of greenhouse gases and/or their effect on climate change	"I just start with, what are greenhouse gases and why do they trap heat?" Also if the teacher mentions how CO_2 is involved in the process since it is a greenhouse gas. "the regular greenhouse effect versus the runaway greenhouse effect we are currently seeing."
	Phase of matter	discussion on how climate change impacts the phases of matter	"what happens with thermal expansion... we look at the heating curve, when things melt, the temperature, and how they expand...eventually we do a calculation of how much water is on the planet when it expands... As we are seeing with sea-level rise."
	Equilibrium	Discussion on the different ways equilibrium is involved in climate change	"liquid-vapor equilibrium, I point out equilibrium's a really centric concept in a lot of sciences, so I talk about equilibrium of energy flow into and out of the Earth with climate change as the example."

Existing climate change-chemistry curriculum connections	Conservation of Energy	Discussion about how conservation of energy is involved in climate change	"when we're talking about conservation energy, I use climate change again, energy in and out, um, as an example. When we're talking conservation of mass, I use climate change as an example for that. I also shoehorn that in some we talk sense of scale and talk about the scale of taking couple hundred million years of sequestered carbon and putting it into the atmosphere in, in a couple of centuries."
	Bonding	Discussing molecular bonding in the context of climate change	"So by the time we get to our bonding unit and we actually start looking at what the structure of those compounds [greenhouses gases] are, they can have a sense of how they behave in their properties."
	Solutions, solubility	discussing solutions and solubility in the context of climate change	"we look at farming with the impact of irrigation we can look at the dissolved solvents and water..."
	Nature of Science	Discussion about how the nature of science impacts the scientific consensus of climate change and explains how climate change topics can be taught through the lens of the nature of science	"incorporating some of the elements of the nature of science and start talking about how science is never certain. That's why can't wait until the science is done. Um, science is tentative and incremental. Science, uh, gives error bars. Science makes mistakes."
	Combustion reactions	discussing the connection between combustion reactions and climate change	"When we talk about combustion reactions we talk about climate change briefly [greenhouse gases]"

Existing mechanisms for climate change-chemistry connections	Diverting from curriculum	Bringing up climate change as an aside or digression separate from the unit or class topic	"I have these asides to climate change ideas" "I haven't taught an extended unit on climate change, or more than just kind of digressions..."
	integrating into curriculum	climate change is used as an example to teach specific units such as bonding or combustion reactions	"I think we can use climate change as the example to teach the principles of chemistry."
	Contextualised lesson plans	Participant believes that the context in which they are teaching is important to how topics of climate change science should be taught	"that's hard, at least in a school like mine, to do that. It's hard to put that in, whereas if I had steps curricula of, "Hey, you're teaching this topic in chemistry or physics. Here is a way to do that using climate change as an example. For setting the setting the sights a little bit lower for those curricula, instead of it being, "They will come out with a full understanding of climate change," and that's what drives the curriculum that just would mean much cover 'cause it is very clear to the community that I'm trying to indoctrinate kids in the, the hoax of climate change"
	Barrier workaround	Participant has figured out a way to maneuver around specific barriers and manages to teach climate change principles regardless of the struggles they face	" I found that much more defensible in terms of blowback from parents because I'm not teaching climate changeI am teaching these chemistry concepts but in my mind, I'm still accomplishing that they get to see that this actual science and they get some sense of how it works and the magnitude of it."

Barriers	Curricular obligations	Real and/or perceived need to cover particular "standard" chemistry topics that create pressure to teach the curriculum or content without climate change topics.	"half a year on chem... I always have in my mind preparing [students] for the [college prep] course and the AP Exam"
	Lack of time	Participant discusses a lack of time to prepare for their classes and/or their labs	"we're struggling right now is just planning time. like having time to sit down, paid time...to figure out how really to include this [climate change topics] into existing units"
	Lack of resources	Participant mentions they do not have the necessary resources to teach more climate change in their classroom	"access to materials [is a barrier]. just being able to do labs... but we do not have the money to do that.
	Hard to focus	Multifaceted nature of climate change makes it difficult for instructors to choose specific components to highlight in class	"I find it a little bit challenging sometimes to kind of focus on what is climate change...and what are some of the problems that we want to address?"
	Lack of appropriate curricula	Participants explains that they do not have access to curricula that are helpful for their classes	"if I had sort of modular, "Hey, here's how to teach eqequilibrium with climate as the example. Here's how to teach conservation energy with climate as an example. Here's how to teach" because a lot of the curricula, their goal, sort of the objective of this curricula is to teach about climate change."
	Proxy Wars	Participant explains that they struggle to teach climate change topics because they have to debate	"I was like, you know, it's not fair for him and I to be debating each other through a kid... a sort of proxy debates which is a big

Barriers		the science through someone as a proxy, in most cases a student	problem."
	Lack of teacher community	A lack of communication and/or collaboration between teachers, which negatively impacts the substance and/or coordination of course material	"the person who teaches environmental science here does not really address climate change...there is very little coordination among the teachers to cover all of the next generation science standards in a coherent way"
	Student Pushback	Students push back against teaching climate change	"you know, there is a lot of pushback from students the minute they hear climate change"
	Parental Pushback	Participant discusses how parents have pushed back against teaching their children climate change topics	"I don't teach a unit on climate change in any of my classes. I used to, um, but I live in a fairly conservative rural community, and that just got to be too much of a headache for me in terms of blowback from parents."
Supports	Admin backing	Support from admin in the form of independence, initiatives from the school, verbal support, etc.	"no institutional barriers, I have a lot of independence here so I am happy with that" "...I was supported by my administration
	External Supports	Initiatives relevant to teaching that the participant utilizes in the classroom	"this is through, Beyond Benign, they're an organization that has this green chemistry initiative. Its a movement within the industry... we are trying to build a hub in the pacific northwest."

Supports	Independence	Participant finds that the independence from administration to be helpful	"They pretty much leave me alone to teach what I wanna teach in chemistry and physics. I'm the only it's a small school and we're sort of, uh, rural enough that I'm the only one who teaches physics and chemistry.
	Support from other teachers	Teacher community and collaboration can make classes more succinct and coherent in addition to allowing for teachers to feel welcome teaching their curricula	"The science teachers had weekly meetings and discussed how to cut up the curriculum and who's going to teach what. So the kids got a more coherent curriculum"
Teacher goals and aspirations	Curriculum redesign	Participant articulates a need for overarching restructuring of their current curriculum	"If I were to redesign the curriculum I would like to start from step one and do something like that [the Big History Project]" "how can I take some of the work that green chemistry does and replace some of the things in our curriculum with that?"
	showing Interconnected reality	Expresses importance of highlight the interconnectedness of chemistry, the environment, and/or our broader lives	"everything should be more interconnected than it is already taught". "Even insurance companies, theyre going to need to start adjusting their formulas to account for climate change"

Teacher goals and aspirations	Preparing students for future impacts	Desire to provide the students with relevant tools necessary for their future as well as promoting the curiosity of climate change topics	"this is the future theyre facing...providing them the opportunity to explore and become interested in that [climate change science topics] it will encourage them to go into those careers or pursue the post secondary education that they're going to need." "I want to empower them with knowledge and make them feel like 'I better understand something and now I have the facts to be able to bring an argument."
	Dedicated class	expresses the desire to have a separate class dedicated to teaching clime change topics	"I would love it to be taught as a standalone, so you get a comprehensive view of that. I don't see a way to shoehorn that into a physics or chemistry class as a climate change unit."
	New ideas	Explains new ideas on how to incorporate climate change topics into their classrooms that they have not yet been able to achieve	" One of the projects that would be really fun is using the mushroom mycelium to fabricate. So I wanted to do something, especially at the beginning of the pandemic with the increase in takeout containers, let's design a recyclable or compostable takeout container."
Climate Change beliefs	Acknowledges science	Participant believes the scientific community's data on climate change	"Climate change is a documented fact... based on models...And climate change denial is a political and not a scientific issue."

Climate Change beliefs	Human involvement	Participant believes that climate change is responsibility of humans, and/or people should be involved in its' mitigation	Climate change is a documented fact, and it is caused by human activities based on models." " in addition to the already existing stressors and I just have very little faith right now that governments and people are going to get it together to really start saying we're not going to stop climate change from happening, we really need to start figuring out how we're going to deal with it."
	Values integrating climate change into HS	Participant believes that integrating climate change topics into high school curriculums broadly would be beneficial	"I think we can use climate change as the example to teach the principles of chemistry, the principles of biology... not just dealing with it as its own separate topic."
	Climate anxiety	Participant expresses a deep worry about the impact of climate change in the world	"I just have very little faith right now that governments and people are going to get it together to really start saying we're not going to stop climate change from happening, we really need to start figuring out how we're going to deal with it."

Appendix G: Participant Recruitment Email

Dear [Name],

We are education researchers at Reed College conducting a study to explore topics incorporated into teaching high school chemistry, particularly topics related to climate science. You are receiving this email because we would like to invite you to participate in this study.

Participation in this study would involve a 20–30-minute Zoom interview to discuss your thoughts, feelings, and experiences related to these teaching decisions. After this interview, we will follow up to ask if you would be comfortable sharing related course artifacts such as example syllabi and/or any assignments mentioned during the interview. Your participation is voluntary and will be kept confidential.

If you choose to participate in this study, your time spent doing so will be compensated with $30. For more information and to indicate your willingness to participate, please click here and complete the form. Participants will receive a follow-up email with further directions for scheduling.

If you have any questions, please contact Kieran Wharton at kiwharton@reed.edu or Prof. Nicole James at njames@reed.edu

Best,
Kieran Wharton
Prof. Nicole James
Reed College

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