Investigating Science Educators' Conceptions of Climate Science and Learning Progressions in a Professional Development Academy on Climate Change Education

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Abstract. We used complementary methods to investigate a model of professional development. The context was a weeklong summer Climate Science Academy that focused on the application of learning progressions in climate change education. We examined the research questions: 1) How did participants evolve in their understandings of climate change through participation in the professional development academy? and 2) How did participants understand learning progressions as potentially informative for their science teaching practices related to climate change, particularly its regionally-relevant aspects? Participants (N=27) in the Academy were middle school (n=14), high school (n=7), higher education (n=2), and informal science educators (n=4) from Delaware and Maryland (approximately half from each state). Findings showed that, as a group, participants improved their scores on a climate science content instrument from pre (mean score: 9.6; S.D. = 2.5) to post (mean score: 10.8; S.D. = 1.8) out of a possible 14 points. However, change in participants' levels of content knowledge was variable. Our analysis of the qualitative data suggested that participants developed a range of conceptions of learning progressions, from less developed to well developed, and a range of views on potential utility of learning progressions to support their instruction on climate change, particularly its regionally-relevant impacts. Implications of our study apply to science teacher professional development in climate change education and professional development that includes a learning progressions focus.

Introduction

Climate change has become increasingly salient in science education with the release of the Next Generation Science Standards (NGSS) (Achieve, 2013), the first set of U.S. national science standards to explicitly include the topic. In this context, it is timely to explore models of professional development that can support science educators in enhancing their science content understandings and teaching practices (Reiser, 2013), including those related to climate change. Our study investigates a model of professional development around climate change education for informal and formal science educators. We focus specifically on the inclusion of learning progressions in a summer professional development academy. We examine the research questions: 1) How did participants evolve in their understandings of climate change through participation in the professional development academy? and 2) How did participants understand learning progressions as potentially informative for their science teaching practices related to climate change, particularly its regionally-relevant aspects?

Climate Change Education and MADE CLEAR

Our project, Maryland and Delaware Climate Change Education, Assessment and Research (MADE CLEAR) is part of the National Science Foundation's Climate Change Education Partnership (CCEP - Phase II) program. Participating projects include experts in climate science and the learning sciences, as well as practitioners from within formal or informal education settings. Key objectives center on innovations in P-20 climate change education, teacher education and professional development to enhance educators' climate change content knowledge and pedagogy, and outreach to promote public understanding of climate change. The two-state collaboration draws on the shared STEM education emphasis and climate change concerns of the states of Delaware and Maryland.

In this study, we focus on the professional development and learning sciences research aspects of our project. Through our professional development model, which incorporated the learning sciences, we address the project goals and objectives listed in Table 1. In addressing these goals, we facilitated and researched a summer Climate Science Academy for middle school, high school, higher education, and informal science educators from our two states. In the Academy, we introduced participants to learning sciences theories through the inclusion of learning progressions. We presented participants with a draft hypothesized learning progression on sea level rise, an example of a regional observation of climate change relevant to our Mid-Atlantic states (NCADAC, 2013). We encouraged participants to consider ways the draft hypothesized learning progression could inform their teaching, and invited them to test the learning progression with their own students.

Table 1. MADE CLEAR project goals and objectives guiding our study.

Goal: *Build and sustain the capacity of educators to deepen student understanding of climate change.* **Objective:** • Include climate change in the in-service professional development for middle and high school teachers and informal educators.
Goal: *Utilize learning principles and the sociocultural diversity of the region to develop effective, scalable, and transferable modes of climate change education.* **Objectives:** • Advance learning sciences research to create new understanding of how individuals from diverse backgrounds learn about climate change. • Assess approaches to professional development that foster changes in teacher knowledge, skills, and dispositions.

Climate Change Presence in the Next Generation Science Standards

Both states involved in our project, Delaware and Maryland, have adopted the Next Generation Science Standards. To gain insight into the climate change science content that science educators will be expected to teach, and to inform the planning of our professional development activities, we conducted a detailed analysis of NGSS performance standards related to the topic (see McGinnis, McDonald, Breslyn, and Hestness, 2013). We identified performance standards explicitly and proximally related to the topic. This process illustrated how the concept is introduced and elaborated over the course of learners' K-12 science education experience. Performance standards we identified as explicitly related to climate change used the terms "global temperatures", "changes in climate", or "climate change". Proximally related standards did not use these precise terms, but addressed concepts we believed to be crucial to understanding the science behind climate change. The standards we identified as explicitly related to climate change are included in Tables 2 and 3 (see Appendix). Our full analysis of the inclusion of the climate change topic in the NGSS is available at:

http://www.climateedresearch.org/publications/2013/Climate-Change-NGSS.pdf

Literature Review

Climate Change in Science Educator Professional Development

While research discussing professional development related to climate change is limited, the existing studies cover an array of professional development approaches and venues. These have included British secondary science teachers' engagement in focus groups on climate change education (Gayford, 2002), U.S. 5th grade teachers' participation in-service workshops related to the implementation of a climate change-related curriculum (Lester, Ma, Lee, & Lambert, 2006), Canadian teachers' participation in weekend-series professional development course on climate change oriented toward environmental behavior change (Pruneau, Doyon, Langis, Vasseau, Ouellet, McLaughlin, Boudreau, & Martin, 2006), U.S. informal science educators' experiences engaging in collaborative "debrief meetings" as they developed an implemented a museum-based climate change education program (Allen and Crowley, 2014), and a synthesis of lessons learned from professional development activities undertaken by the National Center for Atmospheric Research's (NCAR) – including intensive on-site summer workshops, short-course conference-based workshops, and online learning – for middle and high school science teachers across the United States (Johnson, Henderson, Gardiner, Russell, Ward, Foster, Meymaris, Hatheway, Carbone, & Eastburn, 2008). Research in teacher professional development related to climate change has emphasized 1) the unique nature of the climate change topic, 2) teachers' needs for improved science content knowledge and pedagogical approaches related to climate change, and 3) the value of teacher participation communities of practice around teaching the topic of climate change. A number of these themes are also evident in the more extensive body of research on climate change education in pre-service teacher education (Ekborg & Areskoug, 2006; Hestness, McGinnis, Riedinger, & Marbach-Ad, 2011; Lambert et al., 2012; Matkins & Bell, 2007; McGinnis, Hestness, & Riedinger, 2011)

The topic of climate change presents unique affordances and challenges related to the professional development of science educators. Researchers have suggested that practicing teachers view the topic as relevant and motivating for their students (Gayford, 2002; Johnson et al., 2008), particularly due to its presence in the media. However, many teachers do not feel well prepared to teach about climate change (Johnson et al., 2008). Climate change presents particular challenges in terms of both its complex content and the perceived controversy surrounding it. Wise (2010) found that nearly half of the 628 science teachers she surveyed “agreed” or “somewhat agreed” that there is substantial scientific disagreement about the cause of recent warming. This perception can influence the ways that teachers address the topic, frequently leading them to value presenting “both sides” (Wise, 2010, p. 297) of the issue, even though there is significant scientific agreement on the causes of climate change (IPCC, 2013). Alternately, the perceived controversy around climate change causes may lead teachers to avoid discussing the causes of climate change altogether, as was the case for the informal science educators in Allen and Crowley’s (2014) study. These studies point to the need for professional development that assists teachers in understanding the science content related to climate change, and providing them with pedagogical strategies for addressing the potentially sensitive aspects of the topic. Despite these challenges, the topic of climate change offers rich possibilities for science educators. As a topic of ongoing study, or an example of “science-in-the-making” (Latour, 1987 in Kolstø, 2001, p. 294), climate change can help teachers to emphasize the nature of scientific knowledge (Matkins & Bell, 2007) and the process of interpreting and understanding changing information in science (Johnson et al., 2008). It can also offer opportunities for teachers to make connections between scientific disciplines (e.g. Earth Science and Life Science), or between science and other academic content areas (e.g., Social Studies). However, Gayford (2002) found that teachers were hesitant to pursue the interdisciplinary potential of the topic in the context of their already crowded science curricula. Thus, there is an evident need for teacher professional development that supports teachers in maximizing the rich educational possibilities inherent in the climate change topic, while simultaneously addressing existing curricular goals.

Studies of teacher professional development related to climate change education have highlighted the need for professional development that improves teachers' relevant content understanding and pedagogical skills. Research on students' scientific understandings of climate change have revealed a number of persistent alternative conceptions around the issue and related phenomena such as the greenhouse effect (e.g., Boyes & Stanistreet, 1992). As Ekborg & Areskoug (2006) suggested, teachers may have similar alternative conceptions to those of their students. For this reason, as well as the changing nature of information related to climate change science, teacher professional development on climate change frequently seeks to increase teachers' relevant science content knowledge (Johnson et al., 2008; Lester et al., 2006; Pruneau et al., 2006). In their studies of pre-service teachers' knowledge of global climate change, Lambert et al. (2012) demonstrated that teachers can improve their content knowledge with directed intervention, but they may hold onto certain alternative conceptions. Such studies underscore the need for professional development that continues to develop teachers' understandings of the topic.

With regard to climate change education pedagogy and teaching resources, research has suggested that teachers benefit from professional development experiences that introduce age-appropriate activities to use with students and provide opportunities to develop and modify these resources to fit appropriately into their teaching contexts (Johnson et al., 2008). Also related to contextualization, Lester et al. (2006) and Johnson et al. (2008) each emphasized the value of climate change-related professional development activities that supported teachers in making connections to students' cultures and communities. Lester et al. (2006) further underscored the ways in which teachers benefited from opportunities to practice teaching climate change related lessons. This was also evident in Allen & Crowley's (2014) study that described how informal science educators were able to improve their pedagogy and their climate change education program through an iterative process of teaching and redesigning their lessons. In addition to practicing pedagogical approaches, research from pre-service teacher education suggests that teachers can benefit from seeing approaches modeled. In our own work with pre-service teachers (Hestness et al., 2011; McGinnis et al., 2011), we have found that instructional interventions that model and engage participants in useful pedagogical strategies, such as integrating current events into climate change education, examining authentic climate data, and engaging in scientific argumentation, can help teachers feel more confident and prepared to address climate change in their own instruction.

A final theme that emerges from the research on teacher professional development related to climate change education is the value of teacher collaboration and engagement in communities of practice. Several studies (Allen & Crowley, 2014; Johnson et al. 2008) explicitly draw on the sociocultural perspectives of Lave and Wenger (1991), while others allude to such ideas through discussion of community and collaboration amongst practitioners. For example, Gayford (2002) noted that teachers participating in his climate change education focus groups viewed fellow practitioners as the most reliable source of advice and ideas. Similarly, Lester et al. (2006)

described how teachers interacted during an in-service professional development experience, discussing ways they could adapt and modify lessons in a climate change education unit. Pruneau et al. (2006) highlighted the ways in which teachers participating in weekend professional development activities were able to share ideas, encourage each other, and accompany one another in a change process. This idea may be of particular import to supporting teachers as their curricula change, and they begin to change their teaching practices, in response to the Next Generation Science Standards and its climate change-related elements.

Teachers' Conceptualization and Use of Learning Progressions

Learning progressions (LPs) are often defined as descriptions of the increasingly sophisticated ways that learners can think about a science topic over time (Duschl, Schweingruber, & Shouse, 2007). These increasingly sophisticated ways of thinking are generally organized into qualitatively different levels of achievement (e.g., Alonzo & Steedle, 2008; Lehrer & Schauble, 2012; Mohan, Chen, & Anderson, 2009). These levels are considered conceptual steppingstone, benchmarks, or landmarks, which educators can use as diagnostic tools and instructional targets (Lehrer & Schauble; Shea & Duncan, 2013). Additionally, many science educators have argued that learning progressions have the potential to coordinate curriculum, instruction, and assessment (Alonzo & Steedle, Berland & McNeill, 2010; Duschl et al., Furtak, 2012; Gunckel, Covitt, Salinas, & Anderson, 2012; Lehrer & Schauble, 2009; Shea & Duncan; Songer, Kelcey, & Gotwals, 2009). Based on the potential benefits of learning progressions, LPs played a prominent role in the development of the recently released Next Generation Science Standards (NGSS, Achieve Inc., 2013). In appendix E of the NGSS, the authors explained, "Following the vision of *A Framework for K-12 Science Education*, the

NGSS are intended to increase coherence in K-12 science education." The authors then outlined the progressions of disciplinary core ideas that make up the new standards, indicating how learner ideas are expected to grow more complex across the grade bands from K-2 to 9-12.

Learning progressions (LPs) are useful tools for conceptualizing the development of student thinking over time in a particular domain. By implementing detailed curriculum and targeted assessment that map to big ideas in a domain over time, LPs can help researchers and educators identify the learning pathways students navigate and inform pedagogical strategies to support future learning. From a researcher perspective, LPs can inform both practical and theoretical understandings of the development of what students know. However, in order to be useful to educators, LPs must also take into consideration ways in which teachers develop as practitioners. Thus, LPs must be formatted in ways that have instructional utility that support the development of new teaching practices, are accessible to teachers with varying expertise and backgrounds, and have the capacity to scaffold teachers' development of ambitious teaching practices (Furtak, Thompson, Braaten, & Windschitl, 2012). The research supporting teacher use of LPs is thin, however key studies document the utility of LPs in practice and the challenges they pose to practitioners.

One way teachers can connect student thinking and LPs is through assessment. Corcoran, Mosher, and Rogat (2009), suggest that assessments based on LPs could "provide information that is more easily interpreted by teachers and potentially allow them to make better informed and more precise decisions about student needs and how to respond to them instructionally" (p. 23). LPs place emphasis on illuminating how student thinking develops over many grades, which has potential for helping teachers make inferences about students' understandings in a domain and developing their own pedagogical strategies in response to evidence on student thinking

(Furtak & Morrison, 2013). As Furtak and Morrison (2013) describe, one means for increasing the utility of LPs for classroom instruction is to generate evidence on student thinking through assessments aligned with the LP. If the LP combines information about how ideas and practices develop over time with student responses to assessments, teachers may be able to accurately locate students on a trajectory specified by the LP and adjust their instructional sequence or methodology to optimize student learning (Furtak, 2012). However, challenges persist in making clear connections between LPs and instructional practices.

One challenge noted by Furtak and Morrison (2013) is that LPs often treat learning as linear and hierarchal when in fact several studies point to the notion that students thinking may follow a number of different trajectories (NRC, 2007) and may be influenced by the context in which a problem is situated (Nehm & Ha, 2011; Heredia, Furtak, & Morrison, 2012). Furtak and Morrison (2013) found that teachers exploring student thinking along a LP on natural selection required support in understanding the developmental nature of student thinking that was captured by the LP. For example, student thinking often differed by level of sophistication across several ideas within the LP in two ways, (a) a single student may have non-normative, transitional, and normative ideas across several elements of the LP and (b) students' thinking within a classroom may vary considerably for each element of the LP. This made deciding on relevant curricular interventions difficult for teachers. Essentially, the amount of information generated by assessments in Furtak and Morrison's (2013) study was overwhelming to teachers as they considered how to respond to student thinking. The amount of information generated by the LP was not a singular challenge. Teachers also struggled with dichotomous notions of student responses as right or wrong. This dichotomy contrasted with the researchers' view of the LP as mapping the development of student thinking over time and acknowledging all responses as valuable stepping stones towards most sophisticated understandings. This finding was explicated in earlier work by Furtak (2012).

Furtak (2012) conducted a study of six high school biology teachers' interpretation of formative assessment results in connection to a learning progression on natural selection. The learning progression was comprised of two central elements, a horizontal axis that expressed a sequence by which ideas of natural selection unfold (i.e., establishing an order for curriculum) and a vertical axis designed to demonstrate the progression of student thinking about natural selection (i.e., identifying opportunities for formative assessment). Learning progressions are often used as scaffolds for assessment design, but we know very little about how teachers conceptualize learning progressions or find them useful for informing daily instruction. One way learning progressions may be useful to teachers is in determining students' relative position in a sequence of ideas mapped by the learning progression. Furtak's investigation examined teachers' use of formative assessment results to this end.

Instead of thinking about student ideas as progressing, the teachers in Furtak's study often elevated "correct" ideas and sought to "debunk" alternative conceptions. One hallmark of LP work is to treat student thinking as progressive in that non-normative ideas often lay the foundation for developing more sophisticated notions. In effect, alternative conceptions can be productive stepping stones to canonical understandings. In Furtak's (2012) study, teachers viewed ideas as right or wrong without attempting to leverage students' alternative conceptions in their instruction. However, they were able to identify student responses to formative assessments as falling along the trajectory of the vertical axis of the LP indicating that the LP's utility in mapping student responses. Furtak (2012) suggests that researchers need to work with teachers to develop language that goes beyond "get it, or don't get it" so that the variety of student ideas that are non-normative but still productive for progressing towards canonical understandings can be leveraged in instruction. Furtak (2012) offers as a final conclusion: "the learning progression in this study may have helped teachers identify common misunderstandings, but it did not prepare them to respond to student ideas and adapt their instruction" (p. 1206). Further supports are needed in order to help teachers in responding to students and adjusting their instructional practices in ways that elevate student thinking.

Although teachers were able to successfully use the LP to organize their own ideas in preparing their lessons on natural selection, additional challenges persisted in how to communicate results between researchers and teachers. Furtak and Morrison (2013) acknowledged researcher-based challenges such as how to best present student achievement to teachers from pre/post assessments to inform instructional next steps and how to expedite the time between assessment administration and result generation in order to inform teacher practices in a timely manner. Furtak and Morrison (2013) place great emphasis on the need to acknowledge teacher supports as researchers design LPs and assessments.

In summary, three main ideas arise from this body of work. First, teachers in these studies found LPs useful for organizing their ideas for instruction - the LP on natural selection provided a framework for ordering curriculum over time. Second, teachers found the LP useful for identifying student thinking, however teachers typically viewed student ideas as right or wrong without consideration for the progressive nature of student thinking. Finally, challenges persist in timely communication of findings from LP research to teachers in ways they can act upon in their classroom. It is clear that significant work is required in order to better prepare teachers for utilizing LPs in practical ways. These conclusions suggest a need for targeted professional development that includes broadening educator thinking about the utility of student ideas and emphasizes supports for responding to student thinking.

Study Context

This work is situated in the context of MADE CLEAR (Maryland and Delaware Climate Educational Assessment and Research Project), a regional, NSF-funded project focused on the implementation of a comprehensive climate change education plan across Delaware and Maryland. A central component of MADE CLEAR is an annual, residential, weeklong Climate Science Academy that brings together educators from formal and informal settings interested in the teaching of climate change. The work reported here was conducted in the context of the first Academy that took place in summer 2013. The Academy was held at a retreat facility affiliated with the campus of a Mid-Atlantic University. The site provided an outdoor setting surrounded by coastal wetlands, ideal for highlighting local impacts of climate change such as sea level rise. The residential nature of the Academy facilitated sharing of ideas and practices both during formal professional development activities and informal events, and promoted team-building and the formation of a community of like-minded educators.

Design of the Climate Science Academy

The design of the Climate Science Academy was a collaborative effort among climate scientists, learning scientists, practitioners, and policy stakeholders from formal and informal settings. The cross-disciplinary expertise of the design team was purposeful and intended to promote new ways of teaching about climate change centered around four facets: (a) accurate scientific understandings about climate science; (b) use of vetted curricular and technological resources; (c) pedagogical approaches consistent with the teaching and learning of sensitive socio-scientific topics; and (d) considerations related to content and practices aligned with learning progression ideas advocated in NGSS.

The model for our design is based upon prior teacher professional development research and is influenced by the recommendations in the Next Generation Science Standards. The Next Generation Science Standards seeks to build upon the central role of inquiry in previous science education standards (Benchmarks for Science Literacy (AAAS, 1993), National Science Education Standards (NRC, 1996)) and by notably shifting attention away from only inquiry toward a blending of content knowledge and inquiry processes referred to as "science and engineering practices" (Reiser, 2013). In addition, the Next Generation Science Standards place attention on coherence in building ideas across time and among the science disciplines, termed "cross-cutting concepts" (p. 8).

Theoretically, we were drawn to the work of City, Elmore, Fairman, and Teitel (2009) and Desimone (2009) because their ideas aligned well with the different focus on science made by NGSS. These theoreticians in professional development concluded that effective professional development must foster greater understanding of content and pedagogy, provide opportunities for active learning, and include pedagogical elements such as lesson examination and refinement, reflection and group debriefing to generalize to practice. In addition, research related to the teaching and learning of sensitive socio-scientific topics emphasizes the importance of helping participants build regional and personal connections with the topic at hand. Thus, an emphasis on sea level rise intended to help participants build such connections and highlighted the coastal setting in which our Academy was conducted. Table 4 provides an overview of our professional development activities in relation to characteristics of effective professional development recommended in the research literature.

Table 4: Professional Development Activities in Relation to Teacher Learning Principles

Professional Development Element	Activities
Content and Pedagogical Understanding	Climate scientists delivered benchmark lessons on climate change and expert views on sea level rise Learning theory experts engaged educators in the examination of NGSS components specific to climate change. Learning scientists introduced educators to ideas of learning progressions as a means of aligning curriculum, instruction and assessment.
Active Learning	Interactive hands-on activities modeled by learning scientists and education specialists on: (a) carbon cycling and learning progressions, (b) sea level rise in coastal and polar areas, and (c) vetted technology resources aligned with NGSS and climate change.
Activities Supporting Practice	Participants were presented with a draft hypothesized learning progression on sea level rise, a locally-relevant climate change impact. Participants utilized the sea level rise learning progression as they developed, presented and reflected on learning segments they expected to implement in their classrooms in the upcoming year. Participants were asked to consider collecting data on their own students' understanding of sea level rise in the upcoming year in order to test and validate the draft hypothetical learning progression forming educator-researcher collaboration.

Learning progressions in the Climate Science Academy. In our climate change professional development academy, we supported the NGSS recommendation to seek coherence in building ideas over time in content by working with practicing educators to understand learning progressions and their potential applications. We presented an introduction to learning progressions by using the familiar analogy of what it requires to learn over time to ride a bike with developed competence (Figure 1). The learning progression begins with a child riding a plastic tricycle pushed by a mother using an attached handle bar. The analogy also includes two intermediate proposed stages where the rider learns to push the pedals, steer, and maintain balance while moving. Finally, the learning progression ends with an experienced rider moving across challenging terrain. For the educators, we posed the question, "What does the rider need to know about riding a bike at each level of this hypothetical learning progression?" In this way, we are able to help the educators consider what big ideas or 'stepping stones' would be the most essential for learners (all or most) to learn through targeted instructional intervention over a significant duration of time. We then extrapolated this idea through consideration of the processes by which learners become more sophisticated in their thinking and performances in an area of science content.

Figure 1. "Learning to ride a bike" as an analogy for presenting the progressively more sophisticated levels of understanding represented in learning progressions.

After helping educators to understand the notion of learning progressions, we also helped educators to identify progressions of ideas related to climate change in the NGSS. Specifically, we focused on the progression of ideas in the NGSS related to sea level rise, since this is a regional observation of climate change for learners in our region (NCADAC, 2013). To organize these ideas, we categorized the performance expectations related to sea level rise into three qualitatively different levels of achievement, comparable to the levels of a learning progression.

In addition to identifying a progression of ideas related to sea level rise in the NGSS performance expectations, our research group has also developed a draft, four level hypothetical learning progression on sea level rise (beginning with a lower anchor—the knowledge level expected of a learner entering school, two intermediate levels, and an ending level showing what understanding of the construct a graduating high school senior would be expected to hold; see http://www.climateedresearch.org/publications/2012/SLR-LP.pdf). When drafting an initial hypothetical learning progression, researchers typically identify a potential sequence of ideas that could lead to an understanding of the topic based on previous research studies, standards documents, and an analysis of disciplinary knowledge (Alonzo & Steedle, 2008; Mohan et al., 2009; Sikorski & Hammer, 2010; Songer et al., 2009). When developing our hypothetical LP on sea level rise, we based our initial sequence of ideas on the work of Gunckel et al. (2012), who developed a learning progression on the movement of water through socioecological systems—a topic that overlaps with the sea level rise topic. We also drew upon the NGSS performance expectations, since many of these performance expectations address constructs related to sea level rise. After developing an initial sequence of ideas, we solicited feedback from science content experts and made revisions based on this feedback.

Participants

Participants (N=27) in the Academy included middle school (n=14), high school (n=7), higher education (n=2), and informal science educators (n=4) from Delaware (n=16) and Maryland (n=11). All middle school teachers taught general science for grades 5-8 while high school teachers taught physics, biology, chemistry, or earth science for grades 9-12 including AP courses. Informal educators designed and implemented environmental education programs at their respective state parks, and all higher education participants were faculty members in science education (pre-service teacher education programs). All participants participated in the Academy voluntarily.

Methods

Our study employed a complementary research methodology (Jaeger, 1997). By using this methodology, we aimed to enhance our data collection, analysis, and interpretation via triangulation. We collected quantitative data using an instrument, the Climate Science Knowledge Instrument (CSKI) (Lambert & Bleicher, 2012), to assess participants' science content knowledge. We collected qualitative data through individual recorded and transcribed interviews with each participant in the Climate Science Academy.

Climate Science Knowledge Inventory (CSKI)

We used Lambert and Bleicher's (2012) Climate Science Knowledge Inventory (CSKI) to assess participants' climate science content knowledge before and after participating in the Academy. After consulting with Lambert and Bleicher, we selected a subset of the questions from the CSKI (2012 version) to be administered to participants. Questions were selected based upon their relevance to content presented during the Academy, as well as for relevance to foundational climate change concepts. The instrument was administered to participants on the first day of the Climate Science Academy, prior to professional development activities, and again the last day. Sample questions included:

Q1. The greenhouse effect is best described as ____________.
a. A buildup of the ozone layer due to excess greenhouse gases.
b. Greenhouse gases becoming trapped by carbon dioxide.
c. Greenhouse gases absorbing and re-emitting infrared radiation.

d. Infrared radiation absorbing and trapping greenhouse gases.

Q12. Sea level would rise the most if _____________.

a. Thermal expansion of the ocean water continues.
b. The ice over the Arctic Ocean melted.
c. Glacial ice over Antarctica melted.
d. Earth entered an ice age.

In addition to the multiple choice questions two short answer questions were included. These questions asked participants to provide evidence that climate change is occurring as well as potential consequences of increasing levels of carbon dioxide, melting of terrestrial ice, and the impact of living organisms. Using the CSKI, an existing research instrument, to measure participant content knowledge at the Climate Science Academy allowed for more confidence in our analysis and interpretation of participant responses.

Interviews

On the third and fourth days of the Academy, we interviewed all participants to gain insight into their understandings of learning progressions and their applicability to climate change education in the context of the NGSS. During the approximately 20-minute interviews, participants watched two video clips of about two minutes in length, and responded to questions after each. The video clips were recorded during the two Academy sessions that focused on the learning progression topic. The purpose of the video clips was to place participants' thinking back into the context of the sessions (an application of situated cognition) that were presented on days one and two of the Academy. Participants responded to questions regarding their thinking about how learning progressions could inform their teaching about climate change and its impacts, particularly sea level rise. A sample question was:

In the video clip on learning progressions from the Climate Science Academy:

- *(video clip from Sea Level Rise learning progression presentation) What did you learn about how learning progressions can guide your teaching about sea level rise, an example of a locally relevant effect of climate change?*

Interviews were conducted during the Climate Science Academy, after participants had experienced the sessions focused on learning progressions.

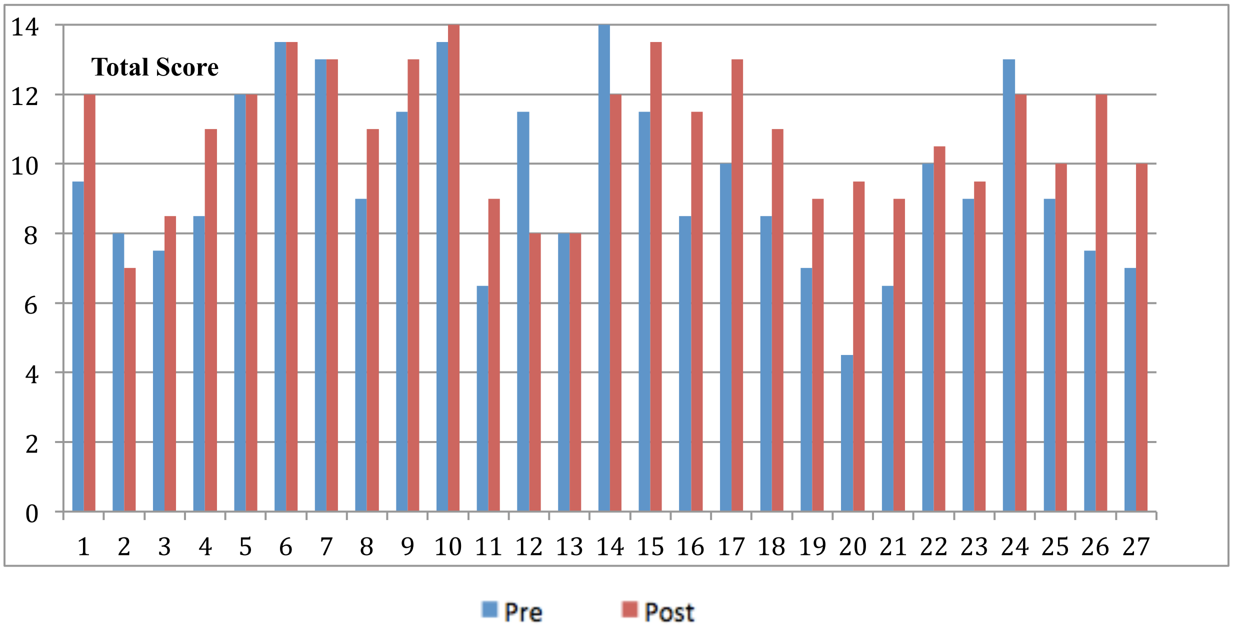
Data Analysis

Climate Change Science Content Knowledge

In regard to our research question related to participants' understanding of climate science content, we administered a portion of a valid and reliable instrument (the CSKI). We scored the participants' responses using a key provided by the instrument's designers. Figure 2 shows pre and post CSKI scores for each participant in order to show the changes for individuals. The mean score for the pretest was 9.6 (S.D.=2.5) and for the posttest was 10.8 (S.D.=1.8) out of a possible 14 points. Effect sizes were moderate (d=0.57). Pretest scores ranged from 4.5 to 13.5. On the posttest, the range was 8 to 14. Five participants scored 12 or above on the pretest and therefore experienced a ceiling effect for the amount of change they experienced in the Academy. Figure 2 shows the distribution of gain/loss of participants for the pre and post CSKI scores. On average, scores increased by 1.25 points.

Based on the multiple-choice items, we found that the influence of the Academy's science content enhancement varied among participants. Namely, of the participants, 18 gained in their scores on the CSKI from pre-Academy to post-Academy, 4 participants' scores decreased (3 slightly and 1 more moderately), and 5 participants' scores remained the same. One participant did not complete both the pre and post assessments, and was therefore excluded from our analysis.

Figure 2. Pre and Post CSKI Multiple Choice Scores by Participant



In addition to multiple choice questions participants also completed short answer items as part of the CSKI. Responses from these items, along with interview data about their climate change content knowledge, allow for a fuller understanding of changes in their climate science content knowledge.

Focal cases. Data for three participants are presented below. These participants were selected to illustrate general trends found in the larger group of participants. For each participant a quote from their participant interview, pre and post scores on the CSKI, and their response to the following open-ended short answer item are provided.

> Item: *Scientists have been making observations that indicate Earth's global climate is changing. List four of these indictors (or observations) and explain how each provides evidence that climate change is occurring.*

Karen: Pre-service Teacher

"I think the, I didn't realize how important it was just because I've been so trained in chem, chem, chem, chem. And I didn't realize what was actually happening and I think it has hit me like

a ton of bricks over the last two days."

Multiple Choice Score: Pre = 7.5 Post = 12

Response to Open-Ended Item

Pre	Change in sea level.	Agriculture.	Ozone layer.	Animals (migration).
Post	Sea level rise. Thermal expansion of water. Melting of land ice.	Rise in CO_2, shows more production of greenhouse gas in atmosphere causing a number of issues.	Rise in overall mean temps. Causes sea level rise, change in precipitation.	Change in precipitation. Caused by global temp increase.

Mike: Experienced Teacher

"It reinforced the way that I approach climate change as a subject because I do sort of expect so kids to have a greater understanding of it …"

Multiple Choice Score: Pre = 13.5 Post =14

Response to Open-Ended Item

Pre	Vostok ice cores: data suggest CO_2 concentrations have increased at a more rapid rate since the industrial revolution.	Polar ice cap coverage and thickness: Satellite data shows decreased coverage and thickness measurements have decreased (average) over time.	Ocean Temperatures: Average ocean temperatures have shown an overall increase over time.	Extreme weather events: hurricane strength and intensity have increased over time, frequency has also increased.
Post	Increase in CO_2 concentration (PPM as measured on Mauna Loa: graphical evidence shows the rate of increase is higher than in past cycles which suggests human influences.	Decrease in Greenland ice sheets as measured by the GRACE tandem satellites. Changes (decreases) in the gravitational field above Greenland suggests changes (decreases) in overall mass of the ice sheet over time.	Identification of climate patterns as identified by Vostok ice cores: patterns of climate change measured by CO_2 analysis of ice cores shos a lower historic range of CO2 concentration than currently measured.	Flower blooming patterns happening earlier than in the past: biological processes indicate warming seasonal trends to be happening earlier suggest a link to average temperature increases.

Amy: Experienced Teacher

"I know that before I walked in here, personally myself, I even had a few misconceptions about climate change. I really thought that climate change and global warming were like, one in the same."

Multiple Choice Score: Pre = 8 Post = 8

Response to Open-Ended Item

Pre	Polar ice caps shrinking- increase in infrared radiation melting the ice caps.	Increase in storms- more heat energy to power the storms.	Sea level rise- more fresh water is being released into our oceans, causing increase in sea levels.	Increase in average temperatures- more infrared radiation being absorbed, increasing temperatures and changing climate.
Post	Sea level rise- thermal expansion due to increased water temps.	Increased temp- CO_2 has increased temperatures, experiencing more droughts and floods.	Loss of habitat/ animals- ecosystems are disappearing.	Extreme weather- due to the amount of heat energy, weather has become more extreme- storms are more powerful and large.

Data from the open-ended CSKI item, as well as data from participant interviews, suggested to us that participants entered the Climate Science Academy with a range of climate science content knowledge. While content knowledge about climate change is an essential component of educators' ability to provide meaningful instruction, pedagogical knowledge is also necessary. In the next section, we discuss how participants thought about learning progressions as potentially informative to their approaches to teaching and learning about climate change, particularly its regionally-relevant impacts.

Teaching About Climate Change

In analyzing our interview data, we returned to the research question: *How did participants understand learning progressions as potentially informative for their science* *teaching practices related to climate change, particularly its regionally relevant aspects?* With this question in mind, we engaged in a four-phase inductive coding and analysis process (Miles & Huberman, 1994).

Phase 1 – Pre-coding. Our interview protocol had asked participants, amongst other questions, to describe the ways in which select Academy presentations and activities informed their understanding of learning progressions and the relevance of learning progressions in general to their teaching about climate change. Because we were interested specifically in participants' understandings and views of learning progressions, we developed a *definition of the situation* code (Bogdan and Biklen, 2006), which aimed to "place units of data that tell how the subjects define the… particular topic… and how they see themselves in relation to… the topic" (p. 174). During our pre-coding phase, one member of our team examined the interview transcripts and identified units of data that fell under the code, "participants' views of learning progressions". We focused subsequent analysis specifically on these sections of the interview data (initially pre-coded as potentially pertinent to our research question), returning at times throughout the analysis process to the full interview transcripts for context.

Phase 2 – Coding. Throughout the interviewing and pre-coding processes, we began to note recurring words and ideas from the participants (e.g., comparisons to scaffolding, knowing "where students are at", advancing student understanding). Drawing from such keywords and ideas, we created a preliminary coding scheme with 14 initial codes. We developed written descriptions for each family of focused codes, and found examples of each within the pre-coded interview data (see Appendix Tables 5 and 6). Using this coding scheme, and adding to it as additional codes emerged during subsequent analysis, two members of our research team independently coded the data segments we identified as potentially providing insight into participants' understanding of learning progressions and their utility for their work. We then discussed our analyses, negotiating any discrepancies amongst the larger research team until consensus emerged.

Phase 3 – Recoding into concepts. During the coding process, we noted redundancies and areas of overlap or close relationship in our codes. For example, we coded some data doubly under the initial codes *Advancing Student Understanding* and *Growth Over Time*. For greater synthesis, and to more succinctly describe and communicate our findings, we collapsed our initial 14 categories into four concepts: *Students should progress* [Advancing student understanding]; *Knowing where students are at* [Assessing student understanding]; *Knowing where you want students to go* [Instructional planning]; and *Meeting students' diverse needs* [Instructional supports] (see Table 7). We then recoded the data within these broader concepts. Two of the initial codes (*3. Belonging to students*, and *6. Empirically-based*) were used only once or twice, so we took note of these cases as interesting outlier stories, but eliminated the codes when we collapsed into concepts.

Phase 4 – Interpretation. After recoding the data within the four concepts, we examined the emergent themes for each concepts and began to interpret the ways in which teachers understood learning progressions as potentially informative for their science teaching practices related to climate change. Throughout this process, our team engaged in ongoing dialogue through the process of developing and revising our written interpretation of key themes.

Insights

Here we present a description of each concept that emerged as teachers explicated their understandings of learning progressions and their potential value for guiding instruction about climate change. For each concept, we present exemplar statements from teacher participants.

***"Students should progress"* [Advancing student understanding].** Nearly all teacher participants in the Climate Science Academy explicitly spoke about learning progressions as related to the advancement of student understanding – or otherwise stated, the idea that *"students should progress"* (Whitney, interview transcript) in their learning. Amongst the participants, there was variation in how this progress was conceptualized. Many teachers blended the idea of learning progressions into their existing theories of learning. For example, teachers commonly spoke about constructivist notions of building on students' prior knowledge. Some teachers spoke about this progress as increasing in sophistication of understanding; others spoke about it simply as growth. With the idea of building up students' understanding, participants frequently adopted the language of steps or levels, with many describing learning as a stepwise continuum or process. For example, teachers used the phrases *"showing what level they are thinking now"* (Jill, interview transcript) and *"move them up in their levels of thinking"* (Carrie, interview transcript). With one exception, described later, participants did not appear to regard the levels of a learning progression as empirically-based or derived from student-generated data. At times, it appeared that participants were referring to learning progressions as individual students' progress in learning, as opposed to empirically-based tools for describing students' increasingly sophisticated levels of understanding of a given construct. In addition, there was variation in the timeframes over which participants were conceptualizing the advancement of student understanding. Because most participants only teach students for one year of their academic life, they primarily discussed the progress a student might make over the course of an academic year – or even an instructional unit – rather than over a longer, multi-year timeframe that learning progressions typically embody.

Snapshot of participant thinking: Tanya. In response to the question, *"What did you* *learn about how learning progressions can guide your teaching about climate change?"*, Tanya, an experienced middle school science teacher, made several connections to the concept of advancing student understanding. Her response illustrates some of the ways she is beginning to blend the idea of learning progressions into her existing theories of teaching and learning. She stated:

> *"I don't really think I learned anything in particular because to me, that is intuitive for good teaching that you are going to start and you are going to build upon that little by little, and that's a name that's been given to it recently, I suppose, but it's not a new idea in teaching to me… That learning progression type of thinking is what... I am starting my 28th year of teaching... it has evolved naturally that you think, okay where are my students at, where do I want them to go and what are the steps that I have to do to get there? And though I never used that vocabulary for that, I have thought that way for a while."* (Tanya, interview transcript)

She also noted that, because climate change has not been an existing part of the elementary or middle school curriculum, it will be challenging to anticipate the kinds of understandings on which students are building.

> *"What is a little difficult for us, since there is no formal curriculum in place for climate change anywhere along the line... I have no idea if they are going to know anything or nothing and for some, in the family or the home... they will be talking about it and have some knowledge but if they are not, they will have no knowledge… so it seems that a learning progression would have to be done along the grade levels. Right? ...You are only going to progress so far in one small unit in your class in 8th grade."* (Tanya, interview transcript)

Here, Tanya also provides an example of a concern, shared by other participants, about the timeframe for the stepwise advancement of student understanding inherent in learning progressions theory, and the kinds of advancement that teachers might expect to observe over the course of their interaction with students at a grade level. Tanya's interview illustrates an example of participants' thinking about the relationship between learning progressions and advancement of student understanding over time—in this case, conceptualized as the timeframe of the academic year.

“***Knowing where students are at*” [Assessing student understanding].** Just as most participants referenced notions of advancing student understanding with learning progressions, nearly as many related learning progressions with assessment *and “knowing where your students are at”* (Tanya, interview transcript), or pre-assessing students before instruction on a topic. Many teachers appeared to express constructivist ideas related to advancing student understanding – that is, a teacher must have an idea of students’ prior knowledge or *level of understanding* in order to be able to build on it. For the majority of teachers, then, the emphasis with assessment and learning progressions was on pre-assessment. A few teachers connected these pre-assessments to instructional planning, particularly, as useful for identifying gaps and for understanding how they would group students by level to differentiate instruction. Some teachers mentioned ongoing formative assessment, as well as summative assessment, as important for monitoring students’ changing levels of understanding, and for knowing whether students have met identified learning goals, or *“did what they were supposed to do”* (Jill, interview transcript).

A few teachers also mentioned student misconceptions or alternative conceptions. For these teachers, it appeared that they took a view of misconceptions as obstacles rather than stepping-stones to a more sophisticated level of understanding. For example, one experienced middle school teacher stated that it is important to *“be careful in that formative phase to really understand what the kids do and don't know, what they may have misconceptions about, before really, sort of, moving forward. Because you just end up causing more problems or, sort of missing things along the way if you don't do that”* (Mike, interview transcript). In this example, the teacher addresses misconceptions as ideas that must be acknowledged to prevent deepening students' non-normative conceptions, instead of leveraging what students know to achieve more normative and sophisticated understandings, the latter being the constructivist approach employed by many learning progressions.

Snapshot of participant thinking: Sandra. Sandra is an experienced high school science teacher. In discussing her thinking about how learning progressions might guide her teaching about climate change, she highlighted one of the Academy activities in which participants compared student data with descriptions of learning progression levels. She explained,

> *"What was really helpful for me was giving the children a set of questions to begin with and assigning a number that we can decide on beforehand and then keeping those questions and being able to retest and revisit those questions at the end and look at how many of our students have misconceptions and really don't have that much background because the learning progression has to start with a background. You can't just assume that they have it and that gives you a clear picture of where the students are in the classroom…"* (Sandra, interview transcript)

Like Tanya, Sandra warned against making assumptions about students' existing understandings related to climate change. She viewed a pre-post assessment strategy as helpful for first gaining understanding of students' prior knowledge and misconceptions, then identifying their initial level of understanding ("*assigning a number"*, as she did in the Academy activity comparing student data with levels of a learning progression), then retesting after instruction to assess change in students' levels of understanding. She emphasizes that the learning progression has to *"start with a background"*, possibly referencing the idea of a Lower Anchor of a learning progression, that acknowledges the understandings students bring to school. She expresses, however, the same concern as Tanya does: that students' background knowledge related to the topic of climate change will likely be limited. However, she viewed the information gained through assessment as beneficial for thinking about appropriate instructional strategies for moving forward. Sandra's case illustrates an example of the ways in which teachers linked learning progressions with assessment, especially gravitating toward the notion of diagnosing students' initial understandings and comparing them with later understandings. It was unclear in many cases, however, whether teachers envisioned themselves using research-based learning progressions as tools to inform this assessment process.

"*Knowing where you want students to go*" [Instructional planning]. In tandem with understanding *where students are at* came teachers' ideas about using learning progressions to understand *"where you want them to go"* (Charlotte, interview transcript), and subsequently, thinking about how to plan instruction to facilitate this progress. For example, one teacher spoke about using the highest level of the learning progression (the upper anchor) for guidance: *"Knowing the goal in mind… Okay, what is a four? That's where I'm trying to get to. And so, having that, you know, road mark in mind, just think okay… find out where we're at now and try and work our way there"* (Todd, interview transcript). Similarly, other teachers mentioned the use of learning progressions for working backwards in planning instruction or for identifying targets for learning. Here again, we noted discrepancies in teachers' thinking about timeframes associated with learning progressions, with some teachers appearing to frame the upper anchor of a learning progression as the end goal for one academic year. Other teachers conceptualized their instructional goals as getting students to "*a level above [where they are]"* (Chelsea, interview transcript), using phrases such as *"yearlong progression"* (Stacey, interview transcript) to think about the changes in student understanding they would hope to see over the course of an academic year.

Several teachers mentioned the Next Generation Science Standards performance expectations, or other standards documents, as useful for conceptualizing how students should progress over shorter timeframes, and how they might plan instruction accordingly. As one teacher stated, *"as soon as I looked at the… NGSS, and I saw that progression, I knew where to* *start, I knew where my beginning, middle and end was"* (Priscilla, interview transcript). This statement suggests that some teacher participants may have viewed standards and learning progressions serving the same function in describing the development of student understanding of constructs. However, while standards draw on canonical endpoints for each grade or grade band, learning progressions typically capture (canonical or noncanonical) stepping-stones along the way. In statements that related learning progressions to instructional planning, a number of teachers compared learning progressions to the notion of the spiral curriculum and the idea of returning to the same topics over time with an increasing level of sophistication. Related to this were several teachers' views that learning progressions theory underscores the importance of *"not throwing everything at students all at once"* (Diana, interview transcript), connecting back to the idea of stepwise advancement in understanding and the relationship of this idea to instructional planning.

Snapshot of participant thinking: Amy. In relating learning progressions to instructional planning, Amy, an experienced middle school science teacher, demonstrated evidence of thinking about learning progressions as supportive for identifying end goals for her teaching. She stated,

> *"I like to work backwards. I like to take the big picture and then work backwards. I think the learning progression does that. I think it is taking it and it's broken down throughout the lessons. I think that is the big thing, because you need to know what the big picture is. You have to know where your curriculum is and for the kids, take those baby steps."* (Amy, interview transcript)

Here, Amy expresses the idea of breaking topics down into manageable pieces throughout instruction, in order to advance student understanding over the course of curriculum implementation. In relating these ideas to her instruction on climate change, particularly the learning segment she was developing related to sea level rise, Amy stated,

> *"It has to build on and you have to make sure that they have that foundation before they move on to the next one. There's many layers to sea level rise. The progression... yeah, it's got to be planned out, it has to be broken down so that it all makes sense. One step builds on the next."* (Amy, interview transcript)

This statement shows Amy's view of sea level rise as a complex topic and the need for it to be presented strategically in order to promote student understanding. It appears here that she is conceptualizing a progression of instruction that would be "planned out" and "broken down" in order to advance student understanding of the topic. Like many participants, Amy's developing understanding of learning progressions engaged her in thinking about where to begin with her instruction, her end goals, and the steps students might take along the way. As she explicates her ideas for instructional planning, however, it appears that she may be blending ideas about curriculum standards, her understanding of learning progressions, and the progress in understanding that students will make through engagement in the planned learning activities.

"***Meeting students' diverse needs*" [Instructional supports].** The final concept that emerged as teachers discussed learning progressions as potentially informative to their teaching about climate change was the notion of instructional support, particularly, learning progressions as informing the ways in which they would differentiate instruction and scaffold student learning. Seven of the teachers specifically mentioned scaffolding student learning, even though this idea was not emphasized in the learning progressions professional development sessions. Similar to the connections they made to existing understandings of constructivist learning theory in the Advancing Student Understanding (*"Students should progress"*) concept, these teachers viewed teaching guided by learning progressions as aligned with their existing theories of teaching practice. As one teacher stated, *"I don't know if they** (we interpret "they" as "experts in the learning sciences" or "learning progressions experts") *specifically call it that, but when you* *help students get from one place to another and you slowly move the supports away, they* (here, we interpret "they" as people in the teaching community) *call that scaffolding. So, I don't know if they have given it that name but that is sort of what we have done automatically, I think"* (Tanya, interview transcript).

In envisioning their own instructional roles in advancing student understanding, scaffolding was an accessible way for participants to conceptualize how they would support students in getting to the next level, however they often did not specify how they envisioned themselves scaffolding students' understandings. Another frequent theme related to instructional support was the use of learning progressions for informing differentiated instruction, particularly for using pre-assessments to identify "where students are at" and then meeting their diverse needs accordingly. Several teachers spoke about students coming to the classroom with different kinds of background knowledge, moving into the language of *different levels* for describing this variety. They saw the leveling associated with learning progressions as helpful for thinking about meeting the diverse learning needs of students in their classroom in order for all to advance to a more sophisticated understanding.

Snapshot of participant thinking: Todd. Todd, a middle school science teacher, discussed learning progressions as useful for helping him to think about differentiating instruction. He stated,

> *"Just like in all learning… people are in different places as far as what their understandings are on any given topic and it's important for us as educators to not just, you know, start at same, that not everybody is going to be ready to start at the same point… So to do some sort of a pre-assessment to understand where our students are in their progression of learning related to that topic. Once we understand what that is then we can differentiate our instruction in order to meet their needs."* (Todd, interview transcript)

In this example, Todd talks about not only knowing "where students are at" in order to make decisions about differentiating instruction, but also appears to possibly conceptualize learning progressions as unique to each ("where students are in their progression of learning") instead of as empirically-based tools based on a larger body of student data. In turning to climate change education specifically, Todd states,

> *"I guess for the idea of learning progressions, it's a little bit redundant but, just in the same idea that people are going to have a different starting point as far as, both their views on climate change, and also their knowledge about what's influencing climate change."* (Todd, interview transcript)

Here, Todd adds an additional layer to the idea of students "being at different places", in considering not only their scientific understandings, but also their "views on climate change". This may relate not only to students' potential skepticism of climate change as a real phenomenon (likely linked to their scientific understandings), but also their opinions about the urgency of the issue or what should be done. It is possible, from Todd's perspective, that instruction for students coming from different "views" (or opinions) might need to be approached strategically, just as instruction for students entering the classroom with different levels of scientific understandings.

An idea that Todd and the other teachers did not appear to consider related to students' diverse levels of understanding is the notion that students may take different pathways as they advance their understandings. An aspect of learning progressions research that teachers, or the activities presented in the Academy, may not have emphasized sufficiently, is the enterprise of charting the different pathways, or stepping stones, that students may take toward a more sophisticated level of understanding science constructs. As suggested by Todd's recognition of students' varying starting points and his emphasis differentiated instruction, teachers appeared to recognize the diverse needs of their students. It was unclear in many cases, however, how teachers clearly envisioned themselves using learning progressions as a tool to inform the support the ways in which they offered students support.

An outlier story: Katherine. Between Phase 2 (coding) and Phase 3 (re-coding into concepts), we eliminated two infrequently used codes from our initial coding scheme. The first encompassed the notion of learning progressions being unique to students or "belonging" to them, as embodied in the first statement from Todd above. Only one other teacher's interview provided evidence of thinking about learning progressions in this way. The other code that was very infrequently used, warranting discussion, related to evidence of teachers' understanding of learning progressions as empirically-based tools. We noted just one teacher, Katherine, who appeared to incorporate this idea into her thinking about learning progressions and their utility for guiding instruction around climate change. Interestingly, Katherine was one of the teachers who stated explicitly that learning progressions were "not any different from anything we have done before" and were like scaffolding, stating:

> *"Well I guess, through this Academy, I was introduced to this new term of learning progressions. It's kind of a new term for me because I am kind of an old teacher. But it's not any different from anything we have done before; it is like scaffolding. For years we have sort of scaffolded kids' understandings so that they are able to think more clearly on their own or make decisions on their own. I can't think of any other word."* (Katherine, interview transcript)

However, she later articulated how learning progressions were a new and different approach to theorizing about learning, especially with regard to their empirical nature. She stated,

> *"It is a little more systematic than we have probably been education in the past. With the data collection, with what kids exactly are saying and then sort of sorting that into the different levels of the learning progression, as knowledge becomes more sophisticated."* (Katherine, interview transcript)

> *"I like the process they used to design their learning progression. How they had collected data from children first and really tried to analyze their thinking and then made learning progressions from there. I think that as teachers, we don't do that enough. We don't have groups of teachers get together and analyze students' responses."* (Katherine, interview transcript)

Here, Katherine provides evidence of a developing understanding not only of learning progressions as empirical, researched-based tools, but also of how teachers might blend their educator perspectives with a researcher perspective in order to systematically analyze student thinking, using these understandings to inform instructional decisions.

Table 7. Organizing concepts for interview data

Concept	Description	Components included from initial coding scheme
"Students should progress" [Advancing student understanding]	Participants related learning progressions with advancing students' understanding of climate change concepts	1. Concrete to abstract, 2. Growth over time, 5. Stepwise or continuum, 9. Building on students' knowledge, 13. Advancing student understanding
"Knowing where students are at" [Assessing student understanding[	Participants related learning progressions to assessment of students' current levels of understanding, possibly including their misconceptions	10. Assessing "where students are at", 12. Understanding misconceptions
"Knowing where students are going" [Instructional planning]	Participants discussed how learning progressions can inform instructional planning, conceptualized over various timeframes	4. Break topics down, 7. Curricular sequencing or spiral curriculum, 14. Identify targets or goals for learning
"Meeting students' diverse needs" [Instructional supports]	Participants discussed how learning progressions can inform how educators support students in advancing their understandings of climate change concepts	8. Scaffolding, 11. Differentiated instruction

Teaching About Sea Level Rise as a Regional Observation of Climate Change

Following a similar data analysis process as previously described related to participants' understandings of learning progressions, we conducted a secondary analysis of the interview data to gain insight into participants' views of teaching about climate change using a regional observations approach. That is, we sought insight into the ways in which participants responded to the possible pedagogical applications of the local relevance of sea level rise, the central construct of the new learning progression introduced in the professional development academy. After the pre-coding process, in which we identified relevant units of interview data and developed an initial coding scheme, we coded our data using 13 initial codes (see Appendix, Table 8). We reviewed the coded data, collapsing the codes into three key concepts (Table 9), and then interpreted the data. Because our semi-structured interview protocol did not include a question explicitly asking about participants' views of sea level rise as locally relevant, eight participants did not address the idea in their interviews. The data we analyzed came from the 19 participants whose interviews did address sea level rise as a regional observation of climate change, and related implications for their science teaching.

Sea level rise as geographically relevant. All participants in the Academy came from Delaware and Maryland, but from geographically diverse communities within them. When addressing the local relevance of sea level rise for their students, many referenced the geography and topography of the communities in which they taught. Some participants who worked in coastal communities viewed sea level rise as a highly relevant issue for their students, such as one participant who stated,

> *"Because of where I live and where my students live, it is definitely locally relevant. Most of my kids live within five miles of the beach."* (Priscilla, interview transcript)

Statements varied from participants who did not teach within close proximity the coast. Some did not believe their students would see sea level rise as relevant to their lives. As one participant noted,

> *"You have to understand one thing, I'm not dealing with sea level rise. It's very valuable but I teach in [the north of the] state. You might have heard someone make the comment that you couldn't flood Philadephia if they tried. It's not meaningful to my students. They don't go down to the beach."* (Nancy, interview transcript)

Others took a view that sea level rise was relevant because it had impacts for the state or the watershed, if not for the immediate community. An example of this view came from one participant who stated,

> *"[For] Maryland and Delaware, it is so relevant. We are all in the same watershed and all have the same bodies of water around us. The kids, even our Baltimore city kids have an understanding of the water because the Inner Harbor is right there."* (Carrie, interview transcript)

In considering the idea of regional observations of climate change, several participants raised additional impacts they saw as equally or more relevant to their students than sea level rise because of their geographic locations, including the urban heat island effect, extreme weather events, biodiversity issues, human health issues, droughts, and flooding.

Impacts of sea level rise on students' lives. Linked to geography was the notion of students' past and future experiences being personally affected by the impacts of sea level rise. As in the geography theme, some participants who taught in coastal communities believed that sea level rise would be relevant to students because they are witness to it. One participant discussed the observably rapid rate of sea level change compounded by land subsidence in some coastal areas:

> *"I came from the Eastern shore… They are definitely sinking and those watermen's kids know there is change in a big way."* (Priscilla, interview transcript)

Other participants mentioned students' prior experiences dealing with flooding and storm surge. A middle school teacher from a coastal community stated,

> *"My kids are going to have some idea of sea level rise because… they are first hand observers of sea level rise, being sent home early from school, storms flooding the roads. Roads were just flooded last week, kids are kayaking down the street."* (Katherine, interview transcript)

A teacher from an urban area similarly noted,

> *"My kids… see the effects of sea level rise and climate change all the time, they flooded for Sandy, they flooded, like for Isabel, we flooded for something else recently. So it's definitely something that they see, they know it is happening to them. So I think it will be of great interest to them."* (Lindsay, interview transcript)

In addition to such already-experienced impacts, several participants mentioned potential future impacts of sea level rise that make the issue especially relevant to their students. Some talked about the ways that sea level rise could affect recreational activities that are important to their students, such as visits to the beach. As one teacher described,

> *"We do have a lot of kids who are involved in both hunting and, they're very ecologically aware and really do care about wildlife and understanding it, and some of that is because they're hunters so they understand what is the animal that they're hunting need… So I think since sea level would really mess up… sea level rise would ruin those habitats that matter to them. You know, they would have to find new hobbies. And as an eighth grade student, that matters."* (Todd, interview transcript)

Other participants mentioned future agricultural impacts, and the economic implications of those for students whose families are involved in agriculture.

> *"I am in a very poor, rural district and last year we had almost no rain and the crops failed and this year they are flooded. Even now, when I left there was standing water on the fields and the kids have to understand about global warming...so they are going to have to make some decisions that may help their families and the community survive there. You have to make it personal to them or it is a hard sell."* (Jennifer, interview transcript).

Other participants echoed the notion of sea level rise as relevant to their students because they would be responsible for decisions about it in the future. One participant viewed her students' tendency to think more about the present than the future as a potential challenge in teaching about sea level rise, but the need for raising their awareness supported her rationale for teaching it:

> *"I know that our kids, being the age that they are, can't see next week, much less ten years down the road. The more we help them see long term implications, the more we help them to see [the importance of] fact based decision making… These guys are going*

> *to be our future leaders... we [adults] are not going to be solving this problem… cause we are going to be dead."* (Priscilla, interview transcript)

As participants elaborated the past and future impacts that would make sea level rise particularly relevant to their students, they generally linked this personal relevance to increased student interest, care, or concern about the issue. One teacher from a coastal area, however, made a connection between felt impacts and learning. Having collaborated with a teacher from another part of the state on the development of her learning segment, she posited different levels of understanding linked to students' diverse experiences with sea level rise:

> *"[My students] are first hand experiencing, it which will be different from what her kids will have, so my kids may come in at a higher learning progressions [level] from the kids in north Delaware…".* (Katherine, interview transcript)

As this statement suggests, participants' discussions about the relevance of sea level rise for their students frequently led to anticipation about what they might experience in their classrooms. They often considered the strategies they would use to teach about the sea level rise in ways that would be meaningful for their students.

Sea level rise as an organizing instructional theme. The final concept that emerged from the data encompassed participants' ideas about teaching sea level rise as a locally-relevant impact of climate change. This included their ideas for pedagogical innovation, finding linkages to the curriculum, and addressing potential challenges to related to teaching about sea level rise. Several participants discussed their ideas for bringing students outdoors to investigate the topic of sea level rise, especially as components of units they were already teaching about the Chesapeake Bay. As two of the participants described,

> *"I can see how this is going to fit all year long and become an overarching theme which blends in well with our goals as we are a green school, we are on one of the last tributaries to the Chesapeake Bay, we do water testing, it is what we do and we have an*

> *ecological green school culture throughout our curriculum so this is just icing on the cake."* (Paula, interview transcript)

> *"They just opened a new exhibit at the aquarium dealing with the coral reef so we can bring that in and along with the Chesapeake bay... the kids, they remember things more if you keep it local, bring in hands on activities, they are going to remember it longer."* (Diana, interview transcript)

Other participants talked about how they would use technology, such as interactive maps of local sea level rise projections, to teach about the regional impacts of sea level rise:

> *"My favorite part… I think it was the Surging Seas website, that was so cool, because you can see, even like in Dover, which is up in the middle of the state, not really next to the beach, you can see how that flooding is going to really affect that area too."* (Charlotte, interview transcript)

In discussing the teaching of sea level rise as a regional observation of climate change, participants also raised concerns about potential challenges. Because curricula in Delaware and Maryland had not yet incorporated the Next Generation Science Standards, explicit focus on the topic of climate change was limited for most participants. Teaching about sea level rise became a matter of discerning how to fit the topic in with existing requirements. As one teacher described:

> *"I have got to figure out a way to make a connection and offshoot from a main trunk of what I am required to do in the curriculum."* (Whitney, interview transcript)

Some participants also discussed logistical challenges for teaching about sea level rise through the experiential approaches they would hope to use:

> *"You know when you think outdoors you gotta get there. So then you got a field trip so then you are in a middle school doing multi-classes, different teachers, it has just become a logistical and financial issue of how we are gonna get students to these spots so they can really get hands on..."* (Whitney, interview transcript)

Only one participant raised a concern about the potentially sensitive nature of the topic itself, though it did not dissuade her from planning to teach it:

> *"I'm a little nervous with the whole, you know, debate, and the people who are out there saying, you know, it's not true or whatever, but I think it will be interesting for the kids."* (Karen, interview transcript)

These three concepts – geographical relevance, felt impacts, and teaching through regional observations - help to illuminate the ways in which participants responded to the regional observations approach to climate change education introduced in the professional development academy. Their views of sea level rise as a worthwhile and relevant issue may have important linkages to their use of the sea level rise learning progression as a tool to support their teaching.

Table 9. Organizing concepts for interview data – Regional observations approach

Concept	Description	Components included from initial coding scheme
Sea level rise as geographically relevant	When addressing the local relevance of sea level rise for their students, participants reference the geography or topography of the communities in which they teach.	Proximity, Elevation, Other issues, Not relevant
Impacts of sea level rise in students' lives	When addressing the relevance of sea level rise, participants mention students' past and future experiences being personally affected by the impacts of sea level rise.	Firsthand knowledge, Economics, Agriculture, Recreation, Long-term, Future problem solving
Sea level rise as an organizing instructional theme	When addressing the relevance of sea level rise, participants discuss their ideas about teaching sea level rise as a locally-relevant impact of climate change.	Controversial, curricular issues, local observations

Discussion

Our findings provided important new insights and suggested fruitful future areas to explore related to our research questions: 1) How did participants evolve in their understandings of climate change through participation in the professional development academy? and 2) How did participants understand learning progressions as potentially informative for their science teaching practices related to climate change, particularly its regionally-relevant aspects?

Understandings of Climate Change

Our findings are supported by our empirical data and linked to prior literature. Research related to climate change education provides evidence that educators can advance their understandings of climate science through quality professional development experiences. Lambert et al.'s (2012) work – that utilized a version of the CSKI assessment – demonstrated that participants increased their knowledge of climate change after a climate change-infused methods course. Similarly, our own prior research demonstrated that even short-term interventions can help improve teachers' understanding of the topic (McGinnis et al., (2011), Hestness et al. (2011)). Based on data collected during the Summer Academy we find it of worth heuristically to place participants broadly in three categories regarding consideration of their levels of content understanding related to climate science: participants who increased their disciplinary core ideas considerably through the professional development (like the focal participant, Karen - approximately 37% of participants), those who entered the Academy with a highly developed level of understanding of climate science and changed minimally (like the focal participant Mike - approximately 22% of participants), and those who entered the Academy with gaps in their understandings of climate science, but did not show evidence of change based on comparison of measurements from pre-Academy to post-Academy (like the focal participant Amy - approximately 22% of participants). The remaining 19% of participants fell in between these categories, generally starting with an intermediate level of content understanding, and increasing to various degrees.

For many, like Karen, a pre-service teacher, learning disciplinary core ideas in climate science was a valuable component of the Summer Academy. Karen advanced appreciably from a score of 7.5 (pre) to 12 (post). In addition, her post Academy responses to open-ended questions were more detailed than in the pre administration of the CSKI. In her interview she indicated that she did not have a developed understanding about climate change and that the information "*hit me like a ton of bricks*." Karen, and other participants like her, benefited from content-based professional development. Research suggests that it is common for teachers to hold alternate conceptions of climate change constructs (Ekborg & Areskoug, 2006). For these participants, content knowledge development was an important component of the professional development experience.

In contrast to Karen, Mike entered the Summer Academy with a more robust understanding of climate change science and scored at the top of the CSKI. While he did add additional detail on open-ended items in the post administration, the change was minimal. For participants like Mike, it was not possible to measure gains in climate content knowledge since they scored at the top of range. In his interview, he speaks about the Climate Science Academy in terms of reinforcing his pedagogical to climate change that consists of representing to his learners that science is defined by its core practices. For him the professional development experience was more about improving his teaching in the Core Practices of the NGSS than about learning climate science Disciplinary Core Ideas

Finally, for a few participants such as Amy, who came to the Academy with a relatively low understanding of climate science, there was little or no improvement in their Disciplinary Core Ideas of climate science. Although our instrumentation indicated there was room to forw in understanding of climate science, none occurred as measured by the CSKI. In her interview Amy stated she had "*a few misconceptions*" about climate change. Although Amy recognized that she had room to improve, the CSKI did not indicate change. For Amy, and a few others who did not increase their content knowledge even though the CSKI indicated gaps, further research is needed to understand the factors contributing to a lack of conceptual growth in Disciplinary Core Ideas in climate science.

These findings indicate that participants may enter professional development with widely differing climate change content knowledge. This has implications for the design of professional development experiences that can support all participants in enhancing their science content knowledge. As Hill (2009) suggested, rather than "one size fits all" (p. 475) learning opportunities, professional development should link educators' specific learning needs with opportunities most likely to address those needs. In the future, providing professional development opportunities - possibly via online learning experiences prior to the Academy - with an emphasis on content in which educators indicate a need for support, could be effective and allow them to focus more on teaching climate change when they enter the in-person Academy experience.

For educators who already possess higher levels of content knowledge, it is likely that Disciplinary Core Ideas-focused professional development will be of minimal value. Instead it would be more effective to provide opportunities for them to apply their existing knowledge in collaboration with other educators with a focus on planning and preparing to teach about climate change in their own classrooms.

Finally, for some educators there may be a lack of motivation, awareness, or perhaps resistance to the need to build their Disciplinary Cores Ideas in climate science. This presents a challenge. While it may be possible to bring the issue to their attention using an instrument like the CSKI, unless they are motivated to address the issue, there is little that can be done. However, more research is needed to understand what types of professional development activities will motivate and lead to increased knowledge of climate change science.

Understandings of Learning Progressions and the Use of a Regional Observations Approach to Teaching About Climate Change

Our analysis of the interview data illuminated several areas of overlap with prior literature, as well as several new insights, on educators' understanding of learning progressions and their applicability to the their science teaching practice related to climate change. It also highlighted the potential challenges and benefits of our strategy of introducing learning progressions to educators using a regional observations approach.

Learning Progressions. Consistent with prior literature on teachers' understanding and use of learning progressions, participants in the professional development academy appeared to view learning progressions as potentially useful for understanding student thinking. This was especially apparent in our findings within the Advancing Student Understanding *("Students should progress")* and Assessing Student Understanding *("Knowing where students are at")* concepts. The idea of *advancing student understanding* clearly resonated with participants, and most participants conceptualized assessment as a critical connection between student thinking and learning progressions. They emphasized the importance of "knowing where students are at" and monitoring their changing levels of understanding over time. In accordance with the suggestion by Corcoran et al. (2009), we presented participants with an assessment tool based on the draft hypothesized sea level rise learning progression shared in the Academy (see items at http://www.climateedresearch.org/publications/2012/SLR-LP.pdf). Participants' work with this tool, and other assessment-focused activities included in the Academy, may have influenced the ways in which they began to associate assessment, student thinking, and the utility of learning progressions. For example, during the Academy, participants engaged in an activity that some noted in as particularly beneficial. In the activity, based on Mohan, Chen, and Anderson's (2009) work on learning progressions and carbon cycling, participants examined student data and used it to locate students on a trajectory specified by a learning progression. As Sandra described: *"What was really helpful for me was giving the children a set of questions to begin with and assigning a number that we can decide on beforehand"* (Sandra, interview transcript). As Furtak (2012) noted, if teachers can locate students on a trajectory specified by a learning progression in this way, they may be able to adjust their instruction to optimize student learning.

Our research highlights several new insights about educators' ideas related to learning progressions and student thinking. First, as we noted in the Advancing Student Understanding concept, participants appeared to be comfortable with the idea of students' increasingly sophisticated levels of understanding, and many readily adopted the language associated with work in learning progressions, such as "levels of understanding" (as one teacher stated about her own understanding of climate change, *"I was pretty 'Level 2' coming in"* (Betty, interview transcript)). The analogy of learning to ride a bike and the four images depicting increasingly sophisticated levels, which we presented early in the Academy, appeared to serve as a useful analogy for introducing learning progressions to science educators. Because the concept of learning progressions is presently unfamiliar to almost all educators, this analogy – though admittedly imperfect for capturing all of the nuances of learning progressions – could be a beneficial starting place for professional development activities around learning progressions. Second, related to learning progressions as a new concept to most educators, we noted that many blended them with existing theories of teaching and learning. For example, many participants made connections between learning progressions and building on prior knowledge in constructivist instruction. While some of these connections to existing theories of learning may have been beneficial for building participants' understanding, others – such as conflating learning progressions with the concept of the spiral curriculum - may have limited the ways in which they were able to conceptualize learning progressions as a new way of thinking about student learning. This suggests that professional development around learning progressions could benefit from explicating the similarities and differences between learning progressions and other theories of learning and teaching that are typically familiar to educators.

New insights also emerged about participants' ideas related to learning progressions and assessment. Linkages between learning progressions and assessment were logical for participants, and many spoke about the importance of formative and summative assessment as integral pieces of using learning progressions to guide their teaching. In particular, the Academy activity in which participants examined sample statements from students and diagnosed their thinking using levels derived from an empirically validated learning progression appeared to inform the ideas teacher held about the connections between formative assessment and learning progressions. However, similar to the ways in which they conflated learning progressions with their existing theories of learning, the extent to which teachers conceptualized assessment informed by learning progressions as anything new was sometimes confused. While participants did not explicitly emphasize "debunking" alternative conceptions as was reported by (Furtak, 2012), we did not find evidence of their intention to leverage alternative conceptions to achieve more sophisticated understandings. This suggests that educators may benefit in particular from support in recognizing and leveraging students' alternative conceptions as stepping-stones to a more advanced understanding.

Evidence was also limited around how or whether participants envisioned themselves using research-based learning progressions as tools to inform assessment process. We noted one exception in Katherine, who spoke about the relationship between student data and learning progressions, and the potential value of having "*groups of teachers get together [to] analyze students' responses"* (Katherine, interview transcript). This raised questions around how professional development related to learning progressions might better emphasize the empirical nature of learning progressions that Katherine was beginning to recognize, and present this ideas in ways that educators see as useful to their teaching practice. A possible suggestion might be that professional development on learning progressions should include opportunities for educators to practice using assessment tools based on learning progressions, especially tools aligned with the National Research Council's guidelines for NGSS assessments (NRC, in press), and consider ways they can integrate such tools into their classroom assessment practices.

Finally, we gained new understandings of the ways in which science educators think about learning progression as informative to their instructional practices – both in terms of instructional planning and in providing instructional support to students. Similar to the ways in which they conflated learning progressions with existing theories of learning, they sometimes conflated learning progressions with existing ideas about instruction. For example, the notion of advancing students from one level to another invoked connections to scaffolding. Participants also made comparisons between learning progressions and backwards planning or the spiral curriculum.

In some cases, these connections may serve educators well in thinking about how they could productively use learning progressions to inform their instruction. In other cases, consideration of learning progressions as similar to existing theories could prevent educators from thinking about their instruction in new ways. It could also lead to unrealistic expectations about student learning – for example, some participants viewed the Upper Anchor of the learning progression as their “end goal” for instruction over a relatively short time period of classroom instruction (to be achieved as quickly as over a two- or three-week instructional unit) rather than a goal to be achieved over years of schooling. We noted that participants were generally inclined to think along the timeframe of a unit or an academic year, rather than on the longer multi-year timeframes typically embodied by learning progressions. Professional development around learning progressions should strongly emphasize this distinction. We learned that it would also be beneficial to clearly articulate the similarities and differences between standards that teachers as expected to address, such as the NGSS and perhaps the Common Core State Standards, and the levels of understanding of science constructs articulated within learning progressions. We believe that educators will benefit from considering the distinct ways in which each of these can help to inform their instruction.

In summary, our data suggest then that the professional development experience provided educators with new ideas, radical in their depth and application, about how to assess and respond to student thinking, and an initial understanding of how learning progressions might inform this process. However, we suggest that participants could benefit from additional support over significant time in applying learning progressions to their teaching practice. In this way, our research supports the work of Furtak and Morrison (2013), that emphasized the need for communicating ideas about learning progressions to teachers in ways that will best support them in enhancing their teaching practice.

Regional Observations. A unique aspect of our learning progressions research was our use of a regional observations approach. We introduced participants to the idea of learning progressions by sharing with them our work on designing a draft hypothesized learning progression on sea level rise, a climate change impact that the National Climate Assessment (NCADAC, 2013) identified as being of particular regional relevance. We noted a number of benefits to this approach. First, presentations by content experts on regional issues related to sea level rise, in tandem with the introduction to learning progressions through the concept of sea level rise, introduced participants to new understandings of Disciplinary Core Ideas in climate science, as well as new ways of thinking about science teaching and learning. Interviews with participants provided evidence of a generally positive response to the Academy focus on the notion of a regionally-relevant issue (although a few suggested differing regional observations may be of more relevance to their particular students, especially those in urban areas away from the coast), and participants were generally open to designing and implementing learning segments for classroom use incorporating the concept of sea level rise. Many participants viewed sea level rise as highly relevant to their students, and of interest to them because of its current or potential impacts on students' lives and communities. And finally, participants had ideas about how to integrate regional observations into their teaching, including through the use of outdoor and online investigations of sea level rise projections and impacts for their geographic regions. Considering these findings, we interpreted the regional observations approach for introducing learning progressions as beneficial for participating educators.

The regional observations approach for introducing learning progressions also, however, presented a number of challenges. From the participants' perspective, not all of the educators – despite being from the same general geographic region – considered sea level rise as relevant to their students. For example, as one participant stated,*"You have to understand one thing, I'm not dealing with sea level rise... It's not meaningful to my students. They don't go down to the* *beach."* (Nancy, interview transcript). In considering future use of the regional observations approach in professional development, this raises questions around how to select topics that will appeal to all. Or, it suggests to a greater degree the potential benefit of providing educators with more regional observations options during such professional development experiences in climate change education. For example, we posited early on in planning for our project that teachers situated in urban and suburban contexts away from the coastal area might find oother National Climate Assessment-identified regional observations for Delaware and Maryland of more relevance, such as the urban heat island effect and extreme weather (NCADAC, 2013). However, due to lack of planning time to prepare new materials for such various options beyond sea level rise, and our primary need to test the concept of modeling a regional observations perspective to climate change education, we decided on only using sea level rise as our one regional observation option in the Academy. Another concern for participants related to the regional observations approach was the perennial issue of "fitting it in" to the existing curriculum if they were not already teaching the topics of climate change and its impacts on the environment. While this is a genuine challenge presently, perhaps it will be remedied to some degree in coming years as Delaware and Maryland adapt their science curricula to align with the NGSS, that includes climate change as an explicit topic.

From our perspectives as researchers, a challenge was discerning how or to what extent participants were prepared to relate the regional observations approach with student learning. At times, it was difficult to pinpoint how the introduction of a learning progression on sea level rise may have influenced participants' thinking about how they would use learning progressions to teach about climate change. While many participants generally thought sea level rise would be useful for engaging students' interest, only one participant conjectured that students' particular experiences within the local region could be an asset to support their learning about a regionally-relevant topic. Moving forward, we see regional observations as a promising approach to introducing learning progressions to educators, however more research is needed regarding the ways in which to make more strategic and coherent connections between the regional observation construct itself and how learning progressions can inform teaching and learning around the construct.

Limitations

Our research provided new insights on science educators' engagement in professional development related to climate change and their introduction to learning progressions. However, we note several potential limitations of our study. One limitation was the short timeframe of our professional development and data collection – a one-week professional development academy - and the limited amount of time participants had to engage in the science and pedagogical content presented. It is possible that a longer professional development experience would have shown a greater level of change in both participants' Disciplinary Core Ideas, Science Core Practices, and Cross Cutting Concepts related to climate change education *and* their understandings of learning progressions. Another limitation related to our decision to use a pre-developed instrument, the CSKI, to measure participants' Disciplinary Core Ideas of climate science. While there were benefits to the use of an established, research-based tool, it is possible that participants would have scored differently on an assessment tool with items even more precisely aligned with the content presented in the Academy. Related to participants' understandings of learning progressions and their classroom teaching of climate change, at this time we present data only from participant interviews. In the future we plan to report how the teachers in our study implemented climate change education in their classrooms by analysis of the learning segments that they taught.

Future Research Directions

From this examination of educators' experiences engaging in a learning sciences-integrated professional development academy on climate change education, we note several key areas for future inquiry. Future research might investigate the types of professional development activities that will motivate and lead to increased understanding of Disciplinary Core Ideas in climate science for teachers with diverse levels of background knowledge. With regard to teachers' understandings of learning progressions, future research should continue to explore the ways in which learning progressions can best be presented in teacher professional development. Such approaches might focus on concrete pedagogical strategies and assessment tools based on learning progressions that teachers can use in the classroom. Finally, while we noted that teachers responded positively to a focus on a regionally-relevant impact of climate change, future research should examine the ways in which participants make decisions on including regional observations in their teaching of climate change, including which regional observations they select and how they integrate them into instruction on climate change.

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Appendix

Table 2. Middle school performance standards explicitly related to climate change

Code	Standard	Clarification Statement & Assessment Boundary
MS-ESS3-5	Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.	Examples of factors include human activities (such as fossil fuel combustion, cement production, and agricultural activity) and natural processes (such as changes in incoming solar radiation or volcanic activity). Examples of evidence can include tables, graphs, and maps of global and regional temperatures, atmospheric levels of gases such as carbon dioxide and methane, and the rates of human activities. Emphasis is on the major role that human activities play in causing the rise in global temperatures.

Table 3. High school performance standards explicitly related to climate change

Code	Standard	Clarification Statement & Assessment Boundary
HS-ESS3-1	Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.	Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards can be from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting and soil erosion), and severe weather (such as hurricanes, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.
HS-ESS2-4	Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.	Examples of the causes of climate change differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition. Assessment of the results of changes in climate is limited to changes in surface temperatures, precipitation patterns, glacial ice volumes, sea levels, and biosphere distribution.

HS-ESS3-4	Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.	Examples of data on the impacts of human activities could include the quantities and types of pollutants released, changes to biomass and species diversity, or areal changes in land surface use (such as for urban development, agriculture and livestock, or surface mining). Examples for limiting future impacts could range from local efforts (such as reducing, reusing, and recycling resources) to large-scale geoengineering design solutions (such as altering global temperatures by making large changes to the atmosphere or ocean).
HS-ESS3-5	Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.	Examples of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (such as on sea level, glacial ice volumes, or atmosphere and ocean composition). Assessment is limited to one example of a climate change and its associated impacts.

Table 5. Preliminary codes for interview data - *Nature of learning progressions* code family

Code	Description	Example
1. Concrete to abstract	Participant discussed LPs as moving from a concrete to an abstract – or less sophisticated to more sophisticated – understanding of a construct	• *"I understood it as, or I assimilated it with what I already knew probably the same way as most people as assessing background knowledge, having a social context, discussing that with their neighbors, putting their hands on, finding the baseline and doing some guided practice* ***moving from concrete to more abstract*** *and then independent practice and then mastery."* • *I like the way she defined what a learning progression is and how it's an* ***increasingly sophisticated way of knowing.***
2. Growth over time	Participant discussed LPs as relating to students' growth (i.e. greater	• *"I like the idea of progression more than I like the standards because progression, just by choice of words,* ***gives you the idea that there is growth over time"***

	understanding of a topic) over a timeframe; assumed timeframes can vary (1 year, K-12 experience)	• *Then, learning progressions, it's* ***going to be seen over tim****e that's why it's a progression, so you will* ***see it as the year develops*** *with the student.* • *I like the way she defined what a learning progression is and how it's an increasingly sophisticated way of knowing. I like being able to think about,* ***not just how that happens throughout a student's academic career, but within my class by itself.***
3. Belonging to students	Participants discussed LPs as something students have	• *"I think having learning progression****, if the kids come to you with a coherent set of them****…"* • *Understand where our students are* ***in their progression of learning*** *related to that topic.*
4. Break topics down	Participants discussed LPs as a way to break topics down into smaller pieces, not trying to teach everything at once	• *"Just the idea that* ***you don't want to throw everything at students all at once****,"* • *I guess it just made me think about not teaching one concept all at once and then being done with it and moving on to the next thing but more of thinking...*
5. Stepwise or continuum	Participants discussed LPs as moving from one step or level to the next; describe learning as a continuum	• *I want them to learn something but [in the past] I wouldn't think of it as a continuum, you know****, learning about a topic in terms of a continuum****. I just never really thought of it that way. That is the general thing I got out of that.* • *see where your students are at and then* ***decide how you are going to help them progress step by step*** *to gain a more sophisticated understanding of the topic.* • *And just a general understanding, which I feel like we do anyway, is understanding that students learn in levels.*
6. Empirically based	Participants described LPs as based on empirical data from students	• *I like the process they used to design their learning progression. How* ***they had collected data from children first and really tried to analyze their thinking*** *and then made learning progressions from there. I think that as teachers, we don't do that enough. We don't have groups of teachers get together and analyze students' responses.*

7. Curricular sequencing or spiral curriculum	Participants described LPs as similar to curricular or topical sequencing, or the notion of the spiral curriculum	• *and as you **go from progression to progression** you are adding on more information that you expect students to learn and to grasp*
8. Scaffolding	Participants described LPs as similar to or the same as scaffolding	• *I don't know if they specifically call it that but when you help students get from one place to another and you slowly move the supports away, they call that scaffolding. So, I don't know if they have given it that name but that is sort of what we have done automatically I think.* • *"Well I guess, through this Academy, I was introduced to this new term of learning progressions, its kind of a new term for me because I am kind of an old teacher. But it's not any different from anything we have done before, it is like scaffolding.* • *I don't know, we, like we don't call them learning progressions, I guess we just, like just call it scaffolding.*

Table 6. Preliminary codes for interview data - *Utility of learning progressions* code family

Code	Description	Example
9. Building on students' knowledge	Participants described LPs as helping to build on students knowledge of a topic; references to constructing understandings	• *"Probably a combination of what she was presenting and even just where we come from is that **you have to build on any topic,** a lot of the students in our district, I think there is very little that they know about climate change, its not really something that we have addressed to any extent, we do the very basic weather vs. climate, so looking at this, if I had to say most of our kids are at a lower level right now as far as understanding and climate."* • "*I don't really think I learned anything in particular because to me, that is intuitive for good teaching that you are going to start and you are going to build upon that little by little and that's a name that's been given to it recently I suppose but it's not*

		a new idea in teaching to me." • *I guess I learned that they can help you to build on what your students know*
10. Assessing "where students are at"	Participants described LPs as useful for assessing students' baseline or prior knowledge; knowing "where students are at"	• *"So I like the learning progressions, I would like to see them* ***used as a formative diagnostic: what do you already know****, pretest kind of thing."*
11. Differentiated instruction	Participants described LPs as informing how they would differentiate their instruction; individualization	• *So to do some sort of a pre assessment to understand where our students are in their progression of learning related to that topic. Once we understand what that is* ***then we can differentiate our instruction*** *in order to meet their needs.* • *the learning progression allows us to sort of group them differently* ***and look at them more as individual learners,*** *or a group of learners, at a place rather than trying to, trying to put them on a different scale,*
12. Understanding misconceptions	Participants described LPs as helping them to diagnose students' misconceptions about a topic	• *To be careful in that formative phase to really understand what the kids do and don't know,* ***what they may have misconceptions about, before really, sort of, moving forward.*** *Because you just end up causing more problems or, sort of missing things along the way if you don't do that.*
13. Advancing student understanding	Participants described LPs as helping them to move students from their current understanding to "the next level"	• *"It's basically just that, like I said, I was thinking about the performance expectations,* ***where they are, trying to get them to a level above that****."*
14. Identify targets or goals for learning	Participants described LPs as helpful for knowing end goals for	• *I like to work backwards. I like to* ***take the big picture*** *and then work backwards. I think the learning progression does that. I think it is taking it and it's broken down throughout the lessons. I think that is the big thing,* ***because you need to***

	instruction, "targets for learning", refer to backwards planning	***know what the big picture is.*** • *So, learning progressions help identify targets for learning in terms of me developing programming*

Table 8. Preliminary codes for interview data – *Regional observations approach*

Code	Description	Example
Proximity	Participants mention sea level rise as relevant due to their school's proximity to the Chesapeake Bay, its waterways, or coastal waters	"Because of where I live and where my students live, it is definitely locally relevant. Most of my kids live within five miles of the beach."
Elevation	Participants discuss sea level rise as relevant because of the topography of their area	"Definitely, we're, I mean anywhere in Delaware, but we're at a low, really low level… On a topographic map it's low. So I think it would be pretty easy for the kids to buy in, that if the waters rise, we live in an area where our basements are going to be filled with water and then more than that this is going to be a problem for society as we have it there."
Not relevant	Participants did not see sea level rise as relevant to their students	"You have to understand one thing, I'm not dealing with sea level rise. It's very valuable but I teach in [the north of the] state. You might have heard someone make the comment that you couldn't flood Philadephia if they tried. It's not meaningful to my students."
Other issues	Participants talk about climate change effects other than sea level rise as relevant to their students	"We might not see the lake rise, we might actually see the lake fall because of other situations like extreme drought because we are a reservoir so I think it helped me be in those shoes and help me think about how I will speak about sea level rise as an effect."
Firsthand knowledge	Participants discuss students as having already observed impacts of sea level rise	"My kids are Baltimore City. So I mean they see the effects of sea level rise and climate change all the time, they flooded for Sandy, they flooded, like for Isabel, we flooded for something else recently. So it's definitely something that they see, they know it is happening to them. So I think it will be of great interest to them."
Economics	Participants discuss sea level rise as having	"…Many of the kids, if they don't live by the beach their parents have seasonal businesses they

	economic impacts for students	work in."
Agriculture	Participants discuss sea level rise as having agricultural impacts relevant to their students	"I am in a very poor, rural district and last year we had almost no rain and the crops failed and this year they are flooded. Even now, when I left there was standing water on the fields and the kids have to understand about global warming...so they are going to have to make some decisions that may help their families and the community survive there. You have to make it personal to them or it is a hard sell."
Recreation	Participants discuss sea level rise as having implications for areas of recreational importance to students	"Because we do have a lot of kids who are involved in both hunting and, they're very ecologically aware and really do care about wildlife and understanding it… So I think since sea level would really mess up all the, sea level rise would ruin those habitats, that matter to them. You know, they would have to find new hobbies. And as an eighth grade student, that matters."
Long-term	Participants talk about sea level rise being difficult for students to conceptualize because of its long-term nature	"I know that our kids, being the age that they are, can't see next week, much less ten years down the road. The more we help them see long term implications, the more we help them to see [the importance of] fact based decision making…"
Future problem solving	Participants mention that students will be dealing with, making decisions about sea level rise in the future	"…It will eventually affect them more because, they're at that age now where when they have kids, like that's where their kids are going to know."
Controversial	Participants talk about sea level rise/climate change as being potentially controversial for their students	"I'm a little nervous with the whole, you know, debate, and the people who are out there saying, you know, it's not true or whatever."
Curricular issues	Participants discuss fitting sea level rise into the curriculum	"I have got to figure out a way to make a connection and offshoot from a main trunk of what I am required to do in the curriculum."
Local observations	Participants discuss ways they could investigate sea level rise in their area	"Like going out and measuring the sea level rises and especially from yesterday, my favorite part, is that, I think it was the Surging Seas website, that was, is so cool, because you can see, even like in Dover, which is up in the middle of the state, not really next to the beach, you can see how that flooding is going to really affect that area too."