A Scientist, Teacher Educator and Teacher Collaborative: Innovative Professional Learning Design focused on Climate Change and Lessons Learned from K-12 Classrooms

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Abstract

The new Next Generation Science Standards (NGSS) call for a dramatic shift in science teaching and learning, with a focus on students engaging in science practices as they make sense of natural phenomena. In addition, the NGSS have a significant and explicit focus on climate change. The adoption of these new standards in many states across the nation have created a critical need for on-going professional learning as inservice science educators begin to implement three-dimensional instruction in their classrooms. This paper describes an innovative professional learning workshop on climate change for secondary science teachers, designed by teacher educators and scientists. The workshop was designed to improve teachers' capacity to deliver effective three-dimensional climate change instruction in their classrooms. We present the structure and goals of the workshop, describe how theories of effective professional learning drove the design of the workshop, and address the affordances and challenges of implementing this type of professional learning experience.

Introduction

In the scientific community, a highly respected Intergovernmental Panel on Climate Change (IPCC) highlighted the certainty of the climate change problem and the evidence that humans are the main cause with the highest greenhouse emissions in history (2014). The panel's report also drew attention to impacts of climate change on the natural systems and on societies (Field et al., 2014). Despite strong evidence provided by scientists, citizens have doubts on humans as the cause of this problem somewhat due to lack of understanding of the practices of climate science (Sezen-Barrie, Shea, & Borman (2017). The recent standards document, the Next Generation Science Standards (NGSS Lead States, 2013) addressed this issue by increasing the focus on climate science (Sullivan, Ledley, Lynds, & Gold, 2014) and using the term "climate change" explicitly (Hestness, McDonald, Breslyn, McGinnis, & Mouza, 2014). This shift in the standards was encouraging, however research shows that teachers need significant support to be able to implement any reform within the realities of their classrooms (Janssen, Westbroek, & Van Driel, 2013).

Driven from the theories of effective professional learning (PL) in the fields of science and environmental teacher education (Shepardson, Niyogi, Roychoudhury, & Hirsch, 2012; Sondergeld, Milner, & Rop, 2014; Wilson, 2013), this paper presents the design of an innovative PL experience on climate change. The recent research on effective PL draws attention to the following aspects: a) alignment with policy and practice; b) active learning opportunities for teachers; c) science content (i.e., what teachers need to learn) and practices (i.e., what teachers need in order to teach the content); d) integrating local environment and relevant context; e) enabling the collective participation of teachers; and f) sufficient duration. After we give a description of the climate change activity and the relevant context, we will describe how we attended to these aspects of effective professional learning.

The Classroom Activity: Looking Backward, Looking Forward

The PL workshop was designed around a classroom activity, Looking Backward, Looking Forward (Stapleton, Wolfson, Sezen-Barrie, & Ellis, 2017); overview in Appendix A) that uses changes in past climate as a stepping stone to learn about current patterns in climate change. LBLF has students take on the role of paleoclimatologists, a field not usually addressed in typical science classes, allowing students an opportunity to learn about the diversity of science fields of study while tackling common misconceptions in understanding past versus modern climate change (“Skeptical Science”, n.d.). The activity was developed using an authentic data set (Yuan, 1995) from the Anacostia watershed region (located just north of Washington D.C., in Prince George’s County, Maryland) allowing students to explore a phenomenon that is locally relevant. One central goal of the activity was supporting students as they make sense of how scientists use observation and inference to build, analyze and interpret data for phenomena that they did not, or could not, ‘see for themselves’ (i.e. changes in climate over the past 12,500 years).

In the activity, students collect data from models of sediment samples from 340 years before present (ybp), 3,000 ybp, 10,000 ypb and 12,500 ybp. The models are small bags of potting soil that contain differently colored beads that represent pollen from various taxa in amounts equal to those found in actual sediment cores (Yuan, 1995). This model serves to both actively engage students while reinforcing how paleoclimatologists collect authentic data. Once students identify percentages of ‘pollen’ taxa using a key provided, they graph their results and are challenged to look for patterns in types of taxa present or absent. Using the observed patterns, they infer past climate based on temperature and moisture requirements of the various taxa. Students then create written scientific arguments (using evidence and reasoning) to support their claims of what the climate in the area was like over the past 12,500 years. The second part of the activity has students exploring rates of change between past and current climate change events to expose and address a common misconception that because climate has changed in the past, current rates of climate change are not of concern. Students are challenged to analyze a graph showing temperature anomaly over the past ~20,000 years. This graph shows a general upward trend in temperature anomaly, with a dramatic increase in the last 200 years (and a predicted continued increase for the next 80 years). After analyzing and interpreting the patterns in the graph, students are challenged to consider what is happening in today's world that is causing the dramatic temperature anomaly increase and the impacts to ecosystems as a result of these changes in climate.

The Professional Learning (PL) Workshop

The innovative PL workshop came out of a collaboration among teachers, teacher educators and scientists with a focus on climate literacy. The LBLF lesson was designed as an activity for secondary science teachers as part of an equipment loan program offered by a local university that supports STEM education in K-12 school systems. The equipment loan program provides science 'kits' (which include curriculum, reagents and equipment) to secondary schools to support and facilitate hands-on, inquiry based instruction in classrooms throughout the state. The main impetus for creating this new activity for the equipment loan program was to address science education standards related to climate change that are part of the new NGSS.

At the time of the workshop (2016-2017 school year), Maryland school systems were preparing for the planned implementation of the NGSS standards in the 2017-2018 school year. The Climate change PL workshop around LBLF was designed to address the needs of Maryland's inservice secondary science educators by providing them with information about how to effectively implement three-dimensional instruction that is the foundation of NGSS in their classroom, thereby aligning with relevant policy and practice (Wilson, 2013). Three-dimensional teaching refers to instruction that integrates each dimension (practices, core ideas and crosscutting concepts) of the NGSS into curriculum. For example, the practices are not meant to be taught in isolation as a set of skills to be learned, but rather should be used by students as they apply core ideas and crosscutting concepts to make sense of phenomena (Krajcik, 2015).

The goal of the PL workshop was to provide contextualized training on the NGSS (NGSS Lead States, 2013) to inservice science teachers while receiving feedback on the newly designed LBLF lesson. In this activity, we also aimed for the coherent building of ideas (i.e. understanding how scientists can use pollen to infer past climates and how understanding past climate patterns can help us understand current climate change patterns). In our professional learning workshop, we supported teachers as they worked to put a meaningful, coherent storyline together (Reiser, 2014). The pilot LBLF lesson was designed for secondary students and the 22 workshop participants were from 18 schools throughout Maryland (Table 1). The workshop was 12 hours over 2-days, eight weeks apart (see Appendix B for agendas). The first day of the workshop was designed to introduce teachers to the classroom activity through active learning, provide opportunities for discussion with a climate scientist, and to introduce participants to the practice of writing scientific arguments. Teachers were then provided with the materials to implement this activity in classrooms. Day

2 of the workshop (~8 weeks later) was designed to allow teachers to share the results of their implementation, provide feedback on the design of the activity and continue to learn about the NGSS.

Table 1: The workshop was open to all secondary science teachers in Maryland. We advertised the opportunity on our website and shared via our newsletter. Of the 85 applications received, 26 were accepted into the workshop and 22 of those chose to attend. Our acceptance decisions were influenced by grade level taught, with a goal of 50% middle and 50% high school educators. We also sought diversity with respect to courses taught (e.g. biology, chemistry, environmental science, etc.), teaching experience and school system. Participants received a $300 stipend for attending both days of workshop.

Demographic Information	# Participants
Total number of Participants	22
High School Science Teachers	11
Middle School Science Teachers	11
0-5 years teaching experience	4
6-10 years teaching experience	4
11-15 years teaching experience	6
15+ years teaching experience	7
Public school systems (private)	11 (1)
Taught at least one high school life science course in 2015-2016 school year	10
Taught at least one high school physical science course in 2015-2016 school year	1
Taught at least one high school earth space science course in 2015-2016 school year	3

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We assessed the effectiveness of the workshop and solicited feedback from the workshop participants through several formats including a) a pre-workshop survey, b) verbal feedback during the workshop sessions, c) exit tickets after each workshop, d) written feedback on an 'Implementation Feedback Form' as well as e) written feedback generated by round-robin groups of participants during Day 2 of the workshop. In addition, one of the authors observed the implementation of the activity by a workshop participant in a middle school classroom.

Features of Innovative PL on Climate Change

The professional learning environment utilized ideas from studies on effective strategies for teacher education such as aligning the workshop to policy and practice and providing support to teachers in sufficient time for their learning. However, our learning environment was also unique in combining research-based strategies that are rarely seen in teacher learning programs. For example, in our PL design teachers not only went through the activity themselves, but were also a crucial component for improving our activities (i.e, teachers assumed the role of critical consumers). Moreover, the PL design focused on accessibility of authentic data from scientists in every classroom (Roth, Reis, & Hsu, 2008).

Alignment to policy and practice

A Framework for K-12 Science Education (National Resource Council 2012, hereafter referred to as "*Framework"*) calls for a significant shift in K-12 science teaching and learning. This new 'three-dimensional' model calls for students to engage in the science and engineering practices (Dimension 1) to provide explanations for real-world phenomena that include crosscutting concepts (Dimension 2) and relevant disciplinary core ideas (Dimension 3). One of the biggest challenges facing inservice science teachers with respect to the new standards is understanding what three-dimensional teaching is, what it looks like in a classroom, and how it may differ from current teaching practices (Reiser, 2013). In addition to changes in how science is taught, the recent reforms in K-12 science education are changing what is taught. In particular, there is an increased emphasis on climate literacy as an instructional goal (National Research Council, 2012), and, as a result, an increasing demand for classroom lessons and activities such as LBLF that focus on climate change. In addition to the disciplinary core ideas related to climate change, three-dimensional learning requires students to also engage in the practices of science. A central focus of the LBLF classroom lessons is engaging in argument based on evidence. Argumentation, as a ‘high-leverage’ practice in the NGSS, connects crucial parts of learning but is more challenging to implement (Reiser et al., 2016). The LBLF activity was also developed around the crosscutting concept of observing and using patterns as evidence for explanations of natural phenomena (National Research Council, 2012). These recent shifts in what, and how, students should learn in the classroom require changes in how science is taught and inservice teachers will require support as they shift their instructional practices to this type of instruction (National Research Council, 2012).

Active learning opportunities for teachers

To address this PL need, we chose to have the workshop participants work through the activity as their own students would. We also built-in deliberate opportunities for explicitly addressing both general pedagogy and pedagogical content knowledge (Shulman, 1986; Gess-Newsome & Lederman, 1999.) As a result, teachers were active participants (Wilson, 2013) as they learned the content of this activity while explicitly exploring how to effectively engage their own students in the science practices, an important component of three-dimensional instruction. In exit surveys, more than a third of workshop participants (8/21) identified working through the activity as one of the most useful parts of Day 1 of the Workshop

During the workshop we wanted to make sure to also provide active learning opportunities that integrated scaffolding and instruction on how to effectively engage students in the practice of argumentation. To that end, we provided teachers with two contexts during the workshop in which they could practice constructing scientific arguments. For the first context, we provided teachers with an already constructed argument (Appendix C). We then introduced a rubric for assessing a scientific argument (Figure 1). The rubric, adapted from materials provided by Science Learning Design, Engineering and Robotics at Georgia Tech (“Making a Strong Argument,” n.d.), addresses the three components of a scientific argument; the claim, the evidence and the reasoning as well as an additional element, persuasion. The argument we used for this exercise was constructed at the middle-school level, allowing all workshop participants to readily comprehend the material, regardless of their primary content area. Participants were given time to work individually, then as pairs, to assess the argument using the rubric provided. Post-program feedback from participants indicated that several teachers used this same example argument to introduce their students to the use of the rubric. We then discussed, as a large group, the various assessments made by participants using the rubric. Much productive discussion came out of this exercise as participants became familiar with the rubric and the progressions of each element. For example, teachers spent time debating whether a claim presented at the end of a written argument was as effective as a claim clearly stated at the beginning of the same argument. Teachers also expressed enthusiasm for including a persuasion component in the rubric, stating that it provided an explicit opportunity for them to discuss the importance of good writing and communication skills in science and served as an answer to the often asked question “Why do we have to write in science class?”. We also spent time discussing the different components of the ‘evidence’ and ‘reasoning’ elements included in the rubric. For example, we discussed how separately assessing the ‘use of data’ and ‘interpretation’ of data can provide more specific and clear feedback for students on the strength of their scientific argument.

Figure 1. Rubric used by both in-service science teacher workshop participants and their students to assess scientific arguments. Adapted from materials provided by Science Learning Design, Engineering and Robotics at Georgia Tech (“Making a Strong Argument,” n.d.).

C-E-R Element	Zero (0)	Early (1pt)	Emerging (2pts)	Sophisticated (3pts)
1) Claim	Does not make a claim that responds to the question.	The claim responds to the question, but is inaccurate claim.	Makes an accurate but incomplete claim in response to the question.	Makes an accurate and complete claim in response to the question.
2a) Evidence **Use of data**	No evidence is provided.	The evidence contains some of appropriate data from an observation.	The evidence contains most of appropriate data from an observation.	The evidence contains all appropriate data from an observation.
2b) Evidence **Interpretation of data**	Does not interpret any evidence.	Interprets only some data accurately.	Interprets most of the data accurately.	Interprets all of the data accurately.
3a) Reasoning **General Statement**	Does not provide any reasoning.	Answers why or how the evidence supports claim with no relevant scientific principles (disciplinary core ideas).	Answers why or how the evidence supports claim with insufficient relevant scientific principles (disciplinary core ideas).	Answers why or how the evidence supports claim with sufficient relevant scientific principles (disciplinary core ideas).
3b) Reasoning **Use of pieces of evidence**	Uses no evidence or relevant big ideas accurately to explain the relationship between claim and evidence.	Uses some piece(s) of evidence and relevant disciplinary core ideas accurately to explain the relationship between claim and evidence.	Uses most pieces of evidence and relevant disciplinary core ideas accurately to explain the relationship between claim and evidence.	Uses all pieces of evidence and relevant disciplinary core ideas accurately to explain the relationship between claim and evidence.
4a) Persuasion **Complete sentences**	No sentences are complete.	Only few sentences are complete.	Most sentences are complete.	All sentences are complete.
4b) Persuasion **Grammatical Choices**	Majority of CER contains many grammatical errors.	CER contains some grammatical errors.	CER contains few grammatical errors.	CER contains minimal grammatical errors.

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Situating PL in science content and practices

Next, we returned to the scientific argument that the teachers themselves had created in the LBLF activity to answer the question “What was the climate like in this region over the past 12,500 years?” This second context was important, as it required teachers to actively participate in the construction of the argument (as compared to the first context where the argument was presented to them) situated in the specific content (climate change) that was the central focus of the workshop, both important components of effective PL (Wilson, 2013). For this exercise, participants were placed in pairs (after individually constructing their own argument) for a peer-review session. Each member of the pair was asked to share their scientific arguments verbally. Once both partners had shared their scientific arguments, we asked them to then critique their own written arguments using the provided rubric. We chose to structure the peer review process in this way in order to model for them a low-risk method they could use in their classroom to encourage and scaffold peer review, collaboration and self-assessment. In this model, participants have an opportunity to hear other ideas, as well as receive verbal feedback from their partners and are then able to focus on assessing their own argument using the rubric. There are many other ways in which peer review sessions can be done. For example, in workshops or classrooms where participants may already be familiar with scientific arguments and/or the rubric, you could choose to have peers assess each other's arguments against the rubric (instead of only assessing their own). Several of our participants indicated they had modified the peer review process to use a peer-review model they already had in place in their classrooms.

Interestingly, our pre-workshop surveys revealed that a majority of teachers were already familiar with argumentation prior to this workshop, as 15/21 were able to accurately identify and define the parts of a scientific argumentation (claim, evidence, reasoning). However, despite their familiarity with this practice, five of those same teachers who were familiar with argumentation and used it in their classroom expressed that they found the opportunity to explore the practice in more detail during the workshop valuable (see comment 1 in Table 2). This feedback from the participants supports the idea that effective transitions to the new NGSS are dependent on teachers being able to access high quality PL opportunities focused on three-dimensional learning (National Research Council, 2012; Reiser, 2013).

Table 2: Comments and feedback from workshop participants

#	Feedback	Source
1	"CER piece- because even though I've used argumentative writing in my class I've never had good training"	Day 1 Exit Ticket,
2	"I was really excited by the opportunity to share real, local data with the students and that was truly impactful to them."	Implementation Feedback form,
3	"I gave students a data table to collect their data (along with class data) [the LBLF lesson suggested having students construct their own data tables]. I was not prepared to spend time scaffolding how to construct data tables. Rationale: I know this is a valuable skill and my students have a hard time with it (from past evidence!), but I did not feel that using the time here was most effective when my end-goal was having students understand (and argue with evidence) that the climate in our region has changed over the past 12,500 years."	Implementation Feedback form
4	"While it aligned with standards, I felt as though it was too 'guided'. Students were told what to do and how to investigate rather than figuring it out themselves. They were followers rather than designers, creators or problem solvers. It would have been helpful to align it to certain PE's rather than just DCI's".	Implementation Feedback form
5	"I did not do [the activity designed to address differences in past and present climate change] but will put it in my lesson plan when I get to the climate chapter. That would have been day 5 and I did not want to spend another consecutive day."	Implementation Feedback form
6	"I felt this lesson had much more emphasis on the first goal [developing a scientific argument] more than the second goal [understanding differences in cause and rates of current versus past climate change]. More activities may want to be included."	Implementation Feedback Form

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Integrating local environment and relevant context

Recent research suggests activities that are relevant to local environments of teachers and their students are most effective, especially when teaching climate (Shea, Mouza, & Drewes, 2016). Sondergeld and colleagues (2014) report that when using data that come from a foreign environment, teachers and their students will have more difficulty understanding data and will be less likely to be engaged in finding solutions to climate change problems. The LBLF lesson, based on authentic data, challenges students to 'figure out', not just 'learn about', a natural phenomenon (changes in past climate) for a region that is local and relevant to them (Passmore & Svoboda, 2012). For example, instead of simply reading a description about what the past climate was like, students used the data they collected (from a model that simulates real data counts from a research group at a local university) on percentages of pollen taxa to 'figure out' what the climate was like at different periods over the past 12,500 years. In addition to having the teachers in the workshop complete the activity themselves (as their students would), we intentionally added in discussion and reflection questions about how this activity allowed students to ‘figure out’ versus just ‘learn about’ a phenomenon. This explicit approach to exploring how the new vision for science teaching and learning differs from current instructional practices provided teachers with a common context and example. Furthermore, the data are locally relevant to students and teachers, having been collected within the Anacostia watershed, a watershed system in Maryland which flows into the Chesapeake Bay. Because many school systems in our state focus on local watersheds, particularly those that drain into the Chesapeake Bay, students and teachers are generally familiar with this area already and are able to relate to it on a more personal level. The *Framework* suggests that “connecting to students’ interests and experiences” is an important component of science learning (National Research Council, 2012, p. 28) and feedback from several teachers support this idea that authentic, relevant data is useful for engaging students (see comment 2 in Table 2).

Enabling collective participation of teachers as critical consumers of curriculum

With the implementation of new science standards occurring in many states across the U.S., inservice science teachers are faced with the challenge of implementing (and many times developing) new curriculum in alignment with the new vision for science teaching and learning. To make this task even more challenging is the fact that many pre-packaged curriculum and texts (such as widely used Project-Based Inquiry Science curriculum) are only partially aligned to the NGSS (Allen & Penuel, 2015). Of additional concern is a report by Banilower et al. (2013) that suggests many science education experts are critical of textbook quality, while most teachers consider the textbooks they use in their classroom to be of high quality. As such, it is imperative that inservice educators are equipped with skills and tools that will allow them to become critical consumers of curriculum and be able to identify curricula and other classroom resources that truly support student engagement in three-dimensional learning. During this workshop, in an effort to support teachers’ ability to critically consume curricula, we introduced teachers to the Next Generation Science Standards Connections table (Appendix D) that was provided with the LBLF activity. This table, modeled after the tables used in the NSTA practitioner journals (*Science & Children*, *Science Scope* and *The Science Teacher*), makes explicit connections between curriculum and the three dimensions of NGSS. Workshop participants discussed how the activity, as presented to them, aligned with the new NGSS. Additionally, we encouraged them to adapt the activity to fit the needs of their students (while still engaging in instructional practices aligned with three-dimensional teaching) and share with us what changes they made.

Duration of professional learning workshop

Wilson (2013) identified sufficient duration as an important element of effective PL. Despite having 12 contact hours with teachers over a 2-month period, we found the contact hours of workshop too short to fully address all the changes called for in the *Framework* (National Research Council, 2012) with respect to science teaching and learning. For example, one teacher reported on their exit ticket after the first day of the workshop when asked to describe what was least useful about the workshop: “Not covering the NGSS connection. I believe we will do that in May”. While she was correct that we would focus more on the NGSS connections on the second day of the workshop, it did highlight that more time for learning about NGSS prior to teaching the lesson may have been beneficial. However, this PL workshop was not intended to provide all the PL teachers will need as they work to align their teaching practices with three-dimensional learning. The professional learning opportunities offered to inservice science teachers by our institution of higher education (which is, by definition, external to the formal K-12 school systems) are meant to supplement the professional learning provided by 24 independent school systems throughout the state. By focusing deeply on a single practice, that of argumentation, we were able to provide teachers with specific tools they could (and did) use in their classrooms as they begin to shift towards three-dimensional teaching and learning. Furthermore, the learning opportunities related to this PL workshop were not confined solely to the 12 hours of the actual workshop. We intentionally designed the workshop to require teachers to implement what they learned about three-dimensional teaching in their own classrooms, and then provide reflections and feedback on those experiences. The comprehensive nature of this PL increased the amount of time workshop participants dedicated to learning about NGSS and the shifts they will need to make in their own teaching practices.

In this section, we described the key components of our professional learning design as they are informed by research on teachers’ learning, reform-based science education and climate change education. The following sections will highlight the affordances that we observed during and after teachers’ implementation of Looking Backward, Looking Forward activity. These affordances will explain the benefits of the PL design on teachers’ implementation. We will also point out the limitations that were apparent upon the completion of our study. These limitations will shed light into future design of PL environments for learning to teach climate change.

Affordances and Challenges to Effective Implementation

Improving teachers’ knowledge about NGSS and the scientific practices

During our workshop, we did not simply provide teachers with an activity that aligned with the NGSS and three-dimensional teaching; we also provided opportunities for participants to explore how and why the curriculum modeled three-dimensional instruction and aligned with NGSS. For example, we provided teachers with a chart that listed each NGSS component addressed in the lab and indicated exactly where and how in the activity it was addressed (Appendix D). In addition, instead of simply having the teachers construct a scientific argument as part of the activity, we spent time discussing how they could scaffold the process using the claim-evidence-reasoning framework developed by McNeill and Krajcik (2012).

While we provided teachers with a comprehensive facilitation guide and student handouts for this activity, we actively encouraged teachers to modify the lesson to fit the individual needs of their students. By enabling the collective participation of teachers (Wilson, 2013) we provided teachers with an opportunity to apply their increasing knowledge of NGSS and three-dimensional teaching in their own unique contexts. The reality of the need for teacher modification of curriculum was supported by a statement provided by a participant (Teacher A) on their implementation feedback form (see comment 3 in Table 2). This type of pedagogical decision making is constantly happening in the classroom. If teachers do not have a strong understanding of the new vision for science teaching and learning as described in the *Framework* (National Research Council, 2012), they may not be able to effectively tailor instruction to meet both educational goals and specific student needs. For example, consider the statement provided on the implementation feedback form by Teacher B about the LBLF lesson (see Comment 4 in Table 2). In contrast to the statement by Teacher A, it seems this teacher did not place the same emphasis on the argumentation portion of the activity, which was presented as the focal point of the activity. As such, the data collection portion of the activity was more aligned with a structured inquiry (Bell, Smetana, & Binns, 2005) to allow more time for students to focus on analyzing and interpreting data and engaging in argument from evidence. As authors of the activity, our goals were more in alignment with Teacher A (building argumentation skills in students) and less with those of Teacher B whose focus was on ‘planning and carrying out investigations’. While both practices are equally important, it is not possible to engage in all practices all the time. Further, Teacher B’s statement regarding aligning the lesson to PE’s (performance expectations) rather than just DCI’s (disciplinary core ideas) indicates s/he may not yet fully understand the goals of our lesson, which were directly aligned to practices and crosscutting concepts in addition to DCI’s (Appendix D), while supporting students’ ability to successfully demonstrate their understanding on selected PE’s. By increasing teacher understanding of goals of the NGSS and how to effectively engage students in each of the science and engineering practices, they will then be able to choose and/or modify activities appropriately to fit the needs of their students.

Table 3. Self-report data on familiarity with the Science and Engineering Practices found in the in the Next Generation Science Standards. Data from pre- and post-program surveys. N = 22 teachers.

Survey	# of workshop participants reporting they were either not at all familiar, familiar with the name only, or only somewhat familiar with the Practices.	# of workshop participants reporting they were familiar or very familiar with the Practices and had begun, or were currently engaging their students in the Practices in their classrooms.
Pre	19	3
Post	15	7

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We found that teacher self-reports of familiarity with the NGSS increased between pre- and post-program surveys (Table 3). We also assessed participant knowledge of scientific arguments by asking on both the pre-and post-surveys “What are the components of a scientific argument? Describe each component in your own words”. While the majority of teachers were able to successfully list and describe most of the components of a scientific argument on the pre-survey, we still saw an increase on the post-test of participants successfully listing and defining all three components (Table 4).

Table 4. Data from pre- and post-program surveys on teachers' ability to accurately list and define the parts of a scientific argument (claim, evidence, and reasoning). N = 22 teachers.

Survey	No answer, incorrect or mostly incorrect answer	Gave partial, mostly, mostly correct list and definitions of a scientific argument	Gave complete and accurate list and definitions of parts of a scientific argument
Pre	5	8	9
Post	1	3	18

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Tackling a misconception on past vs. modern climate change

Misconceptions, or alternate conceptions, are a critical component of science teaching and learning. While many teachers view misconceptions as ‘wrong’ ideas that need to be immediately corrected in students, they can actually be a useful tool for engaging students in the science and engineering practices. Indeed, Campbell, Schwarz, and Windschitl (2016) suggest misconceptions provide a critical ‘stepping stone’ for students as they work toward forming more accurate understandings of how the world works. In the LBLF lesson, we provide students an opportunity to explore the common misconception that current climate change is no different than past climate change events and therefore is not something humans need to be concerned about. Rather than just tell the students current climate change is different than past changes in climates because of its cause (release of CO_2 into atmosphere due to consumption of fossil fuels by humans) and the rapid rate at which it is occurring, we had students examining a graph of rates of climate change for the past 20,000 years. This part was last in the series of activities within the LBLF lesson.

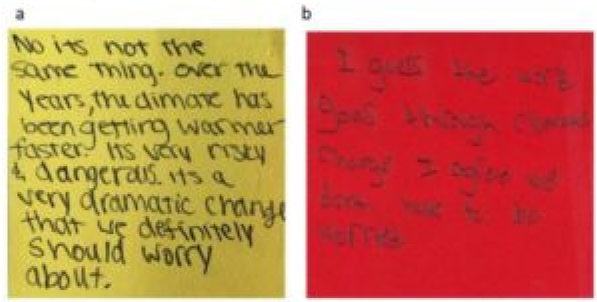
Of the 14 teachers who submitted post implementation reports, eight reported that they did not do this part of the activity. Teachers may have chosen not to complete this part of the lesson for many different reasons, including being uncomfortable teaching about a controversial subject. However, our data suggest that it was lack of time, and not a reluctance to address the content, that prevented teachers from completing this part of the lesson. Seven of the eight teachers who did not complete this part of the activity indicated lack of time was the reason (with five teachers indicating they hoped to come back to it and complete it when their schedules allowed, see comment 5 in Table 2 for example of typical response for why teachers did not complete this part of the activity). Interestingly, one teacher (Teacher C) pointed out (and we agree with the assessment) that the LBLF lesson was more focused on having students develop a scientific argument to explain how the climate has changed, with less focus on the misconceptions related to causes and rates of current versus past climate change (see comment 6 in Table 2). During the LBLF development, we struggled with balancing the number and depth of activities within this lesson, against the amount of time teachers had available in the classroom. We also focused the majority of the workshop time with teachers on this first goal (developing a scientific argument), with less time spend on the second goal (understanding the differences between current and past climate change events). That, combined with the fact that the activity that explored misconceptions about past versus current rates of climate change came at the end of the lesson suggests teachers who did not complete this section of the lesson did so because of time, and not because of a reluctance to teach this topic. It is also interesting to note that Teacher C was the only teacher to report implementing all activities within the lesson and the total time s/he reported devoting to the LBLF lesson (158 min) was well below the average (216 min) of those who were not able to implement all parts of the lesson. This suggests that perhaps Teacher C was addressing each topic in the lesson in less depth than other participants. While the new vision for science teaching and learning calls for “a deep exploration of important concepts, as well as time for students to develop meaningful understand, to actually practice science and engineering, and to reflect on their nature” (National Research Council, 2012, p. 25) it is a reality that instructional time is limited and teachers feel the pressure to move quickly through vast amounts of material.

On the limited boundaries of time

As curriculum developers and PL facilitators, these results suggest several changes we can make in our practices to address the issues of running out of time and, therefore, not addressing key learning goals. The first is to make sure that we find the time in our PL workshops to model all of the activities for the teachers. Similar to what happened to the teachers in the classroom, we ran out of time and were not able to walk teachers through the rates of change part of the activity. This may have contributed to the teachers not implementing it in their classrooms, either because they were not as familiar with it or because they assumed it wasn’t as important. Secondly, we can also look for ways, whenever possible, to integrate key concepts throughout the activity. For example, if we had integrated the ideas about differences between current and past climate change earlier in the activity timeline, it is possible that teachers would have been less likely to have omitted this part of the lesson.

Evidence from one classroom suggests that if teachers are able to find time to implement the part of the activity devoted to how current climate change is different from past climate, it can be effective. Students were asked to respond to the prompt: “I heard that the climate has changed before and this current climate change we are talking about is just like that. So we don’t have to be worried. It’s the same thing.” Of 46 responses (received from two different classes from a single teacher), 31 indicated we should be concerned and suggested the rate of change was the reason (Figure 2a), ten indicated there was cause for concern but did not provide an adequate reason, three suggested there was no cause for concern but did not provide a reason and only two suggested that there should be no cause for concern and gave past climate change as a reason (Figure 2b).

Figure 2. Student responses to the prompt: *"I heard that the climate has changed before and this current climate change we are talking about is just like that. So we don't have to be worried. It's the same thing."* The majority of responses from students were similar to (a) suggesting that the rate of temperature change was faster now than in the past and that this was a cause for concern. Only two students indicated that because climate has changed in the past, current climate change is not of concern (b).



Click on image to enlarge

Conclusion

Recent reforms in K-12 science teaching necessitate high quality PL opportunities for inservice science teachers (National Research Council, 2012; Wilson, 2013). In the paper, we report on an innovative climate change PL workshop designed to increase inservice secondary science teachers' knowledge of, and experience with, the three-dimensional model of teaching and learning (National Research Council, 2012) while actively engaging them in a lesson they used in their own classrooms to teach about climate literacy issues. By providing conceptually (e.g. changes in climate) and epistemologically (e.g. argumentation) aligned instruction and assessment tools, the workshop provided teachers with the necessary resources to effectively engage their students in learning climate science as practice. In accordance with theories of effective professional learning, we used a specific, local context in the LBLF lesson to actively engage teachers in collectively learning about both science content and pedagogy that directly aligned with state and school system policies. Teachers identified the active learning aspect of the workshop, focused on a particular climate change lesson, as one of the most valuable components. Our PL design gave teachers authority not only to consume what they learned, but contribute to their peers' learning and to the improvement of the LBLF activity.

While the opportunities afforded to workshop participants increased their ability to engage their students in three-dimensional teaching and learning, it is clear that continued professional learning support will be necessary as teachers learn to become critical consumers of curriculum and develop the knowledge and skills needed to fully understand, adopt and implement the NGSS. Teachers in this climate change PL workshop expressed their need for more learning opportunities and support to effectively implement the scientific practices in their classrooms. It is likely that these needed supports will come from a variety of sources and take on a variety of forms. For example, school systems often provide district-wide professional learning opportunities for their employees. However, many teachers supplement the mandated district professional learning with opportunities provided by outside entities, such as universities and informal science education programs (e.g. science centers and museums). Engaging in professional learning opportunities by choice (rather than those mandated by the school district) offers educators the ability to choose opportunities tailored to their specific needs. These professional learning opportunities may take the form of professional learning communities (either in-person or on-line), weekend workshops, or extended summer research experiences.

Providers of these professional learning opportunities, whether internal or external to the formal K-12 school systems need to be responsive to the needs of teachers in their areas. Additionally, the increased focus on many climate change ideas and issues in the NGSS (e.g. glacier melting, ocean acidification, carbon cycle, etc.) necessitates on-going support for inservice classroom teachers on the breadth of climate change issues addressed. Finally, providing teachers with support as they begin to make connections to climate change issues in all science domains will increase the likelihood that students will receive multiple opportunities and contexts within which to learn about this important topic.

Research suggests that effective professional learning for teachers should be of sufficient duration. However, even the most carefully designed professional learning opportunities are constrained by resources (most often money and time). While individual professional learning opportunities (such as the workshop described in this paper) may be finite, if they provide teachers with tools they can use to continue revising and reflecting on their teaching practices, their influence continues long after the workshop has ended. For example, instead of simply presenting teachers with a new activity that was "aligned to NGSS" we intentionally integrated opportunities for teachers to explore and understand some of the fundamental shifts called for in the NGSS. As a result, teachers can apply what they learned about NGSS in the context of a single activity to any lesson or curriculum they implement in their classrooms.

Going forward, we suggest paying particular attention to providing teachers with opportunities to deeply engage in the science practices themselves as they learn how to effectively facilitate student engagement in these same practices within the context of their classrooms. Continuing attention should also be paid to supporting teachers in understanding common misconceptions with respect to climate change and how best to elicit and address them with their students. In addition, we responded to research showing that teachers pay little attention to coherence building, but rather choose to implement only engaging and fun activities (Hanuscin et al., 2016). In this workshop, we developed the instructional resources with a focus on coherence building. We not only gave teachers an investigation to do with their students, but we also provided the related argument and data providing conceptual and epistemic coherence. We further suggest that teachers experience coherence building in a variety of professional learning environments so that seeking coherent ideas becomes a habit in the culture of science classrooms. Finally, although this PL learning workshop focused on a population of inservice teachers, we suggest that a future study can focus on preservice teachers' challenges on coherence building (Hollins, 2015). We built formative assessment tools throughout the LBLF activity to support coherent and meaningful learning of the scientific ideas within our activity (Furtak, Morrison, & Kroog, 2014.) For example, a group of preservice teachers engaged in their final teaching internship may take part in a similarly designed workshop (either during or outside of formal classroom time) and be encouraged to implement the common activity (aligned with NGSS and three-dimensional teaching) within their assigned classrooms.

Implementation of NGSS in science classrooms requires a cultural shift for teachers and therefore they need extensive support (Windschitl & Stroupe, 2017). In our paper, we describe the details of a professional learning workshop designed in collaboration with a scientist, teacher educators and with feedback provided from K-12 teachers. In this description, we highlighted effective and/or innovative aspects of our design such as alignment to policy and practice, active learning opportunities for teachers, situating PL in science content and practices, integrating local environment and relevant context, determining an appropriate duration for PL design, and enabling collective participation of teachers as critical consumers of curriculum. Although some challenges remained, considering these aspects can create a supportive learning environment for teachers as they incorporate three- dimensional teaching and learning into their classrooms.

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Supplemental Files

Appendices.docx

References

Allen, C. D., & Penuel, W. R. (2015). Studying teachers' sensemaking to investigate teachers' responses to professional development focused on new standards. *Journal of Teacher Education, 66*, 136-149.

Banilower, E., Smith, P.S., Weiss, I.R., Malzahn, K.A., Campbell, K.M., & Weiss, A.M. (2013). *Report of the 2012 national survey of science and mathematics education*. Chapel Hill, NC: Horizon Research Inc. 1-309.

Bell, R.L., Smetana, L. & Binns, I. (2005). Simplifying inquiry instruction. *The Science Teacher, 72*, 30-33.

Campbell, T., C. Schwarz, & Windschitl, M. (2016). What we call misconceptions may be necessary stepping-stones on a path toward making sense of the world. *The Science Teacher, 83*, 69–74.

Field, C., Barros, V., Dokken, D., Mach, K., Mastrandrea, M., Bilir, T., et al. (2014). IPCC, 2014: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK/New York, NY.

Furtak, E., Morrison, D., & Kroog, H. (2014). Investigating the link between learning progressions and classroom assessment. *Science Education, 98*, 640-673.

Gess-Newsome, J. & Lederman, N.G. (Eds). (1999). *Examining pedagogical content knowledge: The construct and its implications.* Netherlands: Kluwer Academic Publishers.

Hanuscin, D., Lipsitz, K., Cisterna-Alburquerque, D., Arnone, K. A., van Garderen, D., de Araujo, Z., & Lee, E. J. (2016). Developing Coherent Conceptual Storylines: Two Elementary Challenges. *Journal of Science Teacher Education, 27*, 393-414.

Hestness, E., McDonald, R. C., Breslyn, W., McGinnis, J. R., & Mouza, C. (2014). Science teacher professional development in climate change education informed by the Next Generation Science Standards. *Journal of Geoscience Education, 62*, 319-329.

Hollins, E. R. (2015). *Rethinking field experiences in preservice teacher preparation: Meeting new challenges for accountability*. Routledge: New York.

Janssen, F., Westbroek, H., & Van Driel, J. (2013). How to make innovations practical. *Teachers College Record*, *115,* 070378.

Krajcik, J. (2015). Three-dimensional instruction: using a new type of teaching in the science classroom. *The Science Teacher, 82*(8), 50-52.

Marking a Strong Argument. (n.d.). Retrieved from http://slider.gatech.edu/student-edition

McNeill, K.L & Krajcik, J.S. (2012). *Supporting grade 5-8 students in constructing explanations in science: the claim, evidence and reasoning framework for talk and writing*. Boston, MA: Pearson.

National Research Council. (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: National Academies Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by states.* Washington, DC: The National Academies Press.

Passmore, C.M., & Svoboda, J. (2012). Exploring opportunities for argumentation in modelling classrooms. *International Journal of Science Education, 34*, 1535-1554.

Reiser, B.J. 2013. *What professional development strategies are needed for successful implementation of the Next Generation Science Standards?* Invitational Research Symposium on Science Assessment. Retrieved from https://www.chemedx.org/system/files/reiser.pdf.

Reiser, B. J. (2014). Designing coherent storylines aligned with NGSS for the K-12 classroom. In *National Science Education Leadership Association Meeting (April). Boston, MA*.

Reiser, B.J., Michaels, S., Moon, J. Bell, T., Dyer, E., Edwards, K., McGill, T.A.W., Novak, M., Park, A. (2016). *Scaling up three-dimensional science learning through teacher-led study groups across a state*. National Association for Research in Science Teaching Conference, Baltimore, MD.

Roth, W. M., Reis, G., & Hsu, D. P. L. (2008). *Authentic science revisited: In praise of diversity, heterogeneity, hybridity*. Boston, MA: Sense Publishers.

Sezen-Barrie, A., Shea, N., & Borman, J. H. (2017). Probing into the sources of ignorance: science teachers' practices of constructing arguments or rebuttals to denialism of climate change. *Environmental Education Research*. http://dx.doi.org/10.1080/13504622.2017.1330949

Shea, N. A., Mouza, C., & Drewes, A. (2016). Climate Change Professional Development: Design, Implementation, and Initial Outcomes on Teacher Learning, Practice, and Student Beliefs. *Journal of Science Teacher Education, 27*, 235-258.

Shepardson, D. P., Niyogi, D., Roychoudhury, A., & Hirsch, A. (2012). Conceptualizing climate change in the context of a climate system: implications for climate and environmental education. *Environmental Education Research, 18*, 323-352.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15,* 4-14.

Skeptical Science, (n.d). Retrieved from https://skepticalscience.com/climate-change-little-ice-age-medieval-warm-period.htm

Sondergeld, T. A., Milner, A. R., & Rop, C. (2014). Evaluating teachers' self-perceptions of their knowledge and practice after participating in an environmental education professional development program. *Teacher Development*, *18*, 281-302.

Stapleton, M.K., Wolfson, J., Sezen-Barrie, A., & Ellis, R. (2017). Looking Backward, Looking Forward. *Science Scope, 42*(2), 45-53.

Sullivan, S. M. B., Ledley, T. S., Lynds, S. E., & Gold, A. U. (2014). Navigating climate science in the classroom: Teacher preparation, perceptions and practices. *Journal of Geoscience Education, 62*, 550-559.

Wilson, S.M. (2013). Professional Development for Science Teachers. *Science, 340*, 310-313.

Windschitl, M. A., & Stroupe, D. (2017). The Three-Story Challenge: Implications of the Next Generation Science Standards for Teacher Preparation. *Journal of Teacher Education, 68*, 251-261.

Yuan, S. (1995). *Postglacial History of Vegetation and River Channel Geomorphology in a Coastal Plain Floodplain*. Diss. The Johns Hopkins University.