# Supporting the Inclusion of Climate Change in U.S. Science Education Curricula by Use of Learning Progressions

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## Abstract

New and fresh thinking in climate change education is called for to advance our understanding in curriculum, instruction, assessment, teacher education, and policy. Learning progression (LP) research offers the potential to add new insights. Three original hypothetical learning progressions (LPs) for major consequences of climate change—extreme weather, enhanced urban heat island effect, and sea level rise—are presented. Using empirical data from middle school learners and undergraduate students, we demonstrated a process for moving the hypothetical Sea Level Rise LP to an empirically-supported conditional LP.

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## Introduction

As this book exemplifies, climate change is a defining sustainability challenge of our times that requires new thinking throughout the components of the education system worldwide (curriculum, instruction, assessment, teacher education, and policy). This is especially needed in the U.S. due to its recent inclusion of the climate change topic for the first time in U.S. science standards (Next Generation Science Standards (NGSS) Lead States, 2013). In this chapter we report contributions of new and fresh thinking in climate change education from our Maryland and Delaware Climate Change Education, Assessment, and Research (MADE CLEAR) learning sciences team, as supported by two grants from the National Science Foundation's Climate Change Education Program[1].

To add potentially new thinking to climate change education, we made the compelling argument that it would be productive if the project used as its organizing framework the theory of learning progressions (Krajcik, Sutherland, Drago, & Merritt, 2012) in its investigations. The two states participating in MADE CLEAR had adopted the NGSS, and learning progressions (LPs) served a major role in their development. The NGSS are intended to develop deep understanding of the most important science concepts in a coherent manner from grades K to 12. Learning progressions support this achievement, because LPs describe the way in which learners' ideas about a topic become more sophisticated over the years through sustained learning opportunities and targeted instruction.

Furthermore, since the project proposed to advance knowledge of how learners from

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[1] For additional information on the MADE CLEAR project and the Learning Sciences Research team, visit www.madeclear.org and www.climateEdResearch.org, respectively.

diverse regional areas of Maryland and Delaware (coastal, metropolitan, and rural/suburban) learned about climate change, developing LPs that aligned well with observable consequences of climate change (U.S. Global Research Program, 2014) in those diverse regions was recommended and accepted. The LPs that we identified as most relevant to the learners from the three regions that constituted Maryland and Delaware were sea level rise, the enhanced urban heat island effect, and extreme weather (McGinnis, 2013). The development of these three LPs was necessary since the LPs would serve as guides for the projects' efforts to include climate change education in science teacher preparation and in science teacher professional development. The development of a LP for climate change itself, a very complex and dynamic construct, was viewed as something that could only be realistically considered for our research team to pursue once at least one of those smaller in scope consequences of climate change LPs was accomplished. An initial focus on an LP, such as sea level rise, would allow for additional advances in the education research field's (and in the team's) conceptual and methodological knowledge in LP design and validation.

## Learning Progressions[2]

Duschl, Schweingruber, and Shouse (2007) defined LPs as descriptions of the increasingly sophisticated ways that learners can think about a science topic over time. LPs are generally organized into qualitatively different levels of achievement that represent increasingly sophisticated ways of thinking (Lehrer & Schauble, 2012). The levels in LPs are considered conceptual steppingstones, benchmarks, or landmarks, which educators can use as diagnostic tools and instructional targets to coordinate curriculum, instruction, and assessment (Duncan & Hmelo-Silver, 2009). By implementing detailed curriculum and targeted assessment that map to

[2] This section is drawn from Hestness, McGinnis, Breslyn, McDonald, Mouza, Shea, & Wellington (2014) and Hestness, McDonald, Breslyn, McGinnis & Mouza (2014).

big ideas in a domain over time, LPs are posited to assist researchers and educators in identifying the learning pathways students navigate and to inform pedagogical strategies to support future learning (Lehrer & Schauble, 2009).

As noted by Lehrer and Schauble (2009) and Furtak and Morrison (2013), however, a major challenge to LPs is that they are often represent learning as linear and hierarchal when in fact several studies point to the notion that students thinking may follow a number of different trajectories or pathways influenced by the context in which the learners' inhabit (NRC, 2007; Nehm & Ha, 2011; Heredia, Furtak, & Morrison, 2012). Informed by those findings, we thought it prudent in our MADE CLEAR research to develop LPs that aligned with regional observations of climate change that learners would make in different geographical regions of Maryland and Delaware.

## Climate Change in the Next Generation Science Standards

Before focusing our attention on crafting hypothetical LPs for our three LPs (sea level rise, enhanced heat island effect, and extreme weather) we needed to first become familiar with how our primary resource (the NGSS) included climate change as a Disciplinary Core Idea (DCI). Based on that analysis, we anticipated that we would be more informed of the areas in which these three consequences of climate change were referenced. We then could engage in additional in-depth research on those three consequences by examining the science education research literature on learners' thinking, the AAAS Atlas (American Association for the Advancement of Science [AAAS], 2003), and feedback from science content experts. We first conducted a review of the NGSS for the presence of climate change in the performance standards in which we agreed the topic was explicitly referenced. We next broadened our review of the topic in the NGSS by searching for terms that we called proximal, which we agreed were close to climate change but not explicit (see, McGinnis, McDonald, & Breslyn, 2013, for a comprehensive listing of these proximal performance standards).

We found that NGSS performance standards explicitly addressing climate change in the NGSS were present at the middle and high school levels. Those standards used the terms “global temperatures,” “changes in climate,” or “climate change.” One middle school standard addressed the cause of rising global temperatures (MS-ESS3-5). At the high school level, standards introduced the constructs of evidence for climate change (HS-ESS3-1), climate modeling (HS-ESS2-4, HS-ESS3- 5), and geoengineering (HS-ESS3-4).

Our analysis of the NGSS for close or proximal performance standards connections for climate change revealed a more substantial presence of the topic throughout K-12. Though climate change is not explicitly included in the NGSS at the elementary grades (K-5) the performance standards at this level address the scientific constructs that are the foundations of climate change science. For example, the kindergarten performance standards involve the scientific constructs of solar energy (K-PS3-1, K-PS3-2), weather patterns (K-ESS2-1), and severe weather (K-ESS3-2). In later elementary grades (1 through 5), the performance standards elaborate on additional scientific constructs fundamental to an understanding of climate change: Solar energy (1-PS4-3, 4-PS3-2), weather patterns (3-ESS2-1), severe weather (3-ESS3-1), and the relationships between living organisms and the environment (3-LS4-3, 3-LS4-4, 5-LS1-1, 5-LS2-1). However, there is also the appearance of the concept that Earth can change quickly or slowly (2-ESS1-1). This is an important idea in climate change science, since climate change is a gradual process occurring over timescales unfamiliar to normal human experience.

The middle school performance standards mark the first introduction of atomic-molecular models (MS-PS1-1). Atomic-molecular models are necessary to understand how the carbon cycle and the thermal expansion of water relate to climate change and its impacts (e.g., sea level rise).

The high school performance standards present an even more sophisticated level of understanding of the constructs associated with climate change. For example, the high school standards formally introduce the carbon cycle (HS-ESS2-6), which is a key central construct in climate change science.

**Hypothetical Learning Progressions of Three Consequences of Climate Change**

In developing hypothetical learning progressions for our three LPs (enhanced urban heat island effect, extreme weather, and sea level rise) we were assisted by our comprehensive review of the NGSS for the presence of climate change (explicitly and proximally) in the performance expectations. From our review of LPs, we were aware that a variety of approaches existed for the development of a learning progression (Duschl, Maeng, & Sezen, 2011; Salinas, 2009; Shavelson, 2012). It was acknowledged that which approach was taken by researchers depended on the nature of the construct, access to participants, and the researchers' methodological preferences. We decided that since the Water Cycling LP by Gunckel, Covitt, Salinas, and Anderson (2012) was environmentally focused and included an emphasis on impacts, as did the topics we had targeted for LP development, we would model our three hypothetical LPs after its four level structure which represented learners' increasing sophistication of understanding over time by level and by multiple dimensions. The lower anchor (what would be expected of learners to hold of the construct when they entered school) would be level one, and the upper anchor (what would be expected of learners to hold of the construct when they completed 12th grade) would be level four. Levels two and three would represent conceptual areas in LPs that Gotwals and Songer (2010, p. 259) termed "messy middles," where learners development of the ability to reason scientifically about complex topics is complicated and may not be the same for pathway for all learners.

Our task to draft hypothetical LPs for our three consequences of climate change was made more feasible by our earlier decisions of how to structure our LPs and which primary source material to use to develop them. As a result, we were able to construct our desired three hypothetical LPs for the consequences of climate change in the three regions in which the learners in our project lived. See Table 1 (Hypothetical Learning Progression for Enhanced Urban Heat Island Effect), Table 2 (Hypothetical Learning Progression for Extreme Weather), and Table 3 (Hypothetical Learning Progression for Sea Level Rise).

**Table 1**

Hypothetical Learning Progression for Enhanced Urban Heat Island Effect

| Potential LP Indicator | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| Energy Association*<br><br>*based on Jin & Anderson (2012) | Energy is associated with life, conditions, or feelings: Students state that the sunlight enables urban surfaces and air to become hot (by its presence) or cold (by its absence). Students fail to understand that the air continues to warm after the sun goes down. | Energy is associated with a physical necessity powering hidden processes or under-going changes in hidden processes: Students state that sunlight energy is needed to heat materials in an urban environment, and that different materials absorb different amounts of this energy. Students begin to understand that energy is released from hot objects through invisible radiation. | Energy is associated with different sources: Students state that energy can come from sunlight or from hot urban surfaces that release infrared radiation. They understand that radiation from the sun can warm surfaces (differentially), and radiation from surfaces can warm the air. | Energy is associated with its transfer and transformation through different materials: Students state that sunlight is absorbed by urban surfaces (differentially), transforming into sensible or latent heat, kinetic energy, and infrared radiation. This energy can then be transferred to other surfaces, the atmosphere, or space. |
| Energy Tracing*<br><br>*based on Jin & Anderson (2012) | Energy is traced using a cause-effect chain, with actions, functions, physical interaction, or conditions acting as causal mechanisms: Students state that sunlight provides surfaces with the conditions for getting hot. They hit/touch surfaces, move inside of them, and are used up or move into the environment. | Energy is traced through mixing processes between materials and energy: Students describe processes in which sunlight is mixed with surface materials to make heat. The heat can then move and combine with the air, which becomes warmer. | Energy is traced through conversions in physical processes: Students state that light energy may turn into heat or radiation, which is released into the environment. However, students fail to use the law of conservation of energy consistently as a constraining principle. | Energy is traced through transformations and transfers among different materials: Students explain how radiation is absorbed or reflected from the sun, depending on the properties of surface materials. After materials absorb radiation, energy can be transferred to the air through convection or evapotranspiration, or to air or other surfaces through radiation. Students use the law of conservation of energy consistently to explain the urban surface-air energy budget. |
| Role of Materials*<br><br>*based on Mohan, Chen, & Anderson (2009) | Materials are treated as actors that become warm when enablers like sunlight are present. | Materials are used to explain that some surfaces become warmer than other surfaces in response to sunlight, causing a warmer environment. | Materials are used to explain that different surfaces absorb, retain, and transfer different amounts of energy, which then heats the environment differentially. | Materials are used to explain how and why different surfaces absorb, retain, and transfer different amounts of energy throughout the day. |
| Role of Vegetation and Water | Vegetation and water are identified as factors that enable environments to be cooler. | Vegetation and water are used to describe landscapes that do not absorb as much sunlight energy or change temperature as readily. | Vegetation and water are used to explain how vegetation provides shade, lowering surface temperatures, and water absorbs energy without changing temperature readily. | Vegetation and water are used to explain how vegetation provides shade, lowering surface temperatures, as well as how water in vegetation acts to dissipate ambient heat through evapotranspiration. Additionally, bodies of water can act as "heat sinks," due to water's high specific heat. |
| Contributing Factors | Students are aware that there are factors that contribute to the heat island effect, but they are not able to identify specifics. | Students are able to identify the sources that contribute to the UHI effect (e.g., pavement, lack of vegetation), but are not able to explain how they influence the urban heat island effect. | Students are able to identify sources that contribute to the UHI effect (e.g. pavement, lack of vegetation), and explain how these sources contribute to the UHI effect, but are not able to use models to predict outcomes of changes to the sources. | Students are able to use models to predict outcomes when given various scenarios about changing attributes of a UHI (e.g. a park densely populated with trees is converted into an athletic stadium with large parking lots). |

**Table 2**

Hypothetical Learning Progression for Extreme Weather

| Potential LP Indicator | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| Human Contribution | Students are not able to obtain, evaluate, and communicate information that human activities can contribute to the frequency and intensity of some natural hazards. | Students are able to obtain, evaluate, and communicate information that human activities can contribute to the frequency and intensity of some natural hazards. | Students are able to analyze data to evaluate claims that human activities can contribute to the frequency and intensity of some natural hazards. | Students are able to construct and evaluate scientific claims based on evidence that human activities can contribute to the frequency and intensity of some natural hazards. |
| Modifying Climate Systems | Students are not able to use data to identify solutions that may reduce the environmental or societal impacts of a weather-related hazard. | Students are able to use data to identify solutions that may reduce the environmental or societal impacts of a weather-related hazard. | Students are able to apply scientific knowledge to construct explanations for how humans may predict and modify their impacts on future global climate systems. | Students are able to apply scientific reasoning, theory, and models to construct explanations for how humans may predict and modify their impacts on future global climate systems. |
| Links between Climate Change and Extreme Weather | Students are not aware that a changing climate leads to changes in extreme weather and climate events. | Students are aware that a changing climate leads to changes in extreme weather and climate events, though students are not able to consider factors such as frequency, intensity, spatial extent, duration, and timing. | Students understand that a changing climate leads to changes in extreme weather and climate events, though students do not consistently consider factors such as frequency, intensity, spatial extent, duration, and timing. | Students understand that a changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events, and can result in unprecedented extreme weather and climate events |

**Table 3**

Hypothetical Learning Progression for Sea Level Rise

| Potential LP Indicator | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| Scale and Mechanism*<br><br>*based on Gunckel, Covitt, Salinas, & Anderson (2012) | Students explain sea level rise on a macroscopic scale only, focusing on immediately visible structures or phenomena without including mechanisms for phenomena. | Students explain sea level rise on a broad macroscopic to large-scale focus across familiar and visible dimensions. Students can identify a mechanism, though they rely on actors or agents. | Students explain sea level rise on the microscopic to the landscape scale, though they may refer to smaller particles such as atoms or molecules. Students are able to put events in order, but do not include driving forces or constraining factors. | Students explain sea level rise on the atomic-molecular scale. Students use driving forces (e.g. gravity), as well as constraining factors (e.g. topography) to explain changes in sea level. |
| Representations*<br><br>*based on Gunckel, Covitt, Salinas, & Anderson (2012) | Students are able to obtain useful information from representations related to sea level rise, though they are not able to connect these representations to the physical world. | Students are able to make limited connections between the physical world and representations related to sea level rise. | Students are able to connect representations of sea level rise to the three-dimensional physical world, but do not infer driving forces or constraining variables. | Students are able to interpret driving forces and constraining factors related to sea level changes based on representations. |
| Causes | Students identify global warming as a cause of sea level rise. | Students recognize that global warming causes sea level rise, but are not able to identify factors such as thermal expansion and ice melt. Students can identify a mechanism, though they rely on actors or agents. | Students understand that sea level rise scenarios are based on thermal expansion and ice melt, though they do not consistently relate these factors to atomic-molecular models. | Students understand that sea level rise scenarios are based on thermal expansion and ice melt, and they are able to explain these factors using atomic-molecular models consistently. |
| Impacts | Students identify that an impact of sea level rise is that some land in coastal areas and islands will be underwater, though they are not able to elaborate on specific consequences of sea level rise. | Students understand that sea level is projected to rise in the future and are able to identify a limited number of specific consequences, though they do not understand that sea level change will have local effects including those related to storm surge. | Students understand that local impacts of sea level changes can differ, but cannot explain primary factors that can cause this difference. Students are able to elaborate on specific consequences of sea level rise such as loss of habitat, in-land flooding during storms, property loss, and erosion. | Students understand that local sea level changes can differ from global trends based on regional variations in factors such as geographic uplift or subsidence and ocean currents. Students are able to elaborate on specific consequences of local sea level rise. Students recognize that sea level rise projections are based on available data and may be lower or higher than predicted. |

## A Case in Point: Sea Level Rise (SLR)

Recognizing the limitations of our three hypothetical LPs, particularly that the LPs were informed empirically by student thinking as reported in the literature, and they had not benefited from expert science content consultation, we decided to focus first on refining the Sea Level Rise LP by use of science instruction and analysis of learner's conceptual understanding of the construct. From that experience, we hoped to report an example of how one hypothetical LP could be further developed by targeted instruction and by use of empirical data of learners' thinking. We decided to select sea level rise as that example. Research by McNeill & Pimentel, 2010 on learners' understandings of climate change has suggested that place and context may have the potential to shape learners' perspectives on climate change. Our Maryland and Delaware context with coastal areas along both states influenced to a large extent our decision to select sea level rise for this next step of our learning progressions research in climate change education. Lester, Ma, Lee, and Lambert (2006) provided evidence that learners in their coastal context attended to sea level rise as an aspect of climate change that was relevant to their own lives. Because the learners in our study were likewise located in a region likely to be affected by sea level rise (U.S. Global Change Research Program, 2014), we posited that the topic would be of particular relevance and interest to them.

We first conducted a review of the scientific literature to determine what is known scientifically about sea level rise. Three analytical categories emerged: causes and mechanisms, scale and representation and impacts. As a result of this information from the scientific community, we revised the dimensions in our original SLR LP to correspond to them, and not to the four dimensions with which we had taken from Gunckel et al. (2012).

We next reviewed the science education literature on learners' conceptions of sea level rise. We found that only a few studies have included the topic of sea level rise within larger examinations of learners' climate change knowledge. Rebich and Gautier (2005), and Shepardson, Niyogi, Choi, and Charusombat (2011) reported that many learners are aware that ocean levels are likely to rise as a result of melting polar ice. However, they also found that many of the learners may fail to consider the role of thermal expansion in sea level rise. Choi, Niyogi, Shepardson, and Charusombat (2010) suggested that this conceptual omission might relate to the information communicated in Earth Science textbooks for such learners. Their analysis reveals that textbooks typically attribute sea level rise to ice melt and fail to represent the complexity of the issue and Earth's systems. Shepardson et al. also reported that learners may hold the view that sea levels will rise as a result of increased precipitation, or that their view of evaporation led them to think that sea levels declined or stayed the same as a result of evaporation.

Informed by what we had learned by our review of the policy and science education material, we next spent considerable time in collecting empirical data from learners (seventh grade middle school learners in three suburban public schools, n = 95, and senior level teacher education undergraduates at a MidAtlantic University, college, n = 77)[3]. By administration of open-ended surveys, responses to questions in researcher-crafted online sea level modules for middle school learners and for prospective teachers of science, interviews, and a researcher-crafted instrument (16 multiple choice items accompanied by an explanation for why they selected their choices) aligned with the three dimensions of our hypothetical SLR LP, we asked learners to describe what they knew about sea level, especially its causes and impacts (16 multiple choice items accompanied by an explanation for why they selected their choices).

From these empirical data we gained insight into our learners' thinking about sea level rise. Encouragingly, informed by three hours of instruction by their classroom teachers in their school district's Weather and Climate curriculum topic the middle school learners knew much about sea level rise that conforms to canonical scientific understandings. This includes that sea level rise is caused by global warming/climate change, which causes increased ice melt on

[3] This section is informed particularly by unpublished findings of middle school learners thinking of sea level rise by co-author McDonald that were collected for his in-process dissertation study, "A Process For Developing And Refining A Learning Progression On Sea Level Rise Using Learner Explanations."

Earth's surface that could impact humans. As stated by one middle level learner, "*I know in some places and southeast Asia, um, if sea level, like, rose even a few feet, it would displace millions of people*." Learners knew that water cycles among land, ocean, and atmosphere and that water movement causes weathering and erosion, changing landscape features. Learners also knew that the fact that matter is composed of atoms and molecules could be used to explain the properties of substances, diversity of materials, states of matter, phase changes, and conservation of matter. Additionally, learners knew that kinetic energy could be distinguished from the various forms of potential energy. Energy changes to and from each type can be tracked through physical or chemical interactions. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter.

Conversely, we learned from collecting and interpreting data on middle school learners' thinking about sea level rise that some learners might express alternative conceptions. For example, learners may explain that the moon's gravity causes sea level change, conflating the cause of tides with the causes of sea level rise. As stated by one middle school learner, "*When the Ice melts more water goes into the sea increasing the sea level. The moons gravity pulls water towards it so when it's above the seawater gets pulled under it raising the sea level.* And, learners may believe that an iceberg, or sea ice, would contribute to sea level rise, even though icebergs already occupy volume in the sea in solid form, because they are already floating in the sea. As stated by a middle school learner, "*The melting of ice berg (global warming in a sense) ice berg melt (sic) in the heat so where does the melted ice go? Exactly the ocean! The ocean takes all the water and with the extra water the ocean sea level rises.*"

Our sensemaking of our learners' thinking about sea level rise in middle school and at the collegiate level where we employed the same process of instruction and analysis of learner thinking of the construct enabled us to refine our hypothetical SLR LP (the undergraduate sample was instrumental in assisting us to establish the upper anchor). In Table 4, we present our current version (termed "conditional") of our Sea Level Rise LP consisting of three components: *Scale and Representations*, *Causes and Mechanisms*, and *Impacts* (Breslyn, McGinnis, McDonald, & Hestness, 2016, accepted).

**Table 4**

Conditional Learning Progression for Sea Level Rise

| Potential LP Indicator | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| Scale and Representations*<br><br>*based on Gunckel, Covitt, Salinas, & Anderson (2012) | Students explain sea level rise on a macroscopic scale only, focusing on immediately visible structures or phenomena and are able to obtain useful information from representations related to sea level rise, although they do not connect these representations to the physical world. | Students explain sea level rise with a broad, large-scale focus across familiar and visible dimensions and are able to make limited connections between the physical world and representations related to sea level rise. | Students explain sea level rise on the landscape scale and are able to connect representations of sea level rise to the three-dimensional physical world, and begin to connect driving forces (e.g., gravity) or constraining variables (e.g. topography). | Students explain sea level rise on the macroscopic and atomic-molecular scale. Students use driving forces (e.g., gravity), as well as constraining factors (e.g. topography) to explain changes in sea level. They can interpret data from graphs and tables to describe varying projections of sea level rise. |
| Causes and Mechanisms | Students identify global warming due to the enhanced greenhouse effect as a cause of sea level rise. | Students recognize that global warming causes ice melt (not distinguishing between terrestrial and sea ice) leading to rising sea levels but do not identify thermal expansion as a factor in sea level rise. Students can identify a mechanism that relies on thinking about sea level rise anthropomorphically. | Students understand that sea level rise scenarios are based on thermal expansion and ice melt (not distinguishing between terrestrial and sea ice), though they do not consistently relate these factors to atomic-molecular models. | Students understand that sea level rise scenarios are based on thermal expansion and terrestrial ice melt, and they are able to explain these factors using atomic-molecular models consistently. |
| Impacts of Sea Level Rise | Students identify that an impact of sea level rise is that some land will be covered by water, though they are not able to elaborate on specific consequences of sea level rise. | Students understand that sea level is projected to rise in the future and are able to identify a limited number of specific consequences, though they do not understand that sea level rise will have local effects including those related to storm surge. | Students understand that local impacts of sea level changes can differ, but cannot explain primary factors that can cause this difference. Students are able to elaborate on specific consequences of sea level rise such as loss of habitat, in-land flooding during storms, property loss, and erosion. | Students understand that local sea level changes can differ from global trends based on regional variations in factors such as geographic uplift or subsidence and ocean currents. Students are able to elaborate on specific consequences of local sea level rise. Students recognize that sea level rise projections are based on available data and may be lower or higher than predicted. |

The transition from a hypothetical LP, to what we have described as a "conditional LP" (i.e., empirically informed, but provisional in that it would benefit from the collection and analysis of additional K-12 learner data from a diverse sample by age and geographical background), required an iterative and sustained effort. That included the analysis of empirical data to identify, not only growing knowledge about sea level rise, but also the qualitative shifts in understanding students experienced as their thinking grew in sophistication during targeted instruction of the topic. An example of a shift can be seen in the *Scale and Representations* component of the SLR LP.  As students advance in their understanding of the scale and representations of sea level rise they begin to understand that, although sea level is dynamic, it is the average sea level that is rising. This can lead to their viewing sea level rise as varying by geographic area as a result of driving forces (e.g., gravity and flow of water to lower areas) as well as constraining variables (e.g., topography) that influence the extent of sea level rise. As students progress, they are able to use representations such as graphs and tables to describe current and future sea levels and understand that future level are projections that may vary.

Another example of such a shift can be seen in the *Causes and Mechanisms* component. Here students advance from the lower anchor, where explanations are more macroscopic, to a more atomic/molecular understanding of sea level rise. This allows them to include the concept of thermal expansion of water, the most significant contributor to rising sea levels, in their understanding of sea level rise. And for the *Impacts* component of the SLR LP, an example of such a shift is when students advance from lower anchors, where they consider sea level rise to be a gradual, consistent change, to thinking of sea level rise as a more dynamic phenomena where storm surge can intermittently lead to impacts further inland. They also are able to describe a wider range of consequences of sea level rise as they progress. At the upper anchors they can describe the influence of changing geographic features as well as ocean currents.

Finally, students understand projections are useful for predicting impacts, however, projections are based on models and are tentative and may change.

A comparison of our conditional Sea Level Rise LP with our hypothetical LPs for Extreme Weather and the Enhanced Urban Heat Island Effect demonstrates how the process we used leads to a more refined (i.e., detailed and nuanced) description of student thinking of the topic.

As stated, we now classify our hypothetical Sea Level Rise LP as “conditional,” rather than as a more initial status of “hypothetical.” While we consider our conditional Sea Level Rise LP to be more refined than our original hypothetical LP that we constructed based on policy documents and review of the literature on student thinking, it remains available for additional refinement contingent on what additional empirical data from a larger and more diverse sample might reveal. As a result, we believe our most current version of our conditional SLR LP along with accompanying materials (such as its assessment instrument and the Sea Level Module for science teacher educators) (see, Breslyn, McGinnis, McDonald, & Hestness, in press) may be used with confidence by those involved in climate change education, i.e., researchers, curriculum designers, science teacher educators, and practitioners (formal and informal).

## Conclusion

Our decision to approach an investigation of climate change in science education by application of LP theory has been productive, yet much remains to be accomplished. Positively, by focusing on development of a limited subset of hypothetical LPs for the consequences of climate change that were selected to align with the geographical regions represented in our context has resulted in tangible progress in our quest to include climate change in science teacher education and in the science curriculum. Over much time and with considerable concerted effort we have been able to empirically inform our hypothetical Sea Level Rise LP by use of data on learners' thinking, and thus move it to a conditional state. As a result, our conditional Sea Level LP and the process by which we developed and refined it (along with accompanying educational material) are available to the field for use. Remaining to be accomplished is a similar outcome for the hypothetical LPs for Extreme Weather and the Enhanced Urban Heat Island Effect. We offer them to others who may wish to refine them similarly as we did for our conditional SLR LP by use of science instruction and collection and analysis of learners' thinking of the constructs.

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References

American Association for the Advancement of Science. (2001). Atlas of Science Literacy (Vol. Project 2061). Washington, DC: American Association for the Advancement of Science (AAAS) and the National Science Teachers Association.

Breslyn, W., McGinnis, J. R., McDonald, C., & Hestness, E. (2016, accepted). Developing a Learning Progression for Sea Level Rise, a Major Impact of Climate Change. *Journal of Research in Science Teaching*.

Choi, S., Niyogi, D., Shepardson, D. P., & Charusombat, U. (2010). Do Earth and environmental science textbooks promote middle and high school students' conceptual development about climate change? Textbooks' consideration of students' misconceptions. *Bulletin of the American Meteorological Society, 91*(7), 889-898.

Duncan, R. G., & Hmelo-Silver, C. E. (2009). Learning progressions: Aligning curriculum, instruction, and assessment. Journal of Research in Science Teaching, 46(6), 606-609.

Duschl, R., Maeng, S., & Sezen, A. (2011). Learning progressions and teaching sequences: A review and analysis. Studies in Science Education, 47(2), 123-182.

Furtak, E. M. (2012). Linking a learning progression for natural selection to teachers' enactment of formative assessment. *Journal of Research in Science Teaching, 49*(9), 1181–1210.

Furtak, E.M. & Morrison, D. (2013). Challenges in developing classroom assessments linked to a multidimensional learning progression. Paper presented at the annual meeting of NARST: A Worldwide Organization for the Improvement of Science Teaching through Research, Rio Grande, Puerto Rico.

Furtak, E. M., & Heredia, S. C. (2014). Exploring the influence of learning progressions in two teacher communities. Journal of Research in Science Teaching, 51(8), 982-1020.

Gotwals, & Songer, N. (2009). Reasoning up and down a food chain: Using an assessment framework to investigate students' middle knowledge. Science Education, 94 (2), 259-281.

Gunckel, K. L., Covitt, B. A., Salinas, I., & Anderson, C. W. (2012). A learning progression for water in socio-ecological systems. Journal of Research in Science Teaching, 49(7), 843-868.

Heredia, S., Furtak, E.M., & Morrison, D. (2012). Item context: How organisms used to frame natural selection items influence student response choices. Paper presented at the annual meeting of the *National Association of Research in Science Teaching* Annual Meeting, Indianapolis, IN.

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

Hestness, E. McGinnis, J. R., Breslyn, W., McDonald, C. , Mouza, C. Shea, N., & Wellington, K. (2014). Investigating science educators' conceptions of climate science and learning progressions in a professional development academy on climate change education. A presentation at NARST: A worldwide organization for the improving science teaching and learning through research, Pittsburgh, PA, April 1, 2014.

Hmelo-Silver, C.E., & Duncan, R.G. (2009). Learning progressions. Journal of Research in Science Teaching, 46(6): 606–609.

Jin, H. & Anderson, C. W. (2012). A learning progression for energy in socio-ecological systems. Journal of Research in Science Teaching, 49(9), 1149-1180.

Krajcik, J. S., Sutherland, L. M., Drago, K., & Merritt, J. (2012). The promise and value of learning progression research. In S. Bernholt, K. Neumann, & P. Nentwig (Eds.), Making it tangible: Learning outcomes in science education (pp. 261–284). Münster, Germany: Waxmann Verlag.

Lambert, J. L., Lindgren, J., & Bleicher, R. 2012. Assessing elementary science methods students' understanding about global climate change. International Journal of Science Education, 34(8): 1167-1187.

Lehrer, R., & Schauble, L. (2009). Images of learning, images of progress. Journal of Research in Science Teaching, 46(6), 731-735.

Lehrer, R., & Schauble, L. (2012). Seeding evolutionary thinking by engaging children in modeling its foundations. Science Education, 46(6), 731-735.

Lester, B. T., Ma, L., Lee, O., & Lambert, J. (2006). Social activism in elementary science education: A science, technology, and society approach to teach global warming. International Journal of Science Education, 28(4), 315-339.

McGinnis, J. R., (2013, April). Climate change education: Teaching, learning, and assessment. : The case of MADE CLEAR. A paper presented at NARST: A worldwide organization for the improving science teaching and learning through research, Río Grande, Puerto Rico, April 9, 2013.

McGinnis, J. R. , McDonald, C. , & Breslyn, W. (2013). Climate change in the Next Generation Science Standards. Retrieved 2/29/16 from www.climateedresearch.org/publications/2013/Climate-Change-NGSS.pdf.

McNeill, K. L., & Pimentel, D. S. (2010). Scientific discourse in three urban classrooms: The role of the teacher in engaging high school students in argumentation. Science Education, 94(2), 203-229.

Mohan, L., Chen, J., & Anderson, C. W. (2009). Developing a multi-year learning progression for carbon cycling in socio-ecological systems. Journal of Research in Science Teaching, 46(6), 675-698.

Nehm, R. H., & Ha, M. (2011). Item feature effects in evolution assessment. Journal of Research in Science Teaching, 48(3), 237-256.

Next Generation Science Standards Lead States. (2013). Next Generation Science Standards: For states, by states. Washington, DC: The National Academies Press.

Rebich, S., & Gautier, C. (2005). Concept mapping to reveal prior knowledge and conceptual change in a mock summit course on global climate change. *Journal of Geoscience Education, 53*(4), 355.

Salinas, I. (2009, June). Learning progressions in science education: Two approaches for development. In Learning Progressions in Science (LeaPS) Conference, Iowa City, IA.

Shavelson, R. J., & Kurpius, A. (2012). Reflections on learning progressions. In Learning progressions in science (pp. 13-26). Sense Publishers.

Shea, N. A., & Duncan, R. G. (2013). From theory to data: The process of refining a learning progression. Journal of the Learning Sciences, 22(1), 7-32.

Shepardson, D. P., Niyogi, D., Choi, S., & Charusombat, U. (2011). Students’ conceptions about the greenhouse effect, global warming, and climate change. *Climatic Change, 104*(3-4), 481-507.

U.S. Global Change Research Program. 2014. Climate change impacts in the United States. In

Melillo, J.M., Richmond, T.C., and Yohe, G.W., eds., U.S. national climate assessment. Washington, DC: U.S. Government Printing Office. Available at nca2014.globalchange.gov (accessed 3 July 2014).