Examining a Process for Developing a Learning Progression for Sea Level Rise

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Abstract

In this study, we present research from an exploratory study on a learning progression (LP) for sea level rise (SLR), a consequence of global climate change. For heuristic purposes, and in recognition of the value of extant knowledge of the topic in the literature and by experts in oceanography, we began our research by first drafting a hypothetical and provisional learning progression for sea level rise. We generated it from a comprehensive review of the educational literature on the construct and science reference and policy documents (the AAAS Science Literacy Maps, and the Next Generation Science Standards). Our confidence in our provisional LP was greater for the lower and upper anchors than for the middle level(s), but for all levels we were tentative in the absence of empirical data that we could collect from learners of different ages. We next developed an assessment instrument as well as an online activity with accompanying instrument on sea level rise as a way to elicit learners' actual thinking about sea level rise. These instruments were administered to middle school students (N=90) and undergraduate pre-service teachers (N=77). An analysis of the data suggested that our draft hypothetical and provisional learning progression for sea level rise was robust, but it underscored the necessity of probing learners' thinking of the construct to develop, in particular, the middle levels of a hypothetical and provisional LP. The assessment data provided useful information about learner understanding about the construct of sea level rise to assist us in moving our LP development from a provisional to a conditional status hypothetical SLR LP. The development of a conditional SLR learning progression, along with the accompanying assessment instruments contributes to research and thinking about learning progressions, in general, and climate change education, in particular.

Keywords: learning progressions, sea level rise, climate change

Introduction

Learning progressions are an area of high interest and activity in the science education research community (see, for example, Plummer & Maynard, 2014; Neumann, et. al 2013; Furtak, 2014). In the U.S. this is underscored by the recent release of the Next Generation Science Standards (NGSS) which emphasizes learning progressions as a way to connect disciplinary core ideas and practices across grade bands (NGSS Lead States, 2013). Also included in the NGSS are disciplinary core ideas, scientific practices and cross cutting concepts associated with the topic of climate change. This, coupled with a growing sense of awareness and urgency about the consequences of a changing climate (USGCRP, 2014), points to the need for a much more complete understanding of students' thinking about climate change and its resulting effects. Specifically, what pathways do students take as they move from a naive to a sophisticated understanding of sea level rise, and how can this thinking be made visible?

In our research, we focus on the construct of sea level rise, a major effect of climate change. Doing so enabled us to target our research efforts on developing a robust learning progression (LP) for one of the most visible and severe consequences of climate change. Currently, the effects of sea level rise are being felt around the world and sea levels are projected to increase between one and four feet by 2100 (IPCC, 2013). With 39% of the U.S. population, or 123.2 million people, living in counties located on the shoreline (NOAA, 2010), sea level rise represents an important and relevant topic for learners.

While there are a number of climate change constructs needing study, sea level rise is of particular worth because of its relevance to many students who live in communities situated near the sea and because of the accessible nature of the topic. Indeed, it is increasingly common to see sea level rise reported in the mass media as an immediate impact of climate change (Bellafante, 2015; McCoy 2015). However, compared to other science constructs such as energy, there is a dearth of understanding of learners' conceptions of sea level rise. Much remains uncertain as to the path or paths learners take to more sophisticated understandings of it, and of the critical components of those paths.

We believe that the report of our SLR LP study at this time in its development is timely and of particular value to the research community as learning progression research proceeds in the quest to become more mature as a research program. That is, reported interim stages of the LP process are needed to reveal the complexities and the decisions made by investigators in this realm of research. We believe that only by highlighting the necessary steps that constitute the development of a more research-based LP will this research program be open for more informed debate and establishment of warrants to assess LP development. Therefore, in this report of our ongoing four-year-in-duration research, we describe the status of the development of our learning progression for sea level rise with a focus on describing the ongoing exploratory nature of the process. We detail the resources, decisions, and necessary steps taken to bring our research to its present status, built on multiple stages of empirical data collection and an iterative review of the contents and structure of the LP.

Literature Review

Without doubt, learning progression research in science education is in its preliminary phase of development as a research program. There remains much diversity of thought in the research community as to how it is defined and carried out as differing researchers implement it for differing purposes (see, for example, Steedle and Shavelson, 2009). There are even challenges by a few researchers to the assumptions and goals of the learning progressions paradigm with assertions of risk to the field by its application (Sikorski and Hammer, 2010). We hold the belief that it is better for the field to utilize newer thinking, such as learning progressions that have shown promise by adding new methods and by providing new insights concerning how learners learn science. Needless to say, as conscientious researchers we remain on guard not to think of learning progression research as the end all of educational research or to use it to disregard earlier promising findings resulting from applications of different theoretical perspectives in our quest to contribute to climate change education research (see www.ClimateEdResearch.org).

To begin our LP development process, we found it helpful to think of learning progressions as descriptions of the increasingly sophisticated ways that learners think about a science topic over time (Duschl, Schweingruber, & Shouse, 2007). They are generally organized into qualitatively different levels of achievement (e.g., Alonzo & Steedle, 2008; Lehrer & Schauble, 2012; Mohan, Chen, & Anderson, 2009) and these levels are considered conceptual stepping stones, or benchmarks, which educators can use as diagnostic tools and instructional targets (Lehrer &

Schauble; Shea & Duncan, 2013). The upper anchor represents what students should know by the end of high school. The lower anchor represents student understanding prior to instruction on the construct.

A frequently cited advantage of learning progressions is their ability to describe student learning *as it develops*. This provides an opportunity to better align curriculum, instruction, and assessment with how students learn and to anticipate the difficulties they may experience with a given construct. Others also have cited the value of involving teachers in the development of learning progressions as a form of professional development (Furtak & Heredia, 2014; Shea & Duncan, 2013).

The consensus in the research community is that learning progressions take place over extended periods of time (Corcoran, Mosher, & Rogat, 2009; NRC, 2007; Shea & Duncan, 2013). In *Taking Science to School*, NRC (2007) describes quality instruction as:

> *"strategically designing student encounters with science that take place in real time and over a period of months and years (e.g., learning progressions)."*

It is important to note that learning progressions are commonly referred to differently in the mathematics literature than in the majority of the science education literature. They are referred to by mathematics education researchers as learning trajectories and they are based on shorter term, more topical areas of learning (Daro, Mosher, & Corcoran, 2011; Simon, 1995). Often learning trajectories focus on only several grade levels. Similar to learning progressions in science education, trajectories are based on empirical evidence and involve hypotheses about the path or paths students take towards a sophisticated understanding of a topic.

There have been some efforts to reconcile these two stances held by differing education research communities. Plummer and Krajick (2010) and Wilson (2005) have described learning trajectories as sub-progressions making up a larger learning progression. In their work on celestial motion, Plummer and Krajick choose to focus on how learners progress in their understanding of celestial motion from an earth-based observational perspective. Since there are other components of celestial motion (e.g., seasons, phases of the moon) the researchers used the term *learning trajectories* to highlight the smaller grain size of their work.

While the majority of research on learning progressions in science education looks at learning over months or years, based on our review of the literature we believe tentatively that learning progressions may also be studied over shorter timeframes. For example, Steedle & Shavelson (2009) studied the physics topic of force and motion over the course of an instructional unit. The authors cite the work of Wilson (2005) with construct maps and Kennedy et al. (2005) with progress variables as examples supporting the effectiveness of the learning progression framework over shorter timeframes.

Another frequently cited aspect of learning progression research is that it focuses on the "big ideas" of a discipline (Duschl, Maeng, & Sezen, 2011; Krajcik, Sutherland, Drago, & Merritt, 2012; NRC, 2007). These ideas are said to be central to the discipline and generative in nature. The topic of climate change, and its consequences such as sea level rise, is included in the NGSS at the middle and high school grades because it represents a core science idea.

A number of researchers stress the need for the development of learning progressions to take place in the context of classroom instruction (Furtak, 2012; Songer, 2009; Shea & Duncan, 2013). They argue that curriculum is needed to elicit student thinking and uncover alternative conceptions in order to build a robust empirically-supported learning progression for a construct. It is also noted that specific curriculum can influence students' learning pathways (Hmelo-Silver & Duncan, 2009). We also believe that, for topics such as sea level rise where students have limited experience, instruction is critical in order to observe how learning progresses. Moreover, we believe that LPs potential can only be realized if investigators can effectively revise LPs based on empirical findings and develop an acceptable set of methods and heuristics to facilitate such revision. This revision and refinement work often needs to be done in classroom contexts through targeted and LP-driven instruction. Such efforts are challenging given the resulting messy and context-dependent nature of the data (Shea & Duncan, 2013).

Approaches

A variety of approaches exist for the development of a learning progression (Duschl, Maeng, & Sezen, 2011; Salinas, 2009; Shavelson, 2012). Which approach is taken by researchers depends on the nature of the construct, access to participants, and the researchers' methodological preferences. In addition, it may be appropriate to take different approaches at different stages of learning progression development (Shea & Duncan, 2013). In our own work with sea level rise, although we have been investigating it for the past four years, we recognize that we are still in an exploratory stage of development of a LP which influences heavily the research methods that we employ to elicit and measure student thinking.

In the very early stages of developing a learning progression, an initial or hypothetical learning progression is developed around a core science idea. Development often proceeds based on an analysis of standards documents, science education research literature on the topic, as well as science content. Based on this hypothetical progression, instrumentation is developed to elicit and collect data about student thinking on the topic. In our work, these initial stages were essential due to limited educational research on the topic as well as an evolving understanding of the mechanisms and consequences of sea level rise.

A hallmark of learning progressions is their reliance on empirical data to provide evidence to modify and refine the progression. Interviews and open-ended assessments are frequently used (e.g., Furtak, 2012, Gunckel et al., 2012, Gotwals & Songer; 2013; Mohan et al., 2009) as are classroom discourse (e.g. Berland & McNeill, 2010; Schwarz et al., 2009) and multiple choice items (e.g., Steedle & Shavelson; 2009). Often a combination of these methods are used to provide data from multiple sources providing empirical support for the learning progression. Regardless of the data sources, the development and refinement of learning progressions usually follows an iterative path (Schwarz et al., 2009; Alonzo & Steedle, 2008; Shea & Duncan, 2013) as we have found in our present research.

An example of a learning progression that employs multiple data sources, each at different stages of the development of the progression, can be found in the work reported by Neumann et al. (2013). In a learning progression on the topic of energy they first established an initial learning progression based on existing curriculum and research on students' understanding and development on the topic of energy. Based on this information an instrument was developed and refined. Finally, the instrument was used on a large sample of students and the resulting data analyzed using Rasch analysis. For a topic like energy, where a substantial research base exists and the topic is taught across multiple grade levels, the initial stages of development are more accessible. However, for the topic of climate change and sea level rise, where the extant literature is more constrained and the topic is not yet part of formal schooling, the exploratory stages of development are slower and more time consuming.

Typically, the use of statistical modeling takes place after exploratory studies such as our research in students learning the concept of sea level rise have resulted in a conditional LP supported by empirical data. As we continue the process to increase confidence in our sea level rise learning progression, we anticipate that the statistical modeling techniques will be used in the future as part of a large-scale validation study of our conditional SLR LP.

In our exploratory study that has consisted of multiple steps, we viewed data collection and analysis in our LP work for SLR with an emphasis on empirically supporting or challenging our draft progression as well as on developing and establishing instrumentation and methods. To do so we took much care to study in detail instructional interventions of a shorter duration in order to maximize the number of iterations of modifications and refinement. Doing so allowed us to develop even more empirically supported conditional drafts of a SLR learning progression while refining the necessary instrumentation to be used in a future validation study with larger data sets.

Theoretical Framework

As we sought to develop an account of student understanding of SLR we were guided by the learning progressions theoretical framework. In particular, we see students' understanding about sea level rise progressing from a limited towards a more sophisticated understanding.

We conceptualize sea level rise as a construct that is appropriate for a LP investigation. That is, over time and with relevant instruction students progress in the sophistication of their understanding of the construct. Our sea level rise learning progression addresses both the mechanistic elements of sea level rise (e.g., phase changes, kinetic molecular theory) and its effects on humans (e.g., property loss, inland flooding during storms, and loss of ecosystems).

Because our research is in an exploratory stage we are careful to be mindful that there may be more than one pathway to a sophisticated understanding (NRC, 2007) and that these pathways may depend to some degree on the type of instruction students experience (Lehrer & Schaubel, 2009) and the personal and cultural experiences students have had with the construct. It is possible that another instructional experience would result in a different learning progression. Therefore, future data collection will include varying instructional activities as well as attention to including a very diverse study population.

Generally, learning progressions are considered to take place over extended periods of time (NRC, 2007). However, in the case of the sea level rise learning progression we assert that it may be described over a shorter timeframe. We agree with Shavelson (2009) that learning progressions are appropriate for constructs, like sea level rise, where learning is viewed over shorter durations. Our review of the literature and our experience in studying multiple samples of learners support our position that the learning progressions framework is effective for describing learning in shorter contexts as well as over extended periods of time.

Our decision to make sea level rise one focus of our learning progressions research was informed by our context. The National Climate Assessment has reported that sea level rise poses an increasing risk to U.S. coastal zones and to our northeast region in particular (U.S. Global Change Research Program, 2014). Prior research on learners' understandings of climate change has suggested that place and context may have the potential to shape learners' perspectives on climate change (e.g., Chhokar et al., 2011; McNeill & Pimentel, 2010). For example, 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, we posited that the topic would be of particular relevance and interest to them.

Because our learning progression is currently in the early stages of development, although we have spent nearly four years on it and have made productive progress, our primary research goal is to develop an initial empirically supported learning progression on the topic of sea level rise.

We examine the research question: *How can learners come to understand sea level rise in a progressively more sophisticated manner?*

In particular, our focus is on establishing the upper and lower anchors while beginning the more nuanced work to define the intermediate levels of the progression.

Context

Our study took place as part of a multi-year National Science Foundation grant (MADE CLEAR, www.madeclear.org) involving research, K-12, and informal science education organizations across two Mid-Atlantic States in the U.S. A., Delaware and Maryland. The project is tasked with the development and implementation of a climate change education plan for the region.

Both of the two participating states in the project were Lead State Partners in the development of the Next Generation Science Standards (NGSS, 2013) and are currently working to implement the new standards. Because NGSS includes climate change, a topic not traditionally taught in U.S.A. schools, both states have been active participants in the research.

Our data collection took place across three teaching and learning contexts including a middle school classroom, an undergraduate science methods course at a major research university, and at an environmentally themed summer science camp. Students in the middle school classroom (N= 90) completed a researcher-crafted Sea Level Rise Assessment Instrument, including written explanation for their responses. Undergraduate science methods students (N=77) completed an online sea level rise activity designed for our study. A subset of the pre-service teacher group also completed the Sea Level Rise Assessment Instrument. Students in the summer science camp (N=5) completed the assessment instrument and online activity as well as engaging in other activities and discussions about sea level rise.

An advantage to working with a variety of learners and instructional contexts is access to data representing varying levels of sophistication in learner understanding of sea level rise. In general, the undergraduate pre-service science teachers provided more detailed and sophisticated ideas on both the SLR Assessment Instrument and the online activity than did middle school students.

Methods

Development of the Hypothetical Learning Progression

Our work began with the development of a hypothetical learning progression. Initial development involved analysis of the AAAS Science Literacy Maps (AAAS, 2001), the NGSS (NGSS Lead States, 2013), input iteratively from SLR experts, scientific reports on SLR, and feedback from practicing teachers. The education research literature was also influential in the development of the hypothetical LP. Beginning with a hypothetical LP based on existing research and expertise enabled us to begin the process of designing robust assessments and activities to pilot and test.

Since the topic of sea level rise is only mentioned explicitly once in the NGSS (the clarification statement for HS-LS2-6), we looked at constructs closely related to the cause, mechanism, and impacts of sea level rise. For example, phase changes, thermal expansion, and climate change. The AAAS Science Literacy Maps were particularly useful in identifying these constructs and how learning is thought to progress over time. While not generally empirically supported, the Literacy Maps did provide a useful starting point. In addition, they provided access to essential research on conceptual development that identified alternate conceptions students may have on each of the targeted constructs associated with SLR.

Science experts in climate change and sea level rise also reviewed the hypothetical learning progression we produced from this stage of our process. This action was primarily to receive feedback on the accuracy and completeness of the upper anchor of our learning progression. Content experts from university and government provided feedback on the hypothetical learning progression as well as the sea level rise assessment instrument. In addition, middle and high school teachers also reviewed and provided feedback on the hypothetical learning progression and assessment instrument.

Finally, the emerging body of research on learning progressions guided the development of the hypothetical and provisional sea level rise learning progression. In particular, the work of Anderson (Jin & Anderson, 2012; Mohan, Chen, & Anderson, 2009) influenced significantly our early development of a hypothetical LP for SLR (including use of 4 levels for its multiple dimensions).

Development of the Empirically Supported Learning Progression

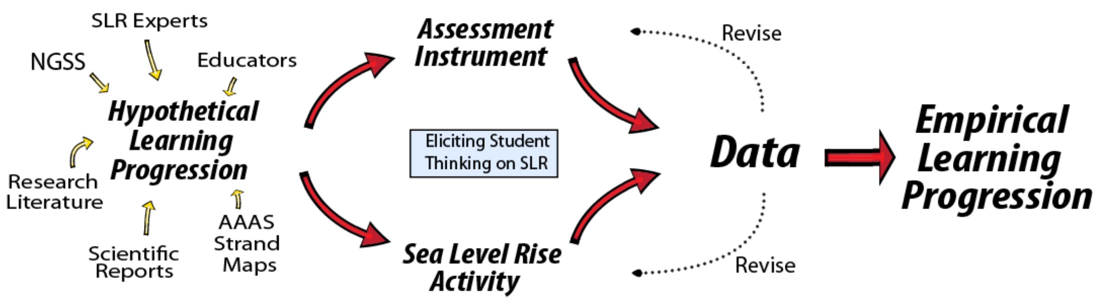
Our study employed a mixed methodology to develop an empirically supported learning progression. This involved the development of a set of assessment items (the SLR Assessment Instrument) to collect both quantitative and qualitative data, and an instructional activity (the Sea Level Rise Online Module) to provide qualitative data for analysis. Student drawings were also used to elicit student thinking about sea level rise.

To establish the upper anchors of the multidimensional LP we gathered data on the learners' understanding of the construct from undergraduate pre-service teachers at a mid-Atlantic university in the USA. We anticipated that this population would possess relatively sophisticated understandings as measured by our instruments. To gather learner thinking related to the lower levels of the LP, we worked with middle school learners.

We used an iterative methodological approach to develop our sea level rise learning progression (Figure 1). This began with the development of a draft hypothetical learning progression. The draft hypothetical LP for SLR served heuristically as a starting point for the first iteration of the SLR Assessment Instrument, which consisted of 15 multiple-choice questions.

The SLR Assessment Instrument (Appendix A) was administered multiple times with revisions between each administration. In piloting the instrument, we asked the undergraduate preservice teachers to provide written explanations of the reasoning behind their answers. Later, small group extensive discussion with middle school students at an environmentally themed summer camp served to further clarify participant responses. Middle school learners during the academic year were also asked to provide their reaction to the instrument. In addition, practicing teachers as well as sea level rise experts also provided feedback on each item.

Figure 1: Research Design



Middle school students and pre-service teachers' responses led primarily to clarifications of vocabulary and rewording text, as well as identification and modification of distractors. For example, learners were confused by the text "*a need for people to accommodate flooding along the coast by relocating structures.*" in the response to Item 5 (see Appendix A). The item was modified to "*a need for people to move and relocate structures further inland to accommodate flooding.*"

Initially we included images to provide context for students answering questions in a manner similar to Neumann (2013). However, for most of the questions we found the images did not further elicit student thinking and in some cases were a cause of confusion. We therefore eliminated images from most of the items.

Practicing teachers were primarily concerned with reading levels of items. We therefore analyzed item Lexile scores and made modifications where needed. This need to simplify was sometimes at odds with feedback from sea level rise experts whose suggestions often included the addition of technical text and terms.

Sea level rise experts focused on the scientific accuracy items. For example, in response to an item on thermal expansion, one science expert suggested:

Use "expand" instead of "grow larger". Molecules can grow larger by coalescence, which has no impact on volume change. Expansion relates to density change which does affect the volume.

Expert feedback on the impact of sea ice (ice floating in sea water) versus terrestrial ice resulted in the modification of number of items. Experts also suggested graphs and citations for information used in items. One expert stated:

"I think it is important to cite the sources of data used to construct the graph. In dealing with climate-related issues, which can be very controversial, do not leave yourself open to criticism because the data source is unknown. For my money, the credibility of the data is just as important as the data itself. I would provide a small citation below the graph stating whose data you are using."

We therefore added citations, as needed, although this increased assessment item complexity.

We followed the same process with the SLR Online Activity, which used SLR data, maps, and video to elicit student thinking on sea level rise. Based on the data we conducted, as guided by our hypothesized and draft LP for SLR, we engaged in three iterations of revision for our SLR Online Activity. These iterations included work with middle school students in a classroom setting, undergraduate preservice teachers in a science methods course, and middle school learners at a summer camp that included attention to sea level rise.

A core component of moving from the hypothetical and draft LP to an empirically supported provisional learning progression for SLR was eliciting learner thinking on sea level rise. This is shown in Figure 1 between Assessment Instrument and the assessment of the Sea Level Rise On-line Activity. Through an ongoing process of collecting and analyzing data we engaged in the process of developing an empirically based learning progression for sea level rise, a necessary extended process that will require additional iterations with more and diverse learners to be finalized.

SLR Assessment Instrument. The SLR Assessment Instrument was developed based on our hypothetical learning progression and modified using data from middle school students (N=90), SLR experts (N=3), and undergraduate pre-service teachers (N=50). In addition, questions were administered and small group discussions were conducted using a mature version of the SLR Assessment Instrument with a diverse sample of middle school students (N=5) at a voluntary environmentally themed summer camp. See Appendix A for the SLR Assessment Instrument.

The instrument initially consisted of 26 questions. Over the course of the project the instrument was iteratively modified through a process of deletion as well as combination of redundant items. All questions were modified in some manner during the process. Several new questions were added to address varying levels of sophistication in student thinking. The instrument currently consists of 16 items.

SLR Online Activity. The second assessment instrument, the SLR Online Activity, was also developed based on our hypothetical learning progression. The activity went through three iterations with in-service (N=15) and pre-service (N=70 and N=7) teachers prior to being used with middle school students (N=5).

The online activity presents learners with a geographically relevant context for investigating sea level rise and its consequences. This involves viewing data on the global projected rise in sea level and using an interactive website (www.SurgingSeas.org) to visualize the effects via satellite imagery and maps showing the degree to which land would be submerged under different projections. Based on projections and maps learners reflect on the impacts of sea level rise in the geographic area. The online activity also presents the science content for the mechanism of sea level rise.

Results

To access learner thinking about sea level rise at the middle to upper anchors of our learning progression, as well as to refine our instrument and activity, we initially worked with undergraduate pre-service teachers in a science methods course. Responses and preservice teacher explanations from the SLR Assessment Instrument were useful for looking at learner thinking about the *mechanisms* of sea level rise. For example, for the SLR Assessment Instrument question, "How does the thermal expansion of water cause sea level to change?" most learners were able to select the correct answer (water molecules will spread out, causing them to occupy more space). Explaining why they selected the answer they stated:

> *"the increased temperature causes them to move"*
> *"I think the water molecules jump around more when the temperature increases"*
> *"educated guess using pictures"*

However, some learners believed that the water molecules split apart and formed additional water molecules. Based on learner explanations for the 15-item SLR Assessment Instrument questions, we made revisions to our instrument and modified our SLR learning progression.

Preservice teacher data from the SLR Online Activity's assessment also addressed mechanisms, but placed an emphasis on the *impacts* of SLR. Based on the analysis of preservice teacher responses (N=77), the following codes represent initial conceptions about the impacts of SLR in response to the prompt: “*Write down three things (or more) you already know about sea level rise (e.g., why it's happening, factors causing it, impacts on communities and ecosystems).*”

Table 1: Preservice Teacher Responses

Flooding (15) Islands/Beaches/Land disappearing (12) Erosion (10) Property loss (6)	More powerful storms (6) Coastlines under water (4) Pop. near coast affected (2) Communities will need to relocate (2) Land “sinks” (not subsidence) (2)	Human habitats affected (2) Coastal cities uninhabitable (1) Threat to communities below sea level (1) Longer planting seasons (1) Negative impact on farmland/plants (1)

Based on these initial responses, as well as data from the SLR Assessment Instrument, we made modifications to the *Impacts* section of our SLR LP (Table 2). Data from the SLR Online Activity was also used to inform the modification of the *Mechanisms, Representations,* and *Causes* sections of our SLR LP.

Data from middle school students informed the lower anchors of our SLR LP. For example, when asked using the SLR Assessment Instrument question, *“Why is sea level rising?”* most responded in accordance with a consensus scientific perspective (i.e., an increase in global temperatures is causing ice melt, increasing sea volume). They stated, for example:

> “*Because the Earth is warming up and when the snow or ice melts it turns into water.”*
> “*Because when ice melts water become more and more so sea level rise”*
> “*Because as global warming occurs when it gets hot.”*
> “*Because temperature change would make snow melt and fall or melt into the sea”*

However one learner attributed the rise in sea level to increased precipitation, despite choosing the correct answer to the assessment question: *“I think that because the more parcipitation* [sic] *that comes from above, the more water comes, and the higher the water rises.”*

In the Online SLR Activity, middle school students responded to the prompt “*Write down three things (or more) you already know about sea level rise…”* in a more limited manner, citing the melting of ice sheets, flooding, ozone as a cause of sea level rise, global warming as a cause for sea level rise, and the impact on polar bears and penguins. We believe much of the information provided may come from experiences outside of school, such as media coverage of the issue, as climate change is a relatively new topic in the school science curriculum.

Changes to the SLR LP Based on Empirical Results

Early in our process in the development of the SLR LP we found it necessary to include a section on the impacts of sea level rise on humans. This decision was guided by both the sociocultural theoretical perspective that places much value on learners' personal and cultural experiences as well as on our early conversations with students and educators.

The decision was further supported during interviews we conducted with middle school science teachers (n=27) during a five day summer professional development experience on teaching climate change. During interviews at the summer academy, a prevailing theme we perceived from analysis of their responses was the potential pedagogical importance of students' personal experiences with impact of climate change, especially sea level rise. For example:

> *I think it will really help the kids because it is something that's so close to them and hits home.* (middle school teacher)
>
> *… the kids, they remember things more if you keep it local, bring in hands on activities, they are going to remember it longer.* (middle school teacher)
>
> *…they see the effects of sea level rise and climate change all the time, they flooded for Sandy, they flooded, like for Isabel, we flooded for something else recently. So it's definitely something that they see, they know it is happening to them. So I think it will be of great interest to them.* (middle school teacher)

Being situated in the mid-Atlantic region, close to the Atlantic Ocean, a majority of the participants in the academy taught within 50 miles of the coast and saw the topic relevant to their students.

Students also exhibited interest in SLR when they saw a personal connection, either for themselves or someone they knew. One middle school student at an environmentally themed summer camp, who initially appeared disinterested, became animated after viewing a video that showed New Orleans as an area threatened by sea level rise. He stated, "My grandmother lives there!"

After the initial addition of the Impacts section to the LP, two changes were made based on student responses to the SLR Assessment Instrument and the Online SLR Activity. The first change was intended to clarify what students know about the consequences of sea level rise as they moved from a Level Two to a Level Three in the LP. The following was added to Level Three of the Impacts section:

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.

The addition was intended to make a clearer distinction between Level Two and Level Three for Impacts. As noted by others, the interior levels, or "messy middle" (Shea & Duncan, 2013) are often challenging.

For Level Four of the Impacts section the following text was added:

Students recognize that sea level rise projections are based on available data and may be lower or higher than predicted.

Students' understanding of the nature of scientific projections for sea level rise indicates a more sophisticated, model-based understanding of the sea level rise. More than just a general addition of knowledge about impacts, at Level Four students understand that, while sea level will rise, it is uncertain the degree of rise, and therefore the impacts.

With supporting data from both teachers and students, as well as making theoretical sense based on sociocultural theory, a separate section of the learning progression focusing on the impacts of sea level rise was added, investigated, and modified.

Discussion

Using our SLR Assessment Instrument we were able to elicit from a small sample middle school learners' thinking about varied dimensions of sea level rise mechanisms, both macroscopic and microscopic. The data on learner thinking mapped well onto our hypothesized learning progression for SLR. Regarding the macroscopic, characterized in Level 1 and Level 2 of our SLR LP, we found that learners were able to articulate explanations to the question, *"Why is sea level rising?"* They provided examples of visible phenomena such as melting ice and some provided a rudimentary mechanism (heat from global warming).

For the microscopic, although learners were able to respond correctly to the SLR Assessment questions when we sought to elicit their thinking, we found their ability to provide an explanation was limited. This indicated that they did not possess an understanding of the construct at Level 3. We therefore interpret this to mean that the middle school students in our study could be located at a Level 1 or 2 on the SLR LP.

Preservice undergraduate teachers possessed more sophisticated thinking about SLR as measured by our instruments. This was evident in their responses to SLR Online Activity prompt *"Write three things you already know about sea level rise…"* Their responses indicated a wider range of knowledge of both the mechanisms and impacts of sea level rise. Many preservice teachers were able to demonstrate an understanding of the microscopic nature of thermal expansion and sea level rise. However, not all possessed this level of sophistication, with some believing thermal expansion resulted from water molecules breaking apart and forming additional water molecules. We interpret this to mean the undergraduate pre-service teachers in our study were at a Level 2 or Level 3 on the SLR learning progression.

Based on data from middle school students and undergraduate pre-service teachers we found that the use of our hypothetical and draft LP for SLR provided useful information about learners' understanding of the SLR construct. That is, it indicated where learners possessed competency and where they needed to continue to grow in their understanding of the construct of SLR.

Table 2. *Mechanisms* of Sea Level Rise from the SLR LP (see Appendix B for full SLR LP)

Level 1 (Lower Anchor)	**Level 2**	**Level 3**	**Level 4** (Upper Anchor)
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.

Based on data from the Sea Level Rise Assessment Instrument and the online activity, we found three areas that warrant additional investigation. These include the timeframe over which sea level rise is occurring, the scale of sea level rise and its consequences, and the role ozone plays in a warming earth and rising seas.

In the online sea level rise activity, students' responses indicated that many did not consider increases in sea level of several feet to be significant. When asked to interpret a graph showing different projections of sea level rise over the next 100 years, a number of students prefaced their predictions with the term "will *only* rise …" This indicates that they were able to interpret the graph but did not have a sense of how the scale related to the impacts of sea level rise.

The timeframe over which sea level rise occurs is also an area where student understanding may be limited. Based on our current data we are unsure of how students conceptualize the timeframe over which sea level rise is projected to occur. The impacts of sea level rise are most often discussed as future events, although that is beginning to change; for example, as we see extreme weather more frequently cited as a result of climate change, it may be that students do not understand the immediacy of the problem. However, additional research is needed to support a change to the learning progression.

A recurring theme we found for both middle school students and preservice teachers was that ozone was thought of as a cause of a warming earth. Previous research (Andersson & Wallin, 2000; Boyes & Stanisstreet, 1997; Hansen, 2010) has also identified ozone as a cause of climate change as an alternate conception held by learners. We therefore modified our learning progression to include the role of ozone in a LP for climate change. While ozone was frequently mentioned, more so at the middle school level, we are unsure if learners are conceptualizing ozone to be equivalent to carbon dioxide or if they consider it to be a separate cause independent of carbon dioxide.

Each of these areas will be explored further in the next iteration of data collection and analysis.

Conclusion

Our report of the development of our conditional SLR learning progression, along with the accompanying assessment instrument and instructional activity, we believe contributes valuable information to the emerging research about learning progressions and specifically about climate change education. We believe our insights are a resource needed to develop research-informed effective curricula and assessment for the SLR construct a major effect of climate change.

We have revealed how one group of researchers approached the development of a literature and empirically-based learning progression for a climate change construct. By detailing the development from an initial, starting point hypothetical LP to a conditional empirically supported LP our work adds meaningfully to the literature. From our review of the literature, such a detailed report of work in LP development in science education is rare. Additionally, we believe that our conditional sea level rise learning progression, along with the SLR Assessment Instrument and SLR Online Activity, contribute to the science education community. These tools which are informed by the NGSS may be used to guide curriculum, instruction and assessment, and educational policy to address a visible and accessible consequence of climate change, sea-level rise.

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Appendix A: Sea Level Rise/Change Assessment Instrument

Draft

September 2014

Comments and questions to wbreslyn@umd.edu.

Name: ____ **Date:** _________

Instructions: For each question below circle the letter you think is the best response to the question. Provide an explanation of your reasoning for your response in the space provided.

Question 1

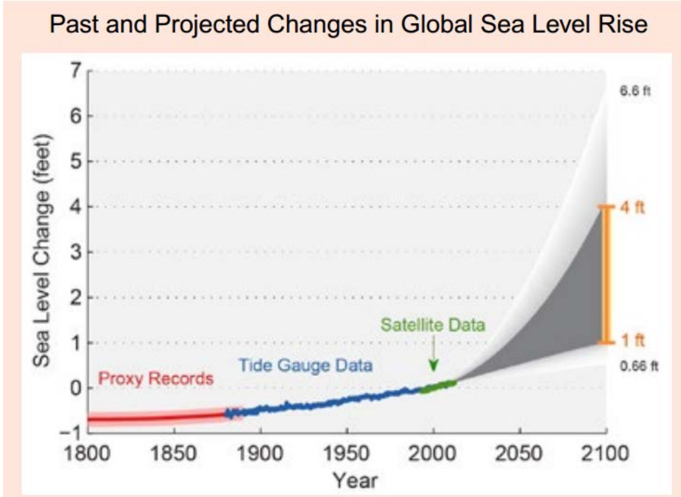
Description of Situation

The graph represents sea level rise projections based on several different scientific models.

Question

Which of the following is the best description of the process used by scientists to produce the sea level rise projections show in the graph?

(Note: *The projected sea level rise for 2100 shows a range of possible sea level rise. This is represented by the black and grey areas on the graph.)*



Select the ***best*** response**.**

Sea level rise projections are:

A. based on available data and predict future sea level with absolute certainty.

B. based on available data and may actually be lower or higher than estimated.

C. relatively uncertain because they are based on scientists' opinions, which can be wrong.

D. not useful because it is impossible to predict what will happen in the future.

Why is this the best explanation?

Graph from: U.S. Global Change Research Program (2014). Chapter 2: Our Changing Climate (p. 45). In *Climate change impacts in the United States: The Third National Climate Assessment*. Available at: http://nca2014.globalchange.gov/report/our-changing-climate/sea-level-rise

Question 2

Description of Situation	Sea level is projected to rise between 1 and 4 feet by the year 2100, with an additional rise of 2 feet possible*.
Question	Why is sea level rising?
Select the ***best*** response**.**	**A.** Increased ultraviolet radiation reaching the earth due to the hole in the ozone layer. **B**. Increased rain and snowfall are adding to the amount of water in the seas. **C**. Shifts in plate tectonics reorganizing the shape of the sea floor. **D**. An increase in global temperatures is causing ice on land to melt, increasing sea volume.

Why is this the best explanation?

* U.S. Global Change Research Program (2014). Chapter 2: Our Changing Climate (p. 45). In *Climate change impacts in the United States: The Third National Climate Assessment*. Available at: http://nca2014.globalchange.gov/report/our-changing-climate/sea-level-rise

Question 3

Description of Situation	Global temperatures are rising and are projected to continue to rise.
Question	How does an increase in the global average temperatures lead to sea level rise?
Select the ***best*** response**.**	***This will cause sea level to rise by:*** **A**. causing more rain or snow, adding to the volume of water in the sea. **B**. causing ice on land to melt which adds to the volume of water in the sea. C. causing water molecules in the sea to expand and occupy a greater volume. **D**. causing more water molecules in the sea to form and increase the volume.

Why is this the best explanation?

Question 4

Description of Situation	The amount of greenhouse gases in the atmosphere is increasing.
Question	How is this related to sea level rise?
Select the ***best*** response**.**	***More greenhouse gases will lead to an increase in global temperature causing***: A. oxygen and nitrogen gases to dissolve in water, increasing sea volume. B. ice on land melting and thermal expansion of sea water, increasing sea volume. **C**. the number and size of water molecules to increase, increasing sea volume. **D**. the atmospheric pressure above the seas to increase and push water towards land.

Why is this the best explanation?

Question 5

Description of Situation	Sea level is projected to rise several feet in the future.
Question	What are the most likely impacts to humans in a coastal community if sea level rises 4 feet (1.2 m)?
Select the ***best*** response**.**	***There will be***: **A.** an increase in home values farther inland because they will be closer to the beach. **B**. a need for people to move and relocate structures further inland to adapt to flooding. **C**. few impacts since four feet is not a significant increase in sea level. **D**. no serious impact since a new coastline would be established.

Why is this the best explanation?

Question 6	
Description of Situation	Additional greenhouse gases in the atmosphere trap heat from the sun causing global temperatures to rise.
Question	What is one way an increase in the amount of greenhouse gases causes sea level rise?
Select the ***best*** response**.**	***Increases in global temperature, due to greenhouse gases, cause sea level rise by:*** **A**. increasing the evaporation of water leading to more precipitation. **B**. making water molecules become larger and more numerous. **C**. melting ice on land which then flows into the ocean. D. dissolving in the sea which causes water to occupy more space.

Why is this the best explanation?

Question 7	
Description of Situation	The overall, or average, global sea level is rising. However, sea level can rise different amounts in different geographic areas.
Question	Why might sea level rise be in different in different geographic locations?
Select the ***best*** response**.**	**A.** in some areas, such as polar regions, sea levels will be higher due to ice on land melting. **B**. humans are putting more waste water into the seas in some areas causing them to rise. **C**. varying amounts of rain and snowfall in different areas leads to different rises in sea level. **D**. the land in some areas is sinking while it is rising in other geographic areas.

Why is this the best explanation?

Question 8

Description of Situation	As temperatures increase, water molecules move faster.
Question	How does this relate to sea level rise?
Select the ***best*** response**.**	***As temperature increases water molecules***: **A**. undergo expansion causing sea level to rise. B. spread out and occupy more space causing sea level to rise. C. increase in number causing sea level to rise. D. will collide more frequently causing sea level rise.

Why is this the best explanation?

Question 9

Description of Situation	Sea level is projected to rise several feet over the next hundred years.
Question	What are the most likely impacts to a coastal ecosystem if sea level were to rise four feet (1.2 m)?
Select the ***best*** response**.**	***Many plants and animals would***: **A**. benefit from the change and increase in numbers. **B.** move further inland and establish new ecosystems. **C.** quickly adapt to the changes caused by sea level rise. **D.** die off but some would be able to adapt or move inland

Why is this the best explanation?

B

Question10

Description of Situation	A solid ice sheet on land warms, melts, and becomes liquid water. It flows into the nearby sea.
Question	What causes sea level to change?
Select the ***best*** response**.**	***The sea level will rise because***: **A**. chunks of ice already in the water melt and increase sea volume. **B**. water from the melting ice sheet adds to water already in the sea. **C**. the surrounding land will not be as tall after the ice melts. **D**. the fresh water will change the density of the water in the sea.

Why is this the best explanation?

Question 11

Description of Situation	The overall, or average, sea level is rising. However, sea level varies with tides, lunar cycles, and weather events.
Question	How would sea level rise affect a weather event, like a hurricane or tropical storm?
Select the ***best*** response**.**	***A rise in sea level would***: **A**. only affect people living right next to the sea. **B**. increase the frequency and amount of coastal flooding **C**. absorb and dissipate the energy from the hurricane or storm. **D**. cause no changes in the nature of a hurricane or storm.

Why is this the best explanation?

Question 12

Question — How does the thermal expansion of water cause sea level to change?

The sea level will rise because an increased temperature will cause water molecules to:

Select the ***best*** response**.**

A split apart and form additional water molecules.
B. spread out, which causes them to occupy more space.
C. become bigger, which causes them to occupy more space.
D. break down and be released into the atmosphere as new chemicals.

Why is this the best explanation?

Question 13

Description of Situation — Scientists have found a warming trend in average global temperatures on Earth.

Question — Which of the following is an impact of the global warming trend?

Global warming causes:

Select the ***best*** response**.**

A. increased evaporation of oceans, contributing to sea level decline.
B. increased precipitation, which contributes to sea level rise.
C. increased ice on land melting, which contributes to sea level rise.
D. the oceans to become warmer but nothing else changes.

Why is this the best explanation?

Question 14

Description of Situation

The picture is an aerial view of a coastal land area that is projected to experience significant sea level rise.

Question

As sea level rises, one impact on coastal areas, as shown in the picture above, could be:

Select the ***best*** response**.**

Some of the land will:

A. flood less during severe weather.

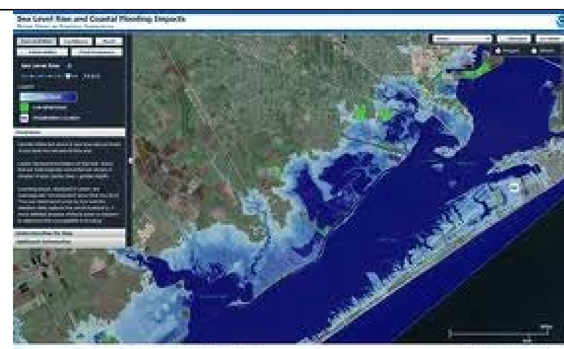
B. be covered by sea water.

C. receive more precipitation (rain and snow).

D. experience no change since nature will adapt.

Why is this the best explanation?

Question 15



Description of Situation

The map below shows land areas affected by sea level rise. For this region, coastal land has been sinking at an average rate of 1.3 mm/yr.

The land shaded in light blue represents areas that will be impacted by 3.3 feet (1 meter) of sea level rise during a high tide.

Question

Areas of the map that are shaded in light blue are more vulnerable to sea level rise because of factors such as:

Select the ***best*** response**.**

A. the expanding size of water molecules.

B. the increasing mass of water molecules.

C. increased precipitation and more erosion.

D. changes in the relative elevation of the land.

Why is this the best explanation?

Question 16

Description of Situation — The picture is an aerial view of a coastal town.

Question — As sea level rises, one impact on coastal areas, as shown in the picture above, could be:

If sea level rise occurred in this area, what would be a likely consequence during storms?

Select the ***best*** response**.**

A. Only areas on the coast would experience increased flooding.
B. Only area further inland would experience increased flooding.
C. Both coastal and inland areas would experience increased flooding
D. Storms do not affect sea level, so there would be no change.

Why is this the best explanation?

Appendix B: Conditional Hypothetical Learning Progression for Sea Level Rise

	Level 1 (Lower Anchor)	**Level 2**	**Level 3**	**Level 4** (Upper Anchor)
Potential SLR LP indicator based on Gunckel, Covitt, Salinas & Anderson (2012, p. 854) "SM" stands for scale and mechanisms	SM1: Students explain sea level rise on a macroscopic scale only, focusing on immediately visible structures or phenomena without including mechanisms for phenomena.	SM2: 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.	SM3: 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.	SM4: 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.
Potential SLR LP indicator based on Gunckel, Covitt, Salinas & Anderson (2012, p. 854) "R" stands for representations	R1: 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.	R2: Students are able to make limited connections between the physical world and representations related to sea level rise.	R3: 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.	R4: Students are able to interpret driving forces and constraining factors related to sea level changes based on representations.

	Level 1 (Lower Anchor)	**Level 2**	**Level 3**	**Level 4** (Upper Anchor)
Potential SLR LP indicator about causes of sea level rise "C" stands for causes	C1: Students identify global warming due to the enhanced greenhouse effect as a cause of sea level rise.	C2: Students recognize that global warming causes sea level rise, but are not able to identify factors such as thermal expansion and ice melt (not distinguishing between terrestrial and see ice). Students are also able to identify a mechanism that relies on actors or agents.	C3: Students understand that sea level rise scenarios are based on thermal expansion and ice melt (not distinguishing between terrestrial and see ice), though they do not consistently relate these factors to atomic-molecular models.	C4: 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.
Potential SLR LP indicator about impacts of sea level rise "I" stands for impacts	I1: 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.	I2: 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.	I3: 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.	I4: 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.