Climate Science Instructional Resources for Implementation of California Next Generation Science Standards (NGSS)

Capstone Report

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I. Executive Summary

This Capstone project, *Climate Science Instructional Resources for Implementation of Next Generation Science Standards,* is the product of a one-year collaboration between Scripps Institution of Oceanography (SIO) and San Diego Unified School District (SDCOE), with support from the California Department of Education (CDE). The Chair of the Capstone Advisory Committee (CAC), Cheryl Peach, led collaborative efforts between SIO and SDCOE.

San Diego Unified School District served as the foundation for this project in developing the *Project Phenomena* website in 2016. *Project Phenomena***,** developed by SDCOE STEM Coordinator John Spiegel, seeks to provide both professional development and instructional resources for teachers regarding the implementation of phenomena-based teaching in San Diego Unified.

The implementation of phenomena-based teaching coincided with the broader statewide California Next Generation Science Standards (CA NGSS) implementation plan that followed the passage of Senate Bill 300 in April 2013 (CDE, 2014). Based upon findings by the National Research Council (NRC) and structured by a group of 26 lead partner states, NGSS structures a new vision for science education rooted in evidence that is focused upon student development of scientific skills (National Academies Press, 2013).

Citing both economic and socioecologic imperatives, NGSS incorporated Global Climate Change as a Disciplinary Core Idea (DCI) for students to engage with throughout middle and high school (NRC, 2012; National Academies Press, 2013). In California, a key method for implementation of the CA NGSS Global Climate Change DCI is phenomena-based teaching (CDE, 2014).

This Capstone project aims to provide professional development and instructional resources to science teachers in San Diego Unified and the state of California that will enable them to plan units and lessons with climate science utilizing phenomena-based teaching in alignment with NGSS. Climate science concept maps and framework submissions for investigative phenomena have been developed for posting on the SDCOE CA NGSS resource website.

Climate science concept maps were constructed following topic classification as outlined by the Intergovernmental Panel on Climate Change (IPCC, 2014) assessment reports. The three main components of climate, oceans, atmosphere, and AFOLU (Agriculture, Forestry, and Other Land Use) outlined by the IPCC served as the starting point for each concept map, respectively. Each map outlines climate science by the components of scientific basis, impacts, and adaptation and mitigation, again following classifications outlined by the IPCC. In total, four concept maps were created, as follows:

- Climate Change
- Oceans
- Atmosphere
- Agriculture, Forestry, and Other Land Use (AFOLU)

As part of the development process in addition to thorough literature review, climate science content experts, representatives of SDCOE, and science teachers in San Diego Unified were consulted in evaluating the project's effectiveness. During this process, a climate science concept map was utilized by the CDE for teacher professional development in its NGSS Phenomena Rollout #4.

The positive and immediate reception of resources created by this Capstone project signifies a statewide need for climate science resources aligned to NGSS for the purpose of phenomena-based teaching. These resources alone, however, will not create high-quality science learning environments without further commitment to teacher professional development in both contexts of climate science and phenomena-based teaching within SDCOE and throughout California. Collaboration must continue between California's scientific community, science education experts, and policymakers to implement high-quality scientific learning as promised by NGSS a reality in California.

II. Acknowledgements

This Capstone project is a product of a variety of advisors and stakeholders.

Capstone Advisory Committee (CAC)

Cheryl Peach, CAC Chair and Expert Advisor, Director of Education and Outreach, Scripps Institution of Oceanography

Darcy Taniguchi, Advisor, Postdoctoral Fellow at University of California, San Diego

Ellie Farahani, Advisor, Executive Director Climate Science and Policy, Scripps Institution of Oceanography

Lynn Russell, Advisor, Climate Science and Policy Program Director, Professor Atmospheric Science and Physical Oceanography, Scripps Institution of Oceanography

San Diego Unified School District

John Spiegel, STEM Coordinator, San Diego County Office of Education

Jennifer McCluan, San Dieguito Union High School District

III. Introduction

Complex issues, both social and scientific in nature, are shaping the world at a fast pace. Climate change is a complex issue central to the social, emotional, and physical well being of Americans. The need for scientific knowledge to make sense of socioecologic issues like climate change has never been more critical (National Academies Press, 2013). To meet the complex demands of the 21st century, science education in the United States must adapt.

The development of the Next Generation Science Standards (NGSS) is a response to this need. The standards, adopted by California in 2013 with the passage of Senate Bill (SB) 300, are research-based, utilizing a three-dimensional learning framework that aims to support the development of students' critical thinking and scientific reasoning. The standards are inclusive of socioecologic issues through the incorporation of Global Climate Change within the Disciplinary Core Idea (DCI) of Earth and Human Activity (Appendix A; ESS3).

Through a collaborative process with San Diego Unified School District (SDCOE), a framework for teacher supplemental professional development and climate science instructional resources for phenomena-based teaching in alignment with NGSS have been developed. These materials are grounded in science education research, and align closely with the goal of Strategy 2 in California's NGSS Implementation Plan (CDE, 2014). They have been arranged in a coherent manner across grades levels and NGSS Disciplinary Core Ideas (DCIs) for teachers to provide students in San Diego Unified with the opportunity to learn climate science in a high-quality science education environment.

3.1 The Need for NGSS-Aligned Climate Science Instructional Resources

The implementation of NGSS represents a large pedagogical shift in teaching practices. Successful implementation will require large-scale professional development (PD) for all science teachers in the state of California. New standards, teaching methods, and topics will be incorporated into teachers' curriculum and teaching style (CDE, 2014).

The California Department of Education (CDE) recognizes this need, and calls for "the development of professional learning resources" through "collaborative partnerships between the CDE, Local Education Agencies (LEA), and community stakeholders" in Strategy 1 of their CA NGSS Implementation Plan (CDE, 2014). An example of partnership between an LEA and a community stakeholder is inherent in this project, collaboration between the San Diego County Office of Education (an LEA) and Scripps Institution of Oceanography, a research institution.

In addition, Strategy 2 of the CA NGSS Implementation Plan calls for the "development, acquisition, and review" of CA NGSS-aligned curricular resources for classroom use (CDE, 2014). California has aligned its performance expectations to be closely tied with those of Common Core State Standards (CCSS), and its interpretation of NGSS in unique in that regard. LEAs must acquire resources to support classroom instruction that incorporate these California-specific performance expectations (see Appendix A). This project incorporates all applicable California performance

expectations within instructional resources NGSS alignment.
Finally, climate change is a complex, interdisciplinary topic that even the most experienced teachers find difficult to scale and deliver instruction for (Hestness et al., 2014; Papadimitriou, V., 2004). This illustrates the need for climate science instructional resources that outline not only how to teach climate science, but how topics within climate science can be explored and leveraged to fit within the NGSS framework and inquiry-based teaching. Thus, the NGSS-aligned climate science instructional resources developed in this project allow SDCOE to reasonably fulfill its obligations with regards to Strategy 1 and Strategy 2 of the CA NGSS Implementation Plan (CDE, 2014).

3.2 Climate Science and Policy Relevance

Strategy 2 of the NGSS implementation plan addresses the need to develop, acquire, and review CA NGSS-aligned curricular resources for instruction (CDE, 2014). The CDE acknowledges that collaboration between LEAs, community partners, and nonprofit organizations is needed to create these high-quality resources. This project aligns itself with the CDE's vision of collaborative effort, leading the partnership between SDCOE and Scripps Institution of Oceanography (SIO) in the creation of CA NGSS-aligned instructional resources.

This project leverages the climate change content specialization of SIO to better serve the research-oriented focus of each dimension of NGSS. The structuring of climate science components and topics included on climate science concept maps (see Appendix E) was done to reflect the rigorous and internationally published findings of the IPCC. Each climate science concept map was created with the most recent scientific findings in mind, including ocean acidification and extreme drought. They were further refined by examining scientific trends in peer-reviewed literature that were specific to the region of Southern California, like sea level rise and coastal erosion (see Appendix E).

3.3 Resource Development Considerations

The implementation of NGSS presents the challenge of scaling high-quality professional development (PD) programs for thousands of teachers in California (Wilson, 2013).
Multiple methods of resource delivery were considered in the development of this project. Existing research on PD suggests that despite the wide array of PD available in the United States, accessibility to high-quality science PD is often lacking (Dede, 2008). A potential answer to this issue is online PD, as online resources are immediately accessible and have to potential to be scaled to larger audiences than face-to-face PD (Dede, 2008). Variations of high-quality online PD include online courses, virtual conferences, and social networks.

Low cost and timely access for teachers were factors in designing online instructional resource submissions for the purposes of this project. In addition, scalability is anticipated from SDCOE to the entirety of California. While the instructional resources do not fully engage in some characteristics that make PD effective, like engaging teachers in active learning (Wilson, 2013), both the climate science content maps and website

submissions do serve as timely, low cost professional development to supplement ongoing face-to-face NGSS PD conducted by SDCOE.

IV. Background

4.1 Science Standards in California

California Senate Bill (SB) 300 was signed into law in 2011, compelling the state to seek, adopt, and implement new science standards. The State Board of Education (SBE) decided to adopt NGSS for its focus on technical and scientific practices rather than strict scientific knowledge. In 2013, the SBE unanimously voted to adopt the standards. SBE also placed an emphasis on the support and development of teachers to ensure that students maximize benefit from NGSS. In 2014, the California Department of Education (CDE) was directed to create a statewide NGSS implementation plan for accountability and district use.

Out of the 19 states to adopt NGSS, California is the largest. San Diego Unified School District (SDCOE) is the 2nd largest school district in the state of California, with over 129,000 students enrolled in the 2015-2016 school year (EdData, 2016). Thus, SDCOE's leadership is invested in determining most effective pathways to succeed in implementing climate change into the classroom..

4.2 Phenomenon-Based Teaching and NGSS

Phenomenon-based teaching utilizes a student's sense of wonder about natural, observable events to facilitate the exploratory nature of questioning and data collection in learning (NextGenScience, 2016). Phenomenon-based teaching is a pillar of NGSS (NGSS; see appendix C). There two main types of phenomena within the teaching framework: anchoring phenomenon (AP) and investigative phenomenon (IP; see appendix C). Anchoring phenomenon are culturally relevant, utilize and meet performance expectations, is observable, and are too complex to explain after one lesson (Penuel, 2016).

V. Project Outline

5.1 Climate Science Concept Maps

Each climate science concept map was designed with both frameworks of phenomena-based teaching and IPCC climate science components in mind. Maps were color-coded to reflect the place of both Anchoring Phenomena (gold; see Appendix E) and Investigative Phenomena (lavender, see Appendix E), along with its place in climate science, as scientific basis, impact, or adaptation/mitigation of a particular climate science and climate change phenomena (green, maroon, and blue, respectively; see Appendix E).

Concepts that fall under the "scientific basis" component of climate change are typically above others in the concept maps, as understanding them will allow students to better explain the secondary impacts of changes to these phenomena and processes through the larger effect of the enhanced greenhouse effect. Climate change impacts are then followed by phenomena within a solutions-based framework of mitigation and adaptation to those climate change impacts, which allow students to directly engage in scientific and engineering practices as outlined by NGSS (National Academies Press, 2013).

The main climate change map breaks down into the three main components of climate as outlined in IPCC assessment reports (IPCC, 2014): ocean, atmosphere, and agriculture, forestry, and other land use (AFOLU). Each component is broken down into non-exhaustive, fairly comprehensive large-scale impacts of climate change, such as sea level rise and extreme heat (see Appendix E, figure 8). Each climate component is ultimately tied to a black box, signaling the need for human action, like coastal erosion and the suffering of fisheries. The main goal of this concept map is to give the viewer an overall concept of how different topics within climate change interact and the degree to which those topics can impact humans.

For a full list of investigative phenomena submissions and their corresponding links, see Appendix F.

5.1.A **Ocean**

The ocean concept map branches out to four main concepts: Thermal Expansion, Ice Dynamics, Heat Transport in the Oceans, and Carbonate Chemistry in the Oceans (see Appendix E, figure 9). These four concepts fall under the scientific basis component of climate change, or investigative phenomena (IPs) as understanding them will allow students to better explain the secondary impacts of changes to these phenomena and processes through the impacts of the enhanced greenhouse effect.

Impacts of these scientific phenomena include sea level rise, coastal erosion, land ice melt, coral reef bleaching, and impacts of ocean acidification on marine life (Leeson, 2014; DeConto, 2017; Bednar, 2014). Sea Level Rise, Ocean Acidification, and Coral Bleaching are both considered Anchoring Phenomena due to the nature of multiple phenomena that cause impacts to become prevalent in the ocean. Adaptation strategies employed by the California Coastal Commission in the form of permitting can be explored as a response to coastal erosion, along with current efforts to restore coral populations.

5.1.B **Atmosphere**

The atmosphere concept map is more simplified than the ocean concept map, branching out to only two scientific basis IPs, the Enhanced Greenhouse Effect and Global patterns of Precipitation (see Appendix E, figure 10). It should be noted that concepts like atmospheric aerosols are intentionally omitted for the sake of brevity, but are undoubtedly a topic of scientific exploration within the atmosphere topic of climate change.

Global Patterns of Precipitation branches further into two concepts that threaten to

impact California in the near future, Atmospheric Rivers and Extreme Drought. Wildfire is also incorporated as an impact of long periods of extreme drought, an IP to which impacts of the Enhanced Greenhouse Effect and the Extreme Heat AP also contribute in California. Infrastructure Challenges and Economic Prosperity in California, along with Forest Management Policy in California and Protecting Vulnerable Populations are all tied to solutions surrounding adaptation and mitigation for communities in California.

5.1.C **Agriculture, Forestry, and Other Land Use (AFOLU)**

The AFOLU concept map is more simplified still, customized to experiences and issues facing California today (see Appendix E, figure 11). Ecosystem Services of Wetlands, Plants Uptake Carbon Dioxide Globally, and the Enhanced Greenhouse Effect are the main branches of this concept map as the scientific basis IPs.

This map focuses on land use changes and the science behind how humans rely upon the climate to maintain land as we know it in California today. Deforestation of Wetlands was chosen as an AP because of its relevance to the depletion of carbon dioxide sequestration and exacerbation of flooding from other impacts of climate change, like Atmospheric Rivers. This map allows climate change concepts to come full circle in many ways, as Future Trends in Agriculture runs parallel to adaptation and mitigation discussions that are tangential to those in the atmosphere concept map.

5.2 Investigative Phenomena Submissions

The phenomena is to the left, along with a description of how to setup the activity itself and questions students may ask to begin the inquiry-based learning. The scientific explanation for teachers is in the next column, and the middle column contains links and descriptions of follow-up activities that students may complete to further investigate the phenomena. The last three columns align the phenomena to a variety of CA NGSS performance expectations (MS-PS1-2, etc.) and the three dimensions of NGSS. Student actions and thoughts are color-coded throughout the submission in keeping with the orange, blue, and green colors of NGSS. Links and "Additional resources" sections are located at the bottom of the document, along with a complete list of references cited in APA style.

5.3 Target Audience

Science teachers in the state of California are the target audience of this project. Presentations given at SDCOE workshops were targeted to teachers within the region of Southern California. The climate change concept map graphic is being used by the CDE to educate over 2,000 educational leaders in the state of California about the integration of climate change and phenomena-based teaching aligned to NGSS (CDE, 2017).

5.4 Capstone Advisory Committee Roles

Expert Advisor: *Cheryl Peach, Director of Education Outreach at Scripps Institution of Oceanography (SIO)*
Cheryl guided the process of project selection and development of resources for phenomena submissions. She served as primary contact for both SDCOE and faculty to collaborate with at SIO.

SIO Faculty Advisor: *Darcy Taniguchi, Postdoctoral Fellow, UCSD*
Darcy specializes in teaching science to informal audience and has worked with many age groups of students both inside and outside of the classroom. Her expertise and experience in K-12 outreach work was valuable in designing the content of my phenomena submissions, and validating classroom activity efficacy.

Climate Policy Advisor: *Ellie Farahani, CSP Executive Director*
With her extensive experience in the Intergovernmental Panel on Climate Change (IPCC), Dr. Farahani served as guide for incorporating climate science components into climate science concept maps.

Climate Science Advisor: *Lynn Russell, CSP Program Director, Professor Atmospheric Science and Physical Oceanography*
Dr. Lynn Russell served as guidance for scientific accuracy when it came to posting scientifically credible phenomenon.

5.5 Project Resource Allocation

My capstone project will be completed at a low cost. Professional development and research costs incurred involved travel and hotel stay at a CDE-ran conference on NGSS Implementation, as well as a professional membership to the National Teachers Science Association. Submissions for the website were designed on Google Docs at no cost. The San Diego County Office of Education will upload these submissions onto their website interface. The breakdown of resource allocation is outlined in Table 1 below.

Item	Itemized Cost	Total	
Registration for NSTA (National Science Teachers Association) virtual conference	$72.95	$72.95	
NSTA (National Science Teachers Association) Membership	$114	$114	
NGSS Implementation Cadre Meeting in Long Beach April 27&28	**Travel** 46.78 **Hotel** $297.85 **Registration:** N/A	$344.63	
			Grand Total $531.58

Table 1: Resource allocation for Capstone project.

VI. Project Methodology

6.1 Guiding Research Questions

This project was conducted through a systematic review of literature, survey data collection, and strategic collaboration to answer the following research questions:

- What are the Next Generation Science Standards, and how do the three dimensions of Disciplinary Core Ideas, Scientific and Engineering Practices, and Crosscutting Concepts, support student learning within the NGSS Framework?
- What defines an appropriate "phenomenon" within the topic of climate change?
- Which regionally based scientific phenomenon can be distilled into valid climate change resources for teachers?
- What instructional resources will be the most useful for teachers in planning for climate science aligned to NGSS?

6.2 Data Sources and Analysis

Two main sources of data were analyzed: survey responses from teachers collected from workshop presentations and systematic synthesis of literature review.

For the survey responses of teachers, each response was averaged to find meaningful patterns that informed the content of IP

submissions and all four concept maps (see Appendix D). Survey responses were collected both on a Likert scale and in open-ended format. The open-ended responses were coded into four categories: Data, Background Knowledge, Websites and Links, and Lesson Plans. Sample sizes were small, as responses were limited to two SDCOE workshops. In total, 29 responses were recorded, and no more than 8 open-ended responses were coded for a particular topic. It should be noted that the purpose of this data collection was to exclusively inform the direction of resource development for this Capstone project.

They synthesis of literature review revealed the most significant resources utilized for this project. The literature review was limited to peer-reviewed scientific journals, published works on climate change, California legislation, NGSS Framework documents, and related grey literature (see Appendix G). Patterns were identified to find the most useful information relevant to research questions, such as grey literature relating to phenomena-based teaching. The literature also helped to identify existing and remaining knowledge gaps (see section 7.2), and inform overall findings (see section 9.1).

VII. Project Management

7.1 Quality Assurance

Quality of this Capstone project was attempted to be assured through the execution of systematic literature review and frequent varied methods of seeking feedback. I began by systematically answering the questions in my research design (see section 6.1). For website phenomena submissions, all content was sent through SDCOE to review prior to dissemination.

In addition, I sought the perspective of my CAC advisor, Darcy Taniguchi, who has extensive experience teaching with phenomena-based methods. She suggested that I incorporate additional phenomena options for teachers in the Effect of Ocean Acidification on Marine Life IP, and noted that misconceptions may arise without defining “glaciers” in the Ice Dynamics IP.

The biggest risk facing this project was lack of objectivity in phenomena selection. This was mitigated by using collected teacher survey data to guide phenomena selection (see section 6.2), as well as the guiding principle (informed by my literature search) that locally-specific (California-specific) climate phenomena are the most effective to use in the classroom (Hestness, 2014).

With any resource created for teachers, the version presented will most certainly not exactly mirror what is produced as instruction in the classroom. The IP submissions are meant to be informative for teachers, and guide best practices for teaching a topic, and are not meant for strict adherence. This poses an inherent risk to the effectiveness of proposed resources. This risk was managed by providing scientifically valid information within resources, and allowing for flexibility in classroom activities by providing more than one for teachers to choose from.

7.2 Knowledge Gaps

Despite extensive research and prior expertise in the field of education, this project inevitably exists with remaining knowledge gaps.

- There is a lack of rigorous research on evidence for what makes a science professional development workshop effective for both students and teachers (Darling-Hammond, 2009). This lack of conclusive evidence creates a knowledge gap that can be mitigated by best practices, but never fully filled.
- Frameworks of phenomena selection can become quite subjective through the lens of one content expert. While feedback was gathered from teachers in SDCOE and CAC advisory members, I made ultimate selection. There are few ways of testing "ideal" phenomena, but sticking to the guidelines for phenomena criteria listed in section 7.1 were methods of mitigating this gap.
- It is nearly impossible to know every resource that exists for climate science education, especially in real time. The best fit resource was always sought after, but as teaching resources are being constantly updated and there are a wealth of resources, as well as new resources being developed for NGSS by publishing companies, a knowledge gap in this area will inevitably exist.

7.3 Dissemination Plan

7.3.A **Tab on SDCOE NGSS Resource Website**

Website instructional resource submissions will be uploaded to the SDCOE NGSS Resource website, and appear as its own tab in Fall 2017. Both climate science concept maps and hyperlinked IP submissions will appear here. This website is trafficked by an average of 500 viewers per day.

7.3.B **CDE NGSS Rollout Presentations**

The original climate science concept map (see Appendix E; climate science concept map) will be used in 6 of 10 CDE NGSS Rollout Presentations. These rollout workshops serve 2,000 -2,500 educational leaders throughout the state of California. The workshops are administered in partial fulfillment of Strategy 1 of the CA NGSS Implementation Plan (CDE, 2014; see Appendix B).

VIII. Future Application

This Capstone project will continue to be utilized in the CDE NGSS Rollout Presentations (see section 7.3.B). It will also become a living document on the SDCOE CA NGSS resource page as a tab for teachers and district leaders to access.

In addition, the project will be used as a model for effective community partnership and collaboration between SDCOE and CDE and STEM institutions. Because the project provides an overall framework for incorporating information from content experts into a larger framework of phenomena-based teaching aligned to NGSS, it will be useful in moving forward with STEM partnerships to create resources for NGSS (ex: San Diego Zoo, SIO).

IX. Conclusion

The success of California's NGSS implementation plan depends upon the success of its teachers in understanding and effectively teaching climate change through methods of phenomenon-based teaching. This Capstone project contributes to a small body of knowledge that is in high demand, as there are few resources that synthesize phenomena-based teaching with climate change as specified by NGSS.

9.1 Findings

- There is a need to incorporate current research and data into the NGSS classroom, and a need to prepare teachers for this task through effective science professional development. While useful in contributing overall to instructional resources pursuant to CA NGSS Implementation Plan, more robust professional development strategies grounded in research must be applied alongside the resources.

- Phenomena-based teaching can be clearly represented and taught through climate science concept maps.

- Structuring investigative phenomena (IP) resources within a larger concept map is an effective framework upon which to base further collaborative work between CDE and STEM institutions.

X. References

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XI. Appendices

Appendix A

Middle School and High School CA NGSS Performance Expectations for DCI ESS2 and ESS3

MS-ESS2-1 Earth's Systems

MS-ESS2-1	Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process.
MS-ESS2-2	Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales.
MS-ESS2-3	Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions.
MS-ESS2-4	Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity.
MS-ESS2-5	Collect data to provide evidence for how the motions and complex interactions of air masses results in changes in weather conditions.
MS-ESS2-6	Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates.

MS-ESS3 Earth and Human Activity

MS-ESS3-1	Construct a scientific explanation based on evidence for how the uneven distributions of Earth's mineral, energy, and groundwater resources are the result of past and current geoscience processes.
MS-ESS3-2	Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.
MS-ESS3-3	Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.
MS-ESS3-4	Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.
MS-ESS3-5	Ask questions to clarify evidence of the factors that have caused the rise in global temperature over the past century.

Appendix A (cont.)

High School CA NGSS Performance Expectations for DCI ESS3
HS-ESS3 Earth and Human Activity

HS-ESS3-1	Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.
HS-ESS3-2	Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.
HS-ESS3-3	Create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity.
HS-ESS3-4	Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.
HS-ESS3-5	Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.
HS-ESS3-6	Use a computational representation to illustrate the relationships among Earth's systems and how those relationships are being modified due to human activity.

Appendix B
CA NGSS Plan Implementation Timeline

Overview: Approved in 2014, the CDE outlined a six year plan for NGSS implementation. At the publishing of this Capstone project (June 2017), the Early Implementation Initiative is nearing an end.

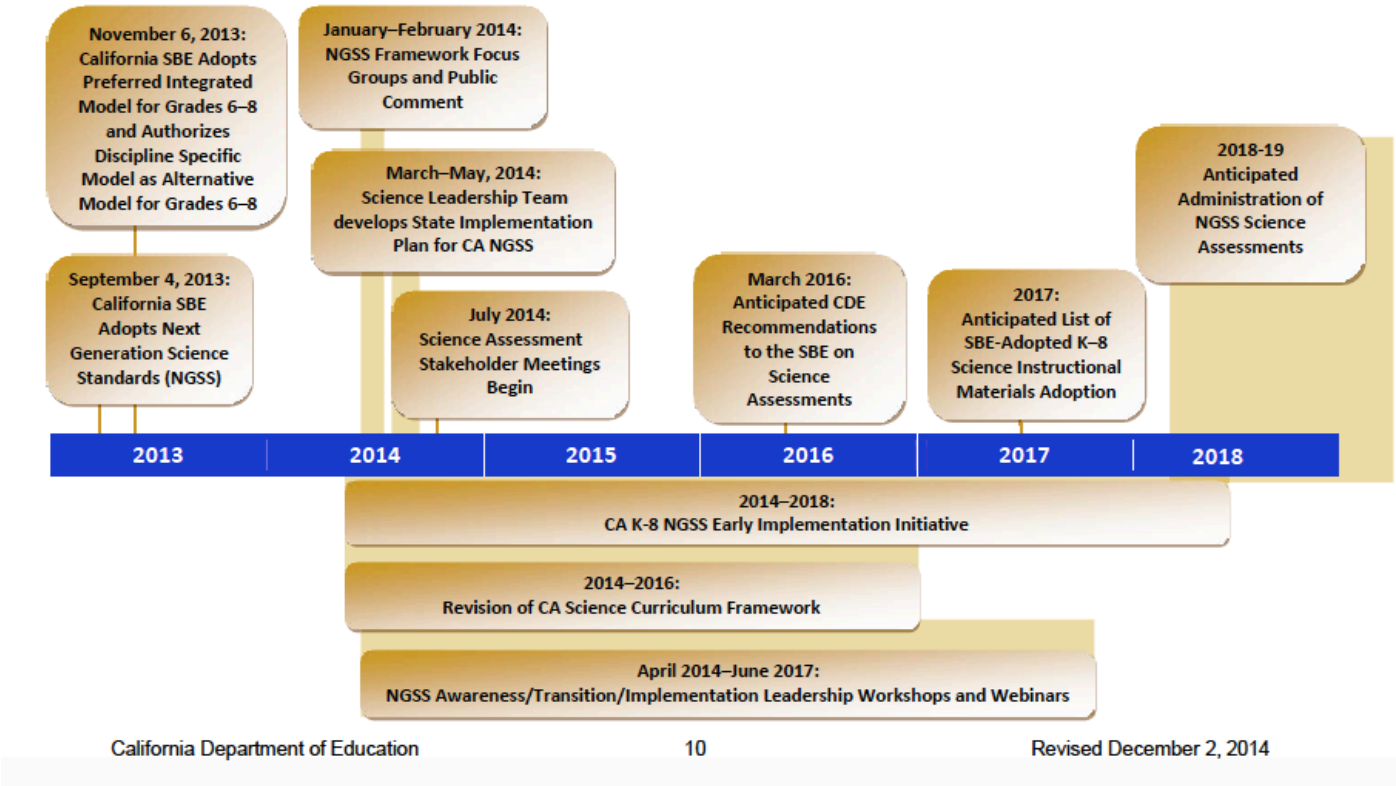


Figure 1: CA NGSS Implementation Timeline

Appendix C

Phenomenon-Based Teaching Framework

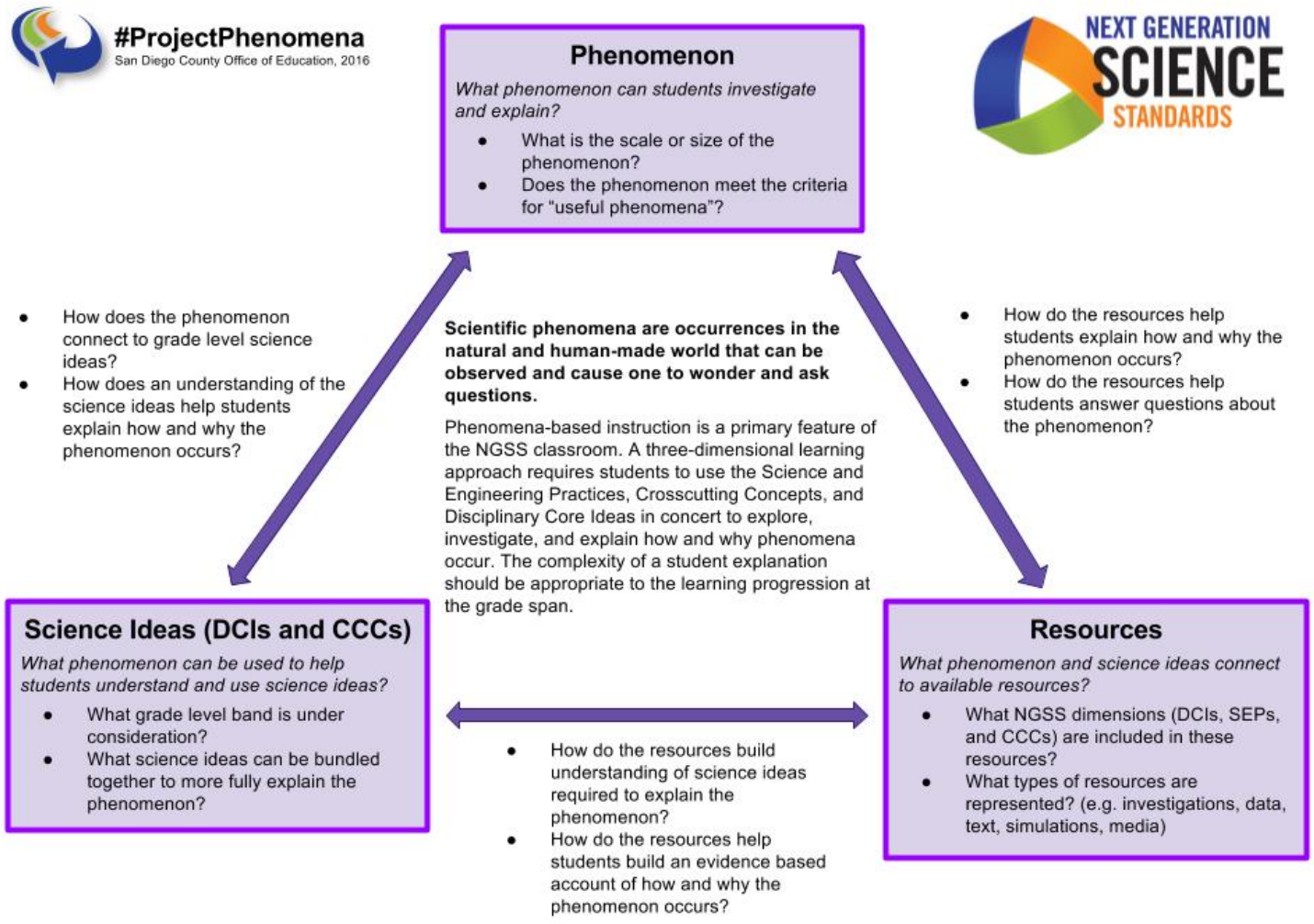


Figure 2: Teaching pedagogy behind aligning phenomenon-based teaching with NGSS. Source: SDCOE

Appendix C (cont.)

Phenomenon-Based Teaching Framework

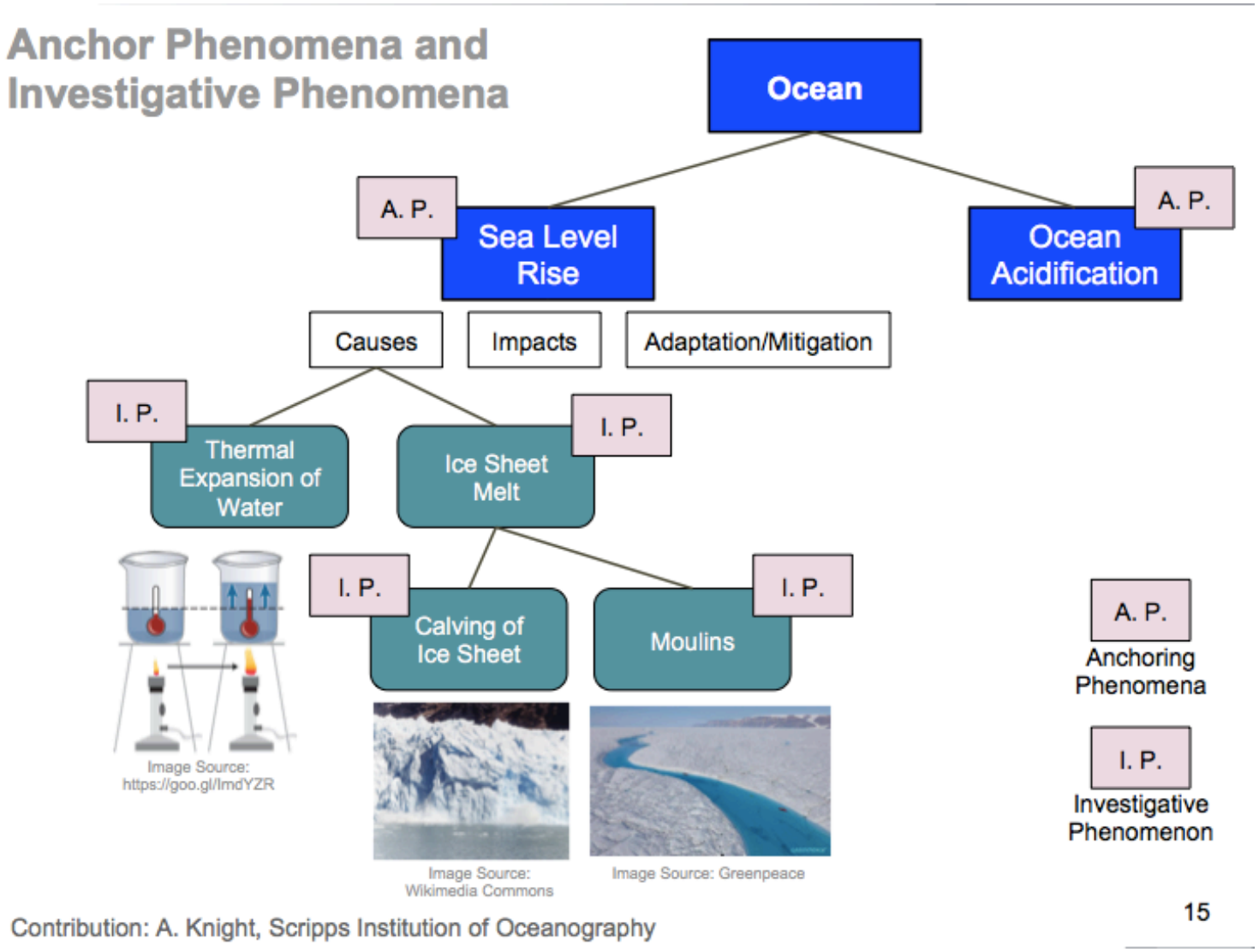
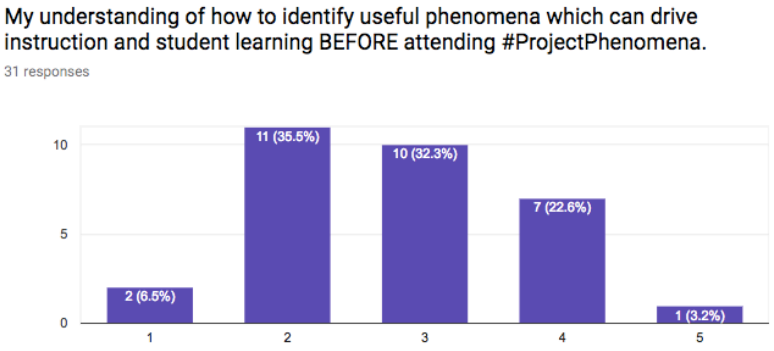


Figure 3: There two main types of phenomena within the teaching framework: anchoring phenomenon (AP) and investigative phenomenon. Anchoring phenomenon are culturally relevant, utilize and meet performance expectations, is observable, and are too complex to explain after one lesson (Penuel, 2016). This graphic was incorporated into the California Department of Education NGSS Rollout #4.

Appendix D
Teacher Survey Results



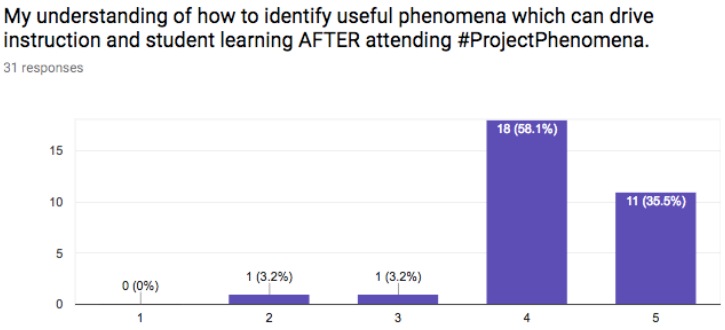
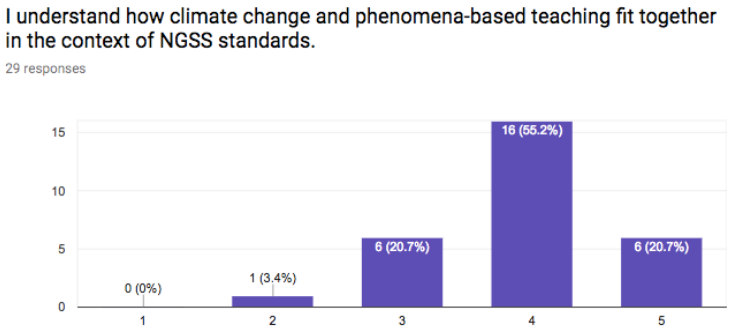


Figure 4 & 5: Teachers respond to overall understanding of phenomenon-based teaching before attending SDCOE workshop I presented at (left) and after (right). All responses recorded on a Likert scale of 1-5, 1 being strongly disagree and 5 being strongly agree.



Open-Ended Survey Results: Qualitative Data
Data that students can analyze themselves (8)
Background knowledge on climate change (3)
Websites & Links (1)
Lesson Plan (1)
Other (3)
Total Responses: 15

Figure 6 & 7: Teachers respond to understanding of phenomena-based teaching and climate change after learning from climate change graphic (see Appendix E)(left). All responses recorded on a Likert scale of 1-5, 1 being strongly disagree and 5 being strongly agree. Open ended survey results were coded for relevance to the categories above. Total number of responses for Likert scale was 29, and for open-ended, 15.

Appendix E
Climate Science Concept Maps

Climate Change Concept Map

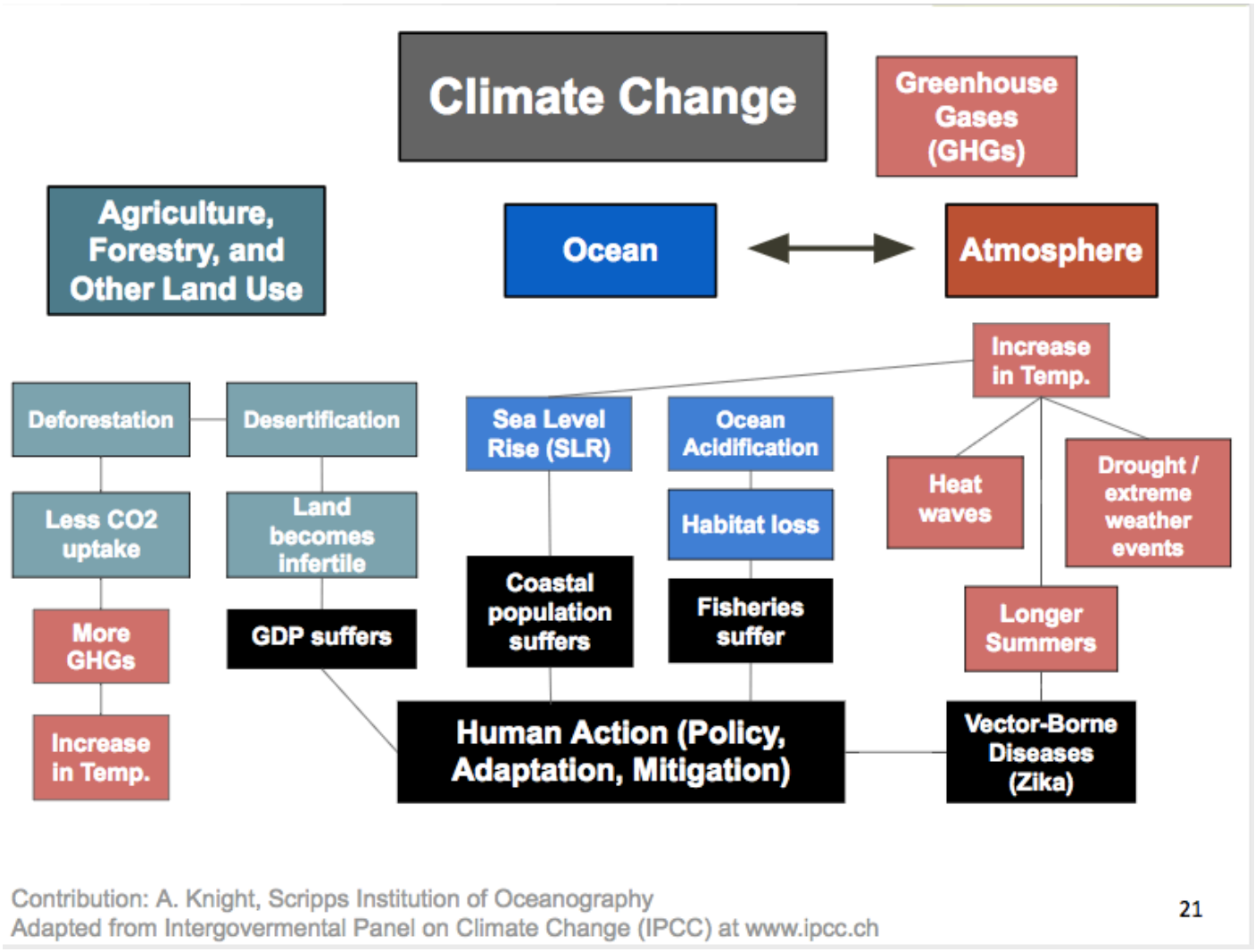


Figure 8: Climate science concept map. For full description see section 5.1

Climate Science Concept Maps

Ocean Concept Map

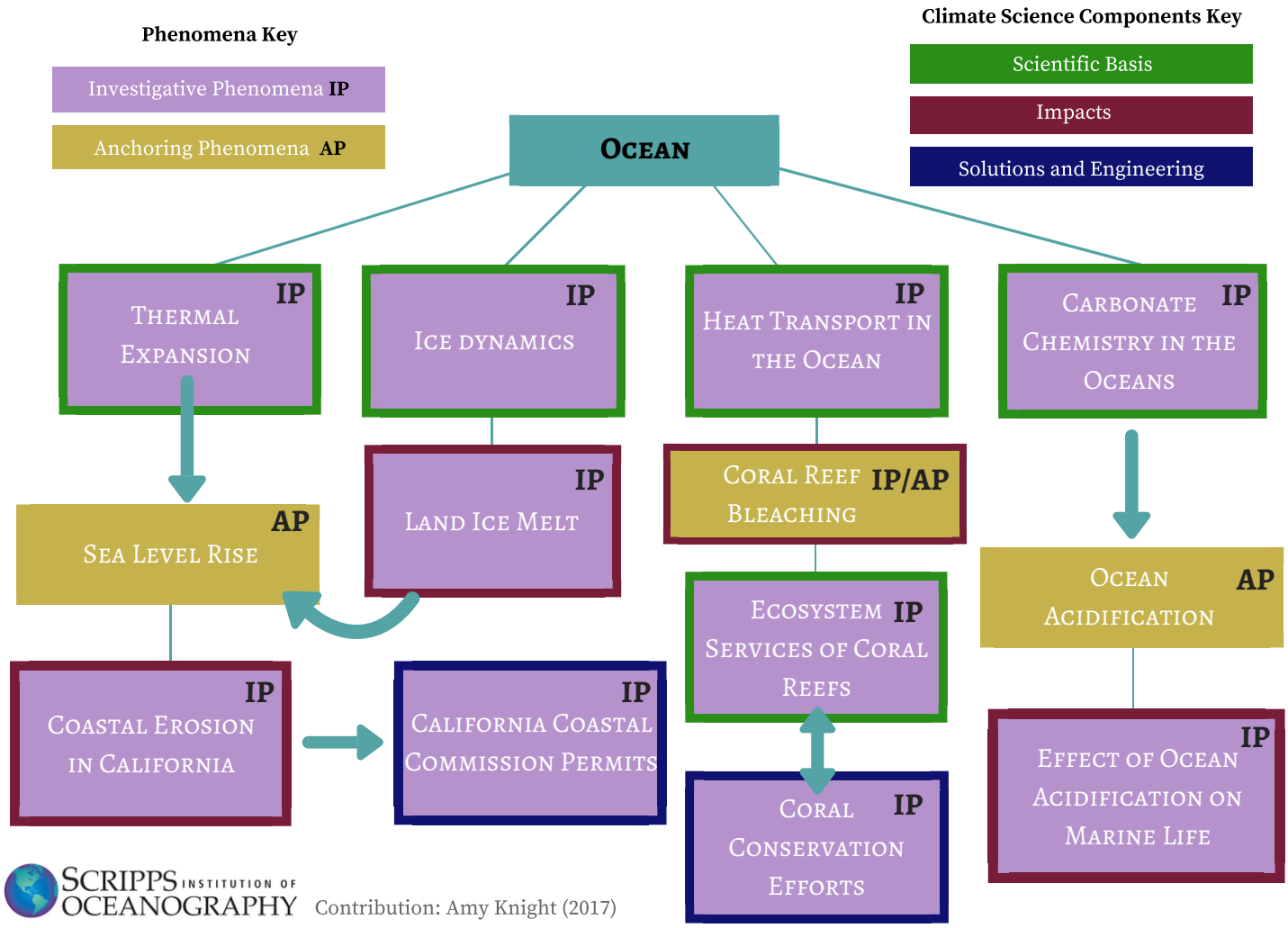


Figure 9: Ocean concept map. For full description see section 5.1.A

Appendix E (cont.)
Climate Science Concept Maps

Atmosphere Concept Map

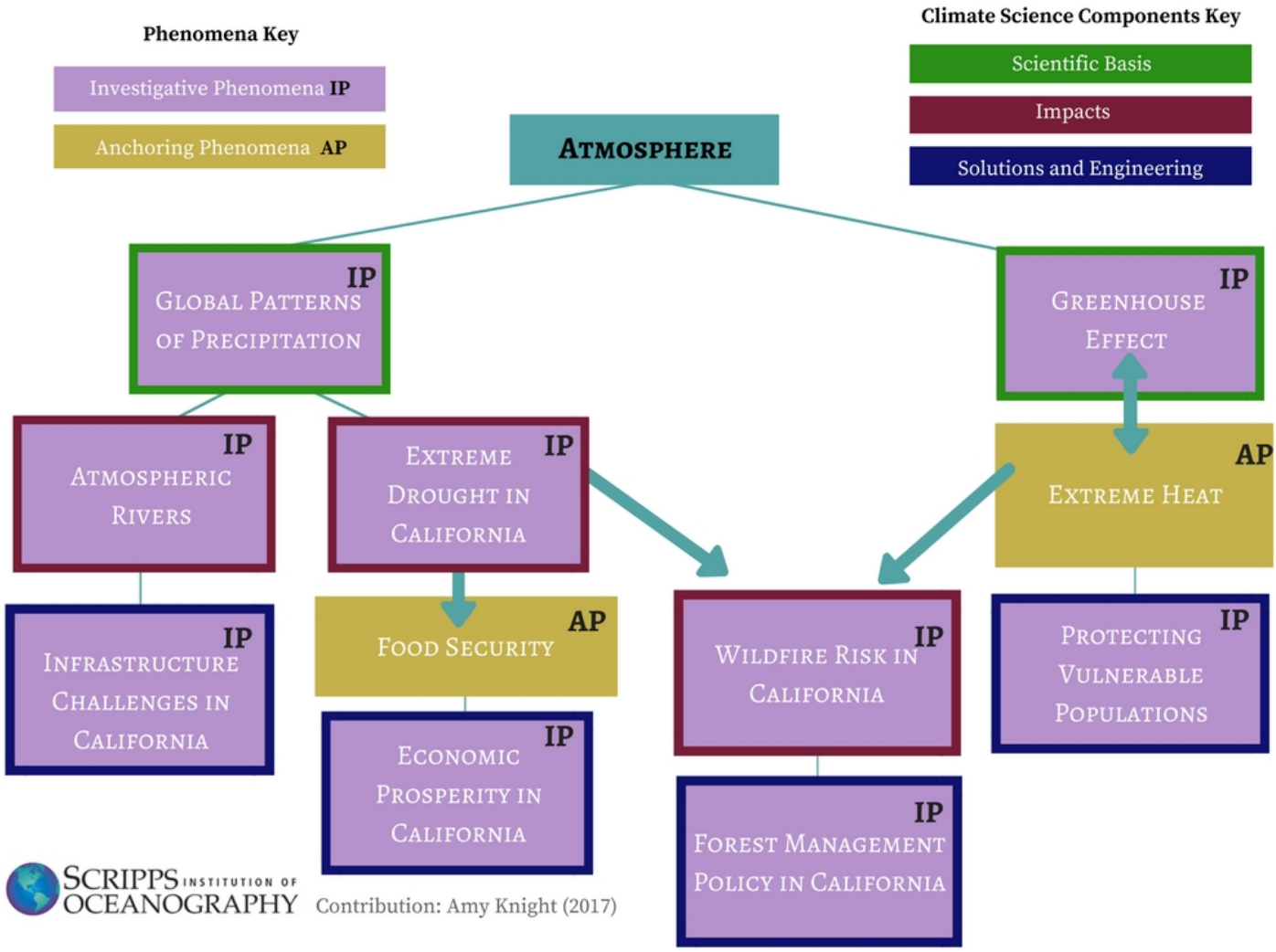


Figure 10: Atmosphere concept map. For full description see section 5.1.B

Appendix E (cont.)
Climate Science Concept Maps

Agriculture, Forestry, and Other Land Use (AFOLU)

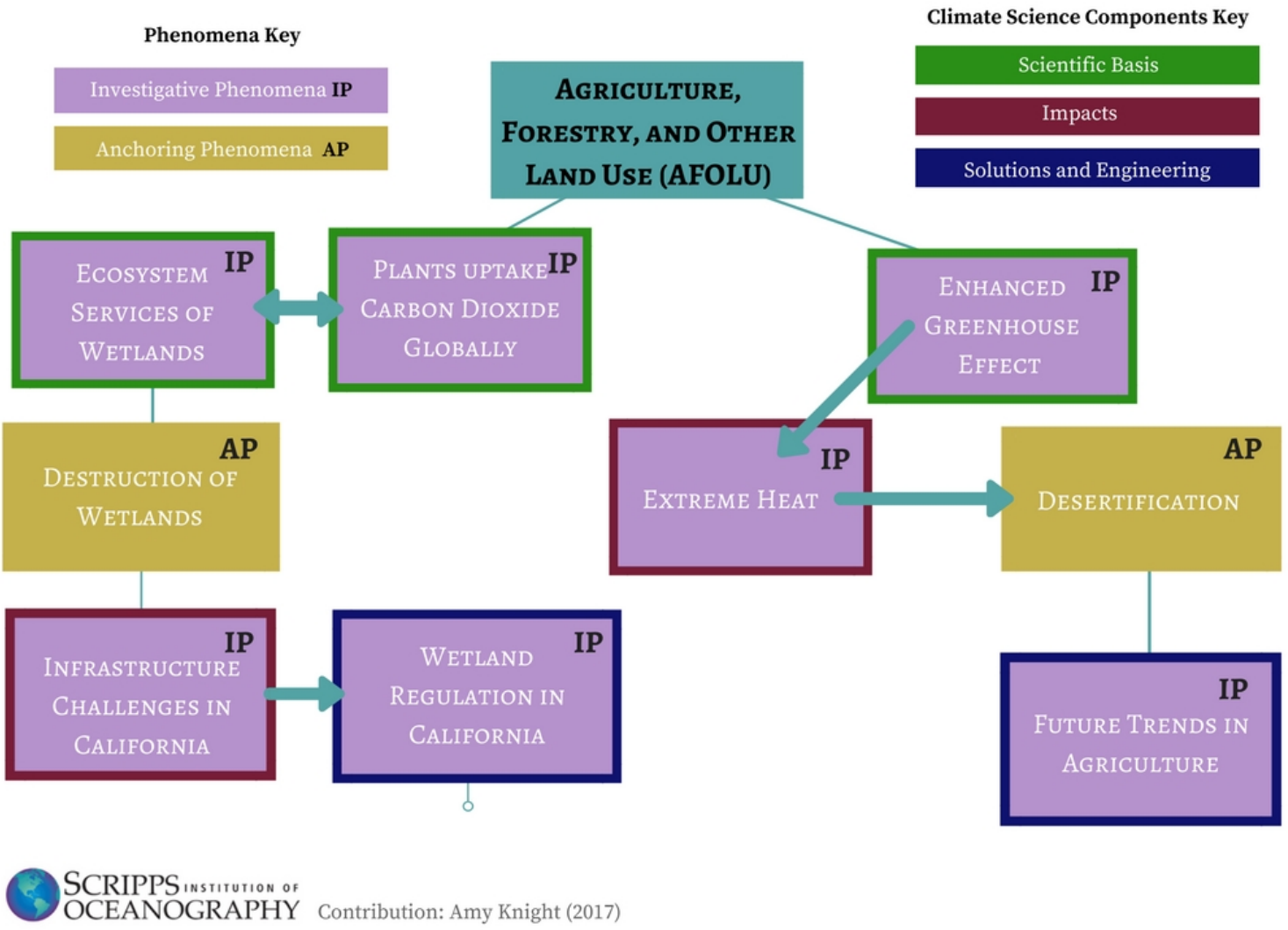


Figure 11: AFOLU concept map. For full description see section 5.1.C

Appendix F
Investigative Phenomenon Submissions

Concept Map	Investigative Phenomena Submission
Ocean	Carbonate Chemistry in the Oceans Impact of Ocean Acidification on Marine Life Thermal Expansion Ice Dynamics Land Ice Melt
Atmosphere	The Greenhouse Effect Extreme Heat Global Patterns of Precipitation Extreme Drought in California
AFOLU	Plants Uptake CO2 Globally

Figure 12: List of IP submissions completed for this Capstone project. Each is linked to a corresponding GoogleDoc.

Appendix F (cont.)
Investigative Phenomenon Submissions

Carbonate Chemistry in the Oceans

Carbonate Chemistry in the Oceans			NGSS Alignment		
What is the scientific phenomenon? What questions might students ask?	**Explanation: What causes the phenomenon to happen?**	**Student Investigation and Explanation**	**Alignment by DCI**	**Alignment by Scientific & Engineering Practices**	**Alignment by Crosscutting Concepts**
The Phenomenon: Cabbage Juice Changing Colors The cabbage juice turns a lighter pink when I breathe bubbles into it. Photo Credit: Liz Heinecke	**Carbonate Chemistry** The **carbon dioxide** (CO_2) from my breath combined with the **water** (H_2O) to form **carbonic acid** (H_2CO_3). $CO_2 + H_2O \rightarrow H_2CO_3$ Cabbage juice is a natural **pH indicator.** It contains a pigment called **flavin** that changes colors in response to changes in **pH** (Science Museum of Minnesota, 2011)	**Middle School** 1. pH variability by ocean ecosystem; CINP Lesson Plan 6 (pg. 66). Activity and reading regarding both abiotic (temperature and salinity) and biotic (photosynthesis) factors that influence pH 2.NOAA Marine Sanctuaries, "Plotting the Dangers of Ocean Acidification". **Students plot carbon dioxide concentrations and make inferences** about future	**Middle School** **MS-PS1.A:** Structure and Properties of Matter **MS-PS1.B:** Chemical Reactions (MS-PS1-2) **MS-LS2.C:** Ecosystem Dynamics,	**Analyzing and Interpreting Data** **Engaging in Argument from Evidence** **Asking Questions and Defining Problems** **Using Mathematics and Computational**	**Stability and Change** **Patterns** **Cause and Effect** **Scale, Proportion, and Quantity**

Figure 13: A screenshot of a sample IP, Carbonate Chemistry in the Oceans. The phenomena is to the left, along with a description of how to setup the activity itself and questions students may ask to begin the inquiry-based learning. The scientific explanation for teachers is in the next column, and the middle column contains links and descriptions of follow-up activities that students may complete to further investigate the phenomena. The last three columns align the phenomena to a variety of CA NGSS performance expectations (MS-PS1-2, etc.) and the three dimensions of NGSS. Student actions and thoughts are color-coded throughout the submission in keeping with the orange, blue, and green colors of NGSS. Links and "Additional resources" sections are located at the bottom of the document, along with a complete list of references cited in APA style.

Appendix G
Annotated Bibliography

Ames, R. T. (2014). A Review of Science Standard History Culminating With Next Generation Science Standards. *Journal of Education and Training,1*(2), 48. doi:10.5296/jet.v1i2.5292

Ames' review of science standard history serves a lens through which to view educational reform in the United States. Ames highlights the historically significant events (USSR Sputnik launch, JFK's moon landing speech) that shaped and advanced science education in America the last half of the 20th century. Decades after those events, studies like the 1983 "A Nation At Risk" revealed an America whose science education was far below expectations. Many research-based papers and science standard benchmarks later, the Next Generation Science Standards (NGSS) were created in April 2013. This review is useful because it provides the historical context for the 2011 paper by the National Research Council (and why they were involved in science education at all) "A Framework for K-12 Science Education: Practices, Crosscutting Concepts, Core Ideas". The suggestions from this 2011 paper would serve as the foundation for NGSS. Knowing this context and foundation allows me to better understand the state-level response to the standards, and how education reform and education policy inform one another.

Feinstein, N. W., & Kirchgasler, K. L. (2014). Sustainability in Science Education? How the Next Generation Science Standards Approach Sustainability, and Why It Matters. *Science Education,99*(1), 121-144. doi:10.1002/sce.21137

This article in *Science Education* explores the way that Next Generation Science Standards (NGSS) approach sustainability. As the first national set of standards to do so, Feinstein and Kirchgasler view NGSS as the "bellwether" for science education in the United States. Feinstein and Kirchgasler argue that the reliance on science to teach sustainability develops an exclusive narrative that relies on the usage of technology to solve problems called "ecological modernization". This approach also runs the risk of abandoning ethical and economic truths surrounding climate change that the science does not capture, like responsibility or socioenviornmental justice. This could cause students to underestimate the threats posed to their communities and how to solve them. The authors suggest that social studies courses (and standards) more effectively partner with the sciences to avoid these risks. This article is strong in reasoning, and brings a perspective to the table that the original NGSS source does not. I will use this source in developing my reasoning for how science education reform has the potential to inform public opinion and public policy.

Heberger, M., Cooley, H., Herrera, P., Gleick, P. H., & Moore, E. (2009). The Impacts of Sea Level Rise on the California Coast. *California Climate Change Center*.

This 2009 report by the California Climate Change Center finds that sea level has risen 8 inches along CA coast over past century, with much infrastructure at risk due to coastal erosion. I will use this source as a reference while planning phenomenon for projected California sea level rise and its impacts.

Hestness, E., Mcdonald, R. C., Breslyn, W., Mcginnis, J. R., & Mouza, C. (2014). Science Teacher Professional Development in Climate Change Education Informed by the Next Generation Science Standards. *Journal of Geoscience Education,62*(3), 319-329. doi:10.5408/13-049.1

This *Journal of Geoscience Education* article analyzes the present needs of teachers that will be teaching climate change through Next Generation Science Standards. The authors note that current climate literacy efforts are focused not solely within the scientific field, but within social and economic realms as well. They suggest that in addition to NGSS, to be fully professionally supported, teachers need a provision of quality resources with which to teach climate change most effectively, the time and space in which to learn climate change science and content, and the opportunity to lead students on regionally based observations of climate change inside or outside of the classroom. This article illustrates what the process of "rolling out" NGSS might look like, and highlights the importance of professional development for teachers unique to climate change. This can help inform the effectiveness of incorporating climate change into NGSS.

Hohenstein, J. M., & King, H. (2007). Learning in and outside of school. In J. Dillon & M. Maguire (Eds.), *Becoming a teacher: Issues in secondary teaching* (3rd ed., pp. 163-174): McGraw-Hill International

This book chapter highlights the diversity of teaching theories and pedagogies. In summary, Theories of learning are diverse, and highlight the importance of learner motivation, cognition, environment, and behaviorism. Phenomena-based learning is based largely on motivation. I will use knowledge from this book chapter to identify classroom activities that correctly leverage intrinsic motivation, which is central to the framework of phenomenon-based teaching. This chapter allows me to continue learning about research-based teaching pedagogies and what works and doesn't work inside the classroom.

This paper was based on case studies of individual classrooms, producing a 10-step guide that has been vetted for teaching using NGSS. I will use this guide to help me in understanding the most effective way to maximize instruction for NGSS from the resources that I identify.

National Academies Press. (2013). *Next Generation Science Standards: for states, by states* (Vol. 1, Ch. 1). Washington, D.C.: National Academies Press.

This document was created through the National Academy of Sciences and authored by the 26 "lead states" to develop and pilot the Next Generation Science Standards (NGSS). It is an original source for gaining a better understanding of how the "three-dimensional learning" of core ideas, crosscutting concepts, and practices fit together. Further broken down are individual Disciplinary Core Ideas (DCI) that serve to guide the development of crosscutting concepts and practices through a conceptual basis. I will find this source particularly useful when referring to the original language and reasoning for the inclusion of Earth and Human Activity and climate

change into Earth Sciences. Further research that I conduct will be largely based upon this document.

Papadimitriou, V. (2004). Prospective Primary Teachers' Understanding of Climate Change, Greenhouse Effect, and Ozone Layer Depletion. *Journal of Science Education and Technology,13*(2), 299-307. doi:10.1023/b:jost.0000031268.72848.6d

This 2004 study distributed a questionnaire to a group of prospective primary teachers to gauge their understanding of climate change. Results indicated that all teachers who participated believe climate change is underway in some form. The main misconceptions surrounded the ozone hole and GHG confusion and that pollution contributes to climate change. Prospective teachers enter University with many misconceptions about climate change, but recognize the importance of caring for the environment and promoting its care. This article prompted my initial thought of including a teacher guide into my capstone project.

Peterson, T. C., Hoerling, M. P., Stott, P. A., & Herring, S. C. (2014). *Explaining extreme events of 2013 from a climate perspective*. Boston: American Meteorological Society

This special report from the American Meteorological Society describes the extreme 2013 drought in California from the perspective of climate change. The High North Pacific pressure/blocking ridge (GPH) displaced jet stream to the north, disrupting storms. CMIP5 models used to compare pre-industrial to modern emissions. I will use this paper as a reference while creating phenomenon for extreme weather events as required by NGSS. In the case of California, I will focus on drought.

Rignot, E., Velicogna, I., Broeke, M. R., Monaghan, A., & Lenaerts, J. T. (2011). Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise. *Geophysical Research Letters,38*(5). doi:10.1029/2011gl046583

This study compares the surface mass balance with perimeter loss of both Greenland and Antarctic ice sheets. Data is collected and analyzed from observations and modeling (RACMO2). It is found that ice sheet loss is accelerating 3 times larger than from mountain glaciers and ice caps). I will use this paper as credibility for sea level rise phenomenon while citing both thermal expansion and contribution of ice sheet losses to projected California sea level rise and its impacts.

Wise, S.B. 2010. Climate change in the classroom: Patterns, motivations, and barriers to instruction among Colorado science teachers. *Journal of Geoscience Education*, 58(5):297–309