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ClimateWEST: A Climate Science Activity

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Abstract

Data literacy and the ability to synthesize and communicate complex concepts are core components of modern scientific practice. Here we present the design and implementation of an inquiry activity about climate variability that was taught as a part of the University of California, Santa Cruz (UCSC) Workshops for Engineering & Science Transfers (ClimateWEST) in 2019. The two-day activity introduced interdisciplinary undergraduate and community college transfer students pursuing graduate school to the field of climate science through a series of inquiry activities. Climate science is a complex topic, and research shows that there are certain concepts that are particularly difficult to grasp. Our climate activity focused on disentangling some of those misconceptions, by emphasizing the following themes or core dimensions of climate variability: (1) Climate varies on both shorter timescales (e.g. seasonal or annual cycle) and on longer timescales (e.g. climate change); (2) Both climate and climate trends vary spatially/geographically and are different from global climate; and (3) Climate is complex and includes not only temperature but also other key variables such as precipitation, ice, wind, ocean circulation, etc. We discuss the inquiry components, assessment-driven tools, facilitation and equity and inclusion design, as well as summarize students' progress toward our goals in the activity.

Keywords: activity design, argumentation & explanation, climate, inquiry

1. Venue and learners

This inquiry activity was taught at the University of California Santa Cruz (UCSC) during the Workshops for Engineering & Science Transfers (WEST). WEST was a 2.5-day workshop designed to build community and promote critical thinking skills among incoming transfer students (Santiago et al., this issue). This particular inquiry activity on climate variability (ClimateWEST) was designed through the Institute for Scientist & Engineer Educators Professional Development Program and was facilitated for 24 learners who were pursuing majors in diverse STEM disciplines (i.e., biology, marine biology, computer science, earth sciences, ecology, electrical engineering, mathematics, neurosciences, and physics). Although no prior formal background or experience in the inquiry context was expected, some learners had prior research experience.

2. Learning outcomes from ClimateWEST

The ClimateWEST inquiry activity was focused on several types of outcomes that drove the design process. Establishing these learning outcomes was the first step in the ClimateWEST design process, following the backwards design model (Wiggins and McTighe, 1998). One of the main objectives of the WEST program and the ClimateWEST activity is that the learners gain knowledge not only of a particular content, in this case climate variability, but also gain familiarity and confidence with key scientific approaches and skills that are transferable across STEM disciplines. Because of that, the ClimateWEST learning outcomes are divided into three following categories:

2.1 Content outcomes

The main content outcome of the ClimateWEST inquiry activity was to teach learners the concept of climate variability, specifically that "Learners will use the concept of climate variability to analyze and evaluate global and regional climate differences at multiple timescales in the present, and in future climate projections". Teaching the concept of climate variability is important because learners frequently confuse weather with climate (Gowda et al., 1997). Because of this confusion, it is important to clarify that weather events occur over short time scales (minutes to hours to weeks), while climate happens over months, seasons, years and into millennia. Additionally, the climate has changed through the history of Earth, over different time periods and due to different causes. Finally, it is important to clarify the difference between climate change, which is multifaceted and complex, and the more specific phenomenon of global warming. ClimateWEST aimed on disentangling these misconceptions, by focusing on the following core dimensions of climate variability: (1) Climate varies on both shorter timescales (e.g. seasonal or annual cycle) and on longer timescales (e.g. climate change); (2) Both climate and climate trends vary spatially/geographically and are different from global climate; and (3) Climate is complex and includes not only temperature but also other key variables such as precipitation, ice, wind, ocean circulation, etc.

2.2 Practice outcomes

An additional goal of ClimateWEST was to help learners improve at a key scientific reasoning skill: constructing an argument based on interpretation of data. This core STEM practice was further broken down into three dimensions: (1) Stating an argument/claim that addresses the content prompt; (2) Using relevant data to support the argument; and (3) Using reasoning that links evidence to the argument.

Constructing arguments or claims from data is a key and everyday practice in science and engineering. The ultimate goal of science is to construct arguments or claims from data that provide explanatory accounts of the world. Constructing arguments is also crucial to develop skills of critical thinking and to understand a core aspect of the practice of "doing science" (Kuhn, 1993; Driver et al., 2000). This practice usually culminates in different ways of communicating and sharing the science (e.g., journal publications and conferences), where it is important not only to construct arguments, but also be able to evaluate arguments that have been made by others and to be able to make judgments about the quality of an argument without having necessarily participated in the process that produced that particular argument (e.g., peer-review publications, arguments from media and politicians). This shows the sociocultural perspective of the practice of scientific argumentation and its link to social sciences (Ryu and Sandoval, 2012).

We chose this STEM practice because learners often struggle to understand what evidence is, what counts as appropriate evidence, and how to use this evidence to support their claims, which is connected to the learners' understanding of the content. When not using evidence, they make conclusions from their own personal beliefs and other knowledge (McNeill et al., 2006). In addition, reasoning is the most challenging part of this practice. Learners often link their arguments to the evidence, but they fail in articulating why, or stating the scientific principle that allowed them to make that connection (McNeill et al., 2006; Ryu and Sandoval, 2012).

2.3 Scientific skills

We wanted learners to have a better understanding of climate variability and climate change, but also to help build their identities as scientists, make them practice tasks performed by professional climate scientists (i.e., working in teams, communicating results, etc.), and to promote a sense of excitement and personal connection to scientific questions. Finally, ClimateWEST was also designed to improve learners' identity as scientists and their proficiency in science communication. This learning outcome was interwoven throughout the activity as they worked in teams to create a final presentation of their work. A key aspect of this learning outcome was that each learner took responsibility for one portion of their project, becoming an "expert" in one area and then communicating those results to the rest of the group. The culmination of their work was a poster presentation, familiarizing the learners with a common method of disseminating results in all scientific disciplines.

3. Activity description

3.1 Introduction

The ClimateWEST activity consisted of a six-hour inquiry activity that took place over 2.5 days (see Table 1 for details of the timing). On the first day of the WEST program, ClimateWEST learners participated in an icebreaker where they shared their backgrounds and interests. Sharing personal and professional information can result in meaningful interactions regardless of their STEM identity strength. Students were presented with a brief introduction to key climate science concepts to provide a theoretical foundation for the activity. These concepts included differences in the timescales of weather vs climate, and global and regional variation in climate trends.

3.2 Raising questions

In the next component of the ClimateWEST activity, termed "raising questions," students began brainstorming potential research questions related to climate and climate variability. This section was broken down into three parts. In the first part, learners rotated around eight stations, each with documents containing climate information from a different region of the world. The documents illustrated how climate and climate change can vary spatially, and how climate interacts with unique social and ecological conditions in each region (see example in Figure 1). In each station, learners spent a few minutes looking through the materials and generating climate questions related to that particular region. The goal was for learners to raise the types of questions about a specific place that a scientist might ask. Once all learners had explored and raised their questions for each of the eight stations, they chose one station or region they were particularly interested in investigating further, and became the "climate experts" of that region.

In the second part of the raising questions section, learners were presented with temperature, precipitation, and sea level rise, all at a monthly resolution spanning from 1980 to 2100. The set of variables was constrained to those three to simulate real situations where observations or data are limited. From the pool of questions generated during the first iteration, learners selected the ones they were able to investigate knowing that the data was limited to only three specific climate variables. During this stage, facilitators were available to ensure questions were reasonable given the available data. Finally, in the third part, learners discussed their question within their regional group, and with facilitation

Table 1: Activity overview.

Inquiry Component	Time (min)	Participant Structure(s)	What is happening? What are learners doing? If possible: *"Prompt given to learners that drives this component"*
Day 1	30	Circle	Icebreaker
Day 2 Introduction 1:15–2:15pm	10	All seated together	Introduction to the inquiry activity (practices, what the activity is, *why* we are doing it)
	15	All seated together	Introduction to climate variability: focused on California, which should be familiar to most learners
Raising questions 2:15–2:45pm	5min/ table (region) = 20	Rotating to different tables throughout classroom	Prompt: Write as many questions as you can think of after looking at this material (newspaper headlines, maps, general information and pictures of climate change impacts in different regions around the world) Task: Learners generate questions at each table. When the timer goes off, they move to the next table. They will visit one table for each region.
Break 2:45–3:00pm Raising questions 3:00–3:20pm	5	Moving	Prompt: Select the region you are most interested in. There should be 3–4 people at each region table. Task: Learners group themselves in groups of 3–4.
	15	They are grouped by regions (Region group expert)	Prompt: All these questions are great, but data is limited. You will be given data for X, Y and Z climate variables taken monthly (or some time interval). Now, what questions can you reasonably answer with this information? (Try to keep questions general to all climate variables). Task: They will generate questions that can be answered knowing what data is available. We will be available as facilitators to ensure questions are reasonable.
	10	By regions	Prompt: Within your group, decide on final investigation questions (all climate variables will be answering the same investigation questions). Next, decide who will work on X, Y and Z climate variables. Task: They decide their final question as a regional group and decide the variables that each learner will investigate.

Inquiry Component	Time (min)	Participant Structure(s)	What is happening? What are learners doing? If possible: *"Prompt given to learners that drives this component"*
Investigations 3:20–5:00pm	5	By regions	Task: Learners are given data, open computers, and explore the data
	45	By regions	Individual time using Excel or graphical user interface (GUI); Prompt: Use the data available for your variable and investigate how it varies at different timescales At the end of this time you will be sharing your investigations of your variable with other experts on that variable in different regions. Task: playing with data (investigation) Facilitate that learners will see 3 major timescales (seasonal, decadal, and future) Given prompt for written artifact:(Before discussion): Q1: How do patterns and trends for your variable and region compare to the global average? Q2: (After): How do they compare to other geographic locations? reflecting time on spatial variability in their climate variable.
Day 3 Investigations 10:00–11:00	45 (20)	Move to be seated by variables	Prompt: Discuss your response to Q1 with your group. Then, answer Q2 based on your discussion. Be prepared to share these results with your region after the discussion. Task: Jigsaw discussion → Students will move to sit with other people studying their climate variable but in other regions. First, they will answer Q1 of the prompt (written). Then, they will discuss answers with their group. Finally, they will answer Q2 of the prompt (written).
	60	Back to seated by regions	Share with the other people in your region what you learned about your climate variable in both your region and others. Task: Start to think about the climate as a whole in your region. Describe patterns across your three variables, and how information from each variable can help you to answer your research question/s
Culminating assessment task 11:00–12:00	60	Seated by regions	Individual prompt (written response): Describe the present and future climate in your region, including all the variables your group collectively investigated. Group prompt: Prepare a digital poster that discusses both present and future climate scenarios (this may require discussing different timescales) for your region. Compare your results to global averages and predictions. Support your discussion with appropriate figures. Be sure to include a section for hypotheses, results, and conclusions.
1:15–2:30	75	Learner poster presentations: ~5–6 min/group, 1 question per group	
Synthesis 2:30–2:45	15	Group Lecture	Instructors give a presentation summarizing findings and content goal

from the instructors, selected their final investigation questions. At this stage, learners within each regional group each selected which variable they wanted to focus on. The final configuration of the ClimateWEST learners was eight groups (named "regional expert" groups), and each regional expert group consisted of three learners, each specializing in one variable each ("climate variable expert") and was given data for that variable at both global and regional scales, detailed in Figure 2a.

3.3 Investigations

In the next phase of ClimateWEST, learners investigated their chosen research question. These investigations followed a jigsaw format and had three parts (Figure 2). During the first part of the investigations, learners were given the data and had some time to explore it and decide which software to use (see extra materials for details about the data and the software provided), before investigating the timescales of variability in their climate variables. Here, instructors facilitated to ensure learners were exploring the data at seasonal, decadal, and long-term timescales, while learners were working with their individual variables (at regional and global scale), and becoming the climate variable experts of their region. The main goal of the first part of the investigation was that the learners establish their expertise (timescale variability of their variables at regional and global scale). For that, learners were prompted that at the end of their individual investigation time, they had to individually answer the following question: *Q1- How do patterns and trends for your variable and region compare to the global average?* This gave them a written artifact that was going to be used in the next part of the investigation (Figure 3).

In the second part of the investigations, all the learners were grouped by climate variables (Figure 2b). During this second interaction, learners shared their expertise (i.e., what were the notable patterns of variability in their climate variable in their region) and learned from the expertise of experts representing the other regions. To facilitate this discussion, learners were prompted with question 2: *Q2- How does the variability of your climate variable compare to other geographic locations?;* and each discussion group was led by a facilitator. As the last step of the jigsaw and third part of the investigations, climate variable experts came back to their original region group and shared what they learnt about how their variable varies in their region compared to others (Figure 2c). Here, as regional experts, they were prompted to propose a description of climate variability in their region using descriptions of the patterns of variability and change across the three variables.

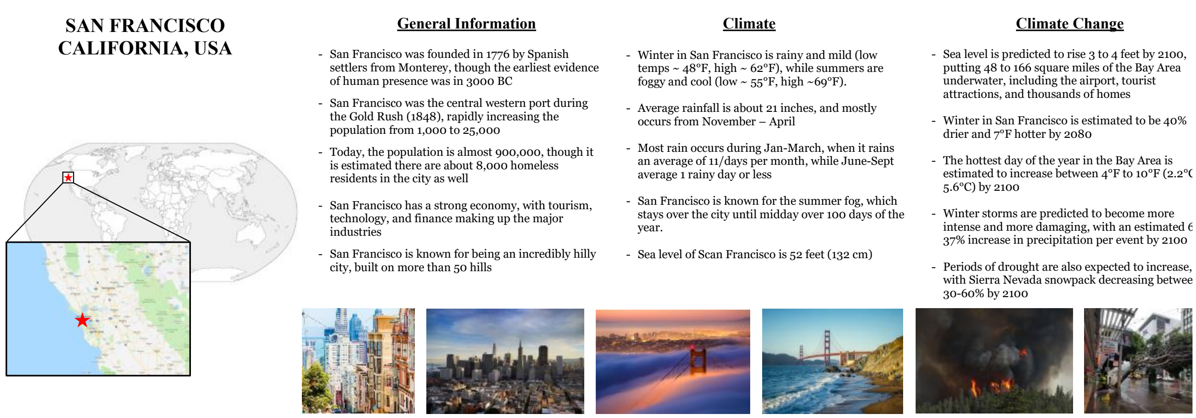

Figure 1: Example of the information provided in a regional station during the Raising Questions step.

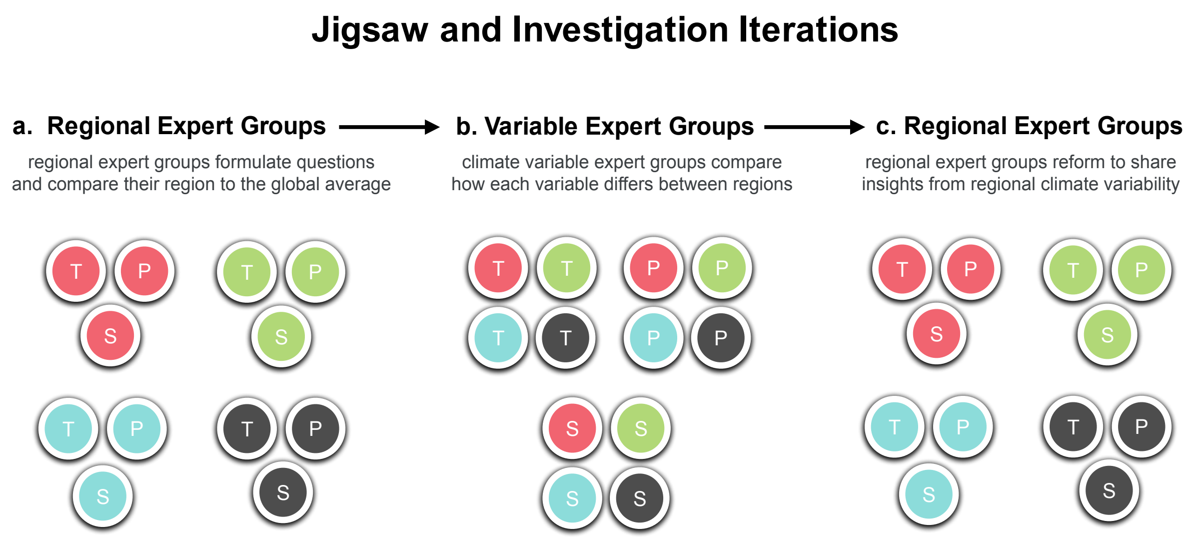

Figure 2: Jigsaw diagram showing the distribution of the learners during the investigations. Only four (from a total of eight) climate regions (color shading) are shown. Each climate variable expert is represented by letters: temperature (T), sea level rise (S), and precipitation (P).

3.4 Culminating assessment task / poster presentations

The final stage of the ClimateWEST activity required learners to present their results by regional groups. Here they were provided with the following content prompt: *Using the data provided, explain and demonstrate the variability at different time-scales of the key features of the climate in your region of interest and how this variability compares with the global average*. Based on this prompt, each group prepared a digital poster. Each regional group gave a 10-minute presentation outlining their questions and findings and answered questions from other participants and facilitators.

3.5 Synthesis

After all the participants within ClimateWEST presented their posters, facilitators gave a final "synthesis" lecture that summarizes findings by the learners and details the STEM practices that participants engaged as climate scientists. In addition, they were further introduced to important pieces of climate science and research, such as the IPCC report (IPCC, 2014). This was an opportunity for the participants to reflect on their experience and acknowledge their accomplishments from the climate inquiry activity.

4. Assessment

Since ClimateWEST was part of the WEST program rather than a formal course component, there was no final grade assigned to the learners. Instead, assessment took several informal forms and occurred mostly throughout the investigations and the learners' final presentations. The low ratio of learners to facilitators allowed close interaction with the learners and formative assessment was performed through conversations during the activity. We primarily used formative assessment to evaluate their current understanding of the content and to give directions to guide them toward the goal of a more complete understanding.

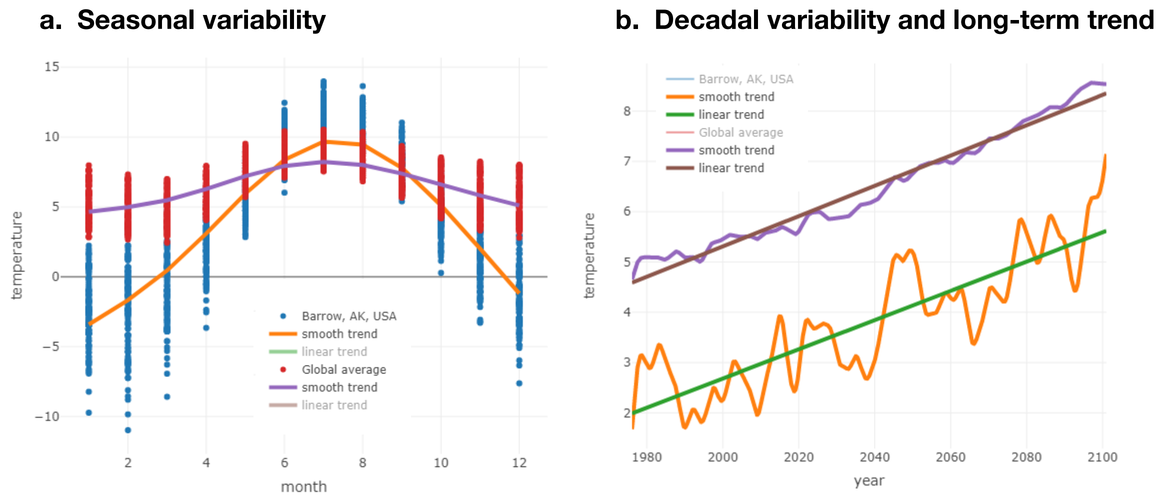

Figure 3: Example illustrating the multiple timescale concept of variability. Seasonal (a), decadal variability and long-term trend (b) of the global and regional temperature in city of Barrow (Alaska).

To assess core dimension #1 (timescales of climate variability), learners were provided with a worksheet at the end of the first iteration of the investigations (i.e., Question 1). Core dimension #2 (spatial climate variability) was assessed through the jigsaw discussions, and core dimension #3 (multiple climate variables), through a group presentation using a digital poster presentation as a culminating assessment task. To assess their content understanding, we developed a rubric (see Appendix Material Content rubric, Table A2) with the following scales: (M) "evidence needed to make a judgment is missing", (1) "evidence that learner has misunderstanding or incomplete understanding", (2) "evidence that learner has intermediate understanding", and (3) "evidence that learner has sufficient understanding". An example of a score of 3 for each of our three core dimensions of climate variability is as follows: Dimension #1: a learner clearly annotates and discusses a seasonal cycle and identifies the direction and approximate magnitude of a long term trend in the time series (e.g., using temperature, the learner identifies a seasonal trend (or lack thereof) in their variable in their region, joins two years 1950 and 2010 by a straight upward line and predicts future change at 2100 of 3°C). Dimension 2: in the learner's plots, at any time scales, there are annotations and comparisons of the change in a climate variable in their region with respect to the global average. It could be a subtraction of a mean value during a period, a difference in values of trends (e.g., during 1950–2000 the increase in global temperature was 1°C, vs. the regional 0.5°C), or only a change in temperature (e.g., there is a global trend of rising temperatures but in our region the temperature is increasing or decreasing at a different rate). Dimension 3: in the discussion part of the poster, there is a "complete" representation of all the variables, they explicitly state that variables may not vary in the same way, and that one variable cannot explain the whole climate. Also, during the presentation all of the variables are treated equally as part of a complex climate system, not only focusing on temperature.

For the final poster presentation, we provided a template of a digital poster to all the groups. Because of that, the cumulative assessment was oriented to assess some of the STEM practices that learners were engaged in during the activity. Besides the content rubric, the cumulative assessment was based on these three STEM practice goals: (1) stating an argument or claim that addresses their question of interest; (2) using relevant data to support the argument; and (3) reasoning that links evidence to the argument (see Appendix Material Practice rubric, Table A3). A concrete example from a proficient team in our STEM practices investigating the climate in a region was: “Our question was what is the projected future rate of changes in temperature, precipitation and sea level in Tokyo by the end of this century? By making linear regressions of the variables in time, we found that the temperature and sea level are projected to increase at rate of change of 0.0023 °C/year and 0.04 cm/year, respectively, while the rate of change of precipitation is projected to decrease by 0.02 m/s/year by the end of the century”. They made a clear statement of the rate of change of the variables using the provided data and justified their argument with it.

5. Future considerations and reflections

In retrospect, we found some areas that could be improved in our future iterations of this activity. The first is that the third core dimension (i.e., climate is complex and includes not only temperature but also other key variables such as precipitation, ice, wind, ocean circulation) was hard for learners to comprehend. Specifically, they were trying to establish correlation/causation relations between the three variables and became confused when they realized that was not possible. Some extra facilitation about climate and statistics was needed at this point, though it would have been useful to address this in the introduction. Additionally, because each learner took ownership of one climate variable, in the final presentations, most learners only addressed the first two dimensions of content for their specific variable, but did not necessarily each address the complexity of climate as a whole. This made it difficult to assess whether learners fully grasped the third dimension. In the future, we would suggest explicitly asking each individual learner to address this dimension either verbally or written, especially if a grade is dependent on demonstrating proficiency in this area.

The second area for improvement was that some learners needed extra facilitation for formulating their research questions. Some learners found it difficult to formulate questions about climate variability and instead were focused on the ecological and social impacts of climate change on their regions, which were beyond the scope of the activity. Making a clear statement of the data that they will use for the activity and how to use it helped others to formulate compelling research questions and allowed them to demonstrate an understanding of how to make an argument that is supported by available data. Implications of climate change globally and in the regions provided were discussed in some of the presentations.

Finally, future teaching of this activity should include the exploration of spatial maps of the variables. Learners here worked with spatial averages of variables and it is important that climate spatial variability is explored. Maps could provide a more useful visual tool to illustrate the core concept of spatial variability, especially in cases where people are not used to comparing data in formats like time series. In addition, if the future potential teaching of the activity includes grading, it would be helpful to share the designed rubrics with the learners so they can understand the evaluation criteria and the associated scores of the activity.

Overall, the ClimateWEST activity received extremely positive feedback and accomplished most of its goals. We highlight that the majority of learners clearly grasped the first two dimensions of the inquiry content, focused on spatial and temporal climate variability. Additionally, learners appeared to grasp the targeted core STEM practice, using data to support scientific arguments. The learners were also highly engaged in the activity, and most gained confidence in their ability to ask questions and think through complex ideas relating to climate variability and change. Learners were given the opportunity to formulate questions that were of interest to them, took ownership of their regions, and acknowledged their specific expertise in their climate variable. Finally, the jigsaw discussions and poster presentations were accomplished by most of the groups with a high level of proficiency, making it clear that learners interpreted climate data in a meaningful way, and communicated a strong understanding of core concepts.

An important aspect of our activity that made it easier to achieve these positive results was that we provided a graphical user interface (GUI) developed specifically for the activity (see Materials section). This GUI helped students that were not proficient with Excel or other software to analyze and plot the data easily. For future versions of this activity, this kind of pre-made software will help students with less background in Excel or other coding/plotting software. A potential extension of the activity to be applied with a statistical content objective could be to make the students compute the seasonality and trends by themselves and not with the help of Excel or our GUI to demonstrate an understanding of basic mathematical concepts, or the activity could be taught to beginning research students with a content goal of teaching basic programming in a chosen statistical computing language.

In addition to the intended learning outcomes, we also experienced some anecdotal outcomes, or outcomes that were not necessarily captured in our assessments but nevertheless were achieved by some students. One example of an anecdotal outcome related to content was that multiple learners gained an appreciation for the complexity of using models to predict data. For example, at the end of the activity, one learner stated: "data is from only one climate model and we should work with other climate models to trust their future projections". This is another level of knowledge that was not explicit in the activity, that an ensemble of climate models is needed to state statistically robust arguments about the future climate.

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References

Chang, W., Cheng, J., Allaire, J., Xie, Y., and McPherson, J., 2017, Shiny: web application framework for R: R package version, v. 1, p. 2017.

Driver, R., Newton, P. and Osborne, J. (2000), Establishing the norms of scientific argumentation in classrooms. *Sci. Ed. 84*: 287–312. https://doi.org/10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.0.CO;2-A

Dunne, J. P., John, J. G., Adcroft, A. J., Griffies, S. M., Hallberg, R. W., Shevliakova, E., et al. (2012). GFDL's ESM2 global coupled climate–carbon earth system models. Part I: physical formulation and baseline simulation characteristics. *J. Climate 25*, 6646–6665. doi: 10.1175/jcli-d-11-00560.1

Gowda, M., Fox, J., and Magelky, R. (1997) Students' understanding of climate change: Insights for scientists and educators. *Bulletin of the American Meteorological Society*, Vol. 78, No. 10, October, 2232–2240.

IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Kuhn, D. (1993). Science argument: Implications for teaching and learning scientific thinking. *Science Education, 77*(3), 319–337

McNeill K.L., Lizotte, D.J., Krajcik, J., and Marx, R.W. (2006) Supporting Students' Construction of Scientific Explanations by Fading Scaffolds in Instructional Materials, *The Journal of the Learning Sciences, 15*:2, 153–191, DOI: 10.1207/ s15327809jls1502_1

Ryu, S., and Sandoval, W.A. (2012). Improvements to Elementary Children's Epistemic Understanding From Sustained Argumentation, *Science Education, 96*: 488–526

Sievert, C., 2020, Interactive web-based data visualization with R, plotly, and shiny: CRC Press.

Wiggins, G, and McTighe, J. (1998). Backward Design. In *Understanding by Design* (pp. 13–34). ASCD.

Appendix — Materials

Materials 1 — Data & Rubrics

Data for the activity was selected from the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) ESM2M (Dunne et al., 2012), an earth system model that belongs to the phase 5 of the Coupled Model Intercomparison Project (CMIP5) archive. Key characteristics of the selected data are summarized in table A1. We focused on the period from 1980 to 2100 using historical forcing (1980–2005) and the Representative Concentration Pathway (RCP) 8.5 climate change scenario (2006–2100). The monthly regional time series were extracted by averaging boxes of 5°longitude and 5°latitude centered at the following eight regions: 151.2°E, 33.8°S (Sydney, Australia); 156.8°W, 71.3°N (Barrow, USA); 78.4°W, 0.2°S (Quito, Ecuador); 71.1°W, 42.4°N (Boston, USA); 72.9°E, 20°N (Mumbai, India); 139.8°E 35.6°N (Tokyo, Japan); 30°E,31.2°N (Cairo, Egypt); and 122.4°W, 37.8°N (San Francisco, USA).

Table A2 contains the content rubric and Table A3 contains the practice rubric.

Table A1: Resolution of the variables selected

Precipitation resolution	Temperature and Sea surface height resolution
2.5° lon	1° lon
2° lat	~ 0.3–1° lat
24 levels	50 levels

Materials 2 — Data Visualization Shiny App

Since we expected the students to have varying levels of familiarity with common data visualization and exploration tools (e.g., Microsoft Excel, Google Sheets), we developed a simple web app for the students to use in lieu of more complex software (Figure A1). Written using the `Shiny` R package (Chang et al., 2017), the web app was designed to allow easy exploration, comparison, comparison, and plotting of the selected climate data. Furthermore, since `Shiny` allows reactive content, the app will dynamically resize so students can use personal computers, tablets or smartphones. Students select data sets to compare from drop-down menus and can assign different climate parameters (temperature, sea level, precipitation) to different axes. Their selections are then displayed as interactive `Plotly` plots (Sievert, 2020). The visualizations are fully interactive; students can zoom in or out to inspect changes to climate variability over different periods of time. We also included basic linear and non-linear regression options to help students interpret underlying trends when the raw climate data might be quite variable.

The app is hosted using the shinyapps.io platform at https://robintrayler.shinyapps.io/pdp-climate-visualization/ and the code is available at https://github.com/robintrayler/PDP-Climate-Visualization.

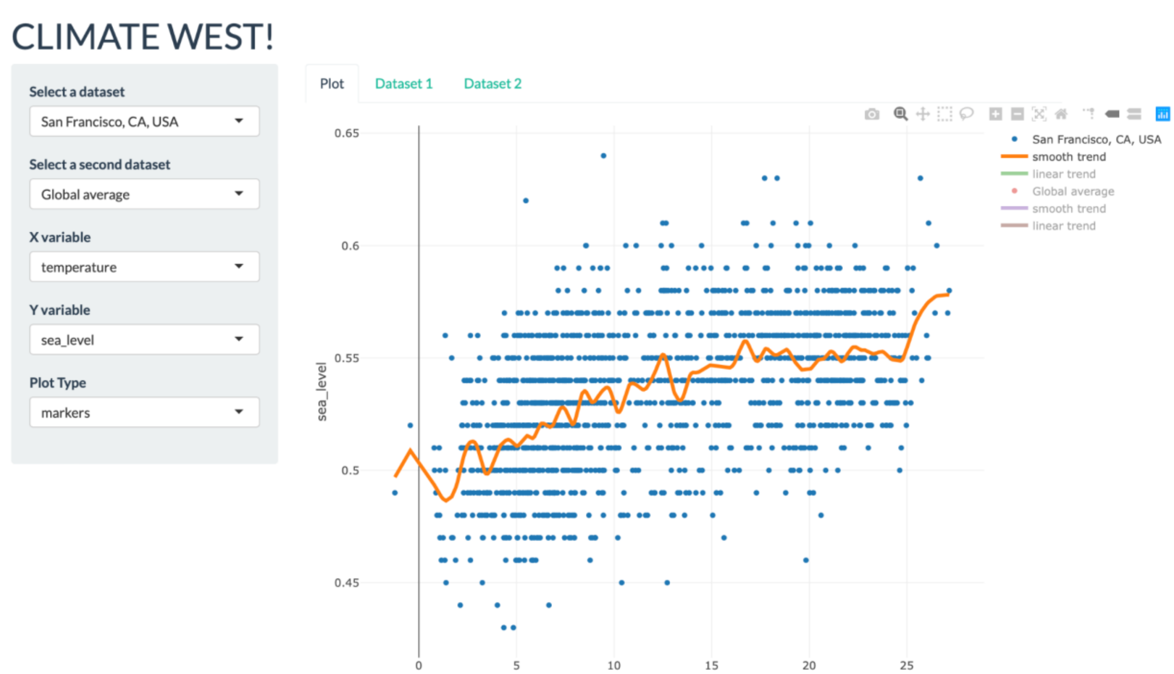

Figure A1: Screenshot of the data visualization and exploration Shiny app used for this inquiry. Here the covariance between mean temperature and sea level is shown for San Francisco California. A smoothed trendline is plotted over the data to help reveal underlying trends.

Table A2: Content Rubric

Dimensions: **Components or "knowledge statements"**	**M** **evidence needed to make a judgment is missing**	**0** **evidence that learner has misunderstanding or incomplete understanding**	**1** **Evidence that learner has intermediate understanding**	**2** **evidence that learner has sufficient understanding**
Climate varies on both shorter timescales (e.g. seasonal or annual cycle) and on longer timescales (e.g. climate change) Terminology: seasonal, decadal (10–30yr), future long-term. Present climate and future climate	They don't discuss timescales at all, not in their region, not in the global. If a variable doesn't show any seasonal variability, it should at least be noted/commented but not ignored.	They confuse cycles with trends (e.g., mixing the seasonal variability with the long-term trend) by annotation or discussion.	They only correctly identify cycles or trends but not both by annotation or discussion.	A student clearly annotates and discusses a seasonal cycle and identifies direction and approximate magnitude of a long-term trend in the time series (e.g., temperature: identifies seasonal trend (or lack of) within their variable in their region, joins two years 1950 and 2010 by a straight upward line and predicts future change at 2100 of e.g. 3C)
Both climate and climate trends vary spatially/geographically and it is different from global climate.	No discussion, annotation, or comparison of regional and global climate. Even if regional and global change similarly, there should be discussion that this isn't always the case.	They confuse regional with global climate or use the terms interchangeably. They demonstrate in their plots or discussion the climate in their region and the global average should be changing /behaving similarly (magnitude and direction).	Their plots and discussions only include annotations the time series of the global or regional variable but not both.	In their plots: At any time scales, there are annotations and comparisons of the change in variable of their region respect the global value. It could be a subtraction of a mean value during a period, different values of trends (e.g.: during 1950–2000 the increase in global temperature is 1C, vs the regional is 0.5C). (e.g., using only change in temperature: **there is a global trend** of rising temperatures **but in our region X**, the temperature is increasing(decreasing) at a different rate).
Climate is complex and includes not only temperature but also other key variables as precipitation, ice, wind, ocean circulation, etc.	They do not discuss the climate variables.	They only use one variable to describe climate. (e.g., "the climate is warming")	Their representation of the climate of a region is missing one variable and/or only focus on temperature or other	At any moment during their poster presentation or when they are together as a region group: Their representation and poster of the climate of a region have a **"complete" representation of all the variables.** They explicitly state that variables may not vary in the same way, and that one variable cannot explain the whole climate. During the presentation all of variable are **treated equally**, not only focus on temperature.

Table A3: Practice Rubric

Dimensions of core practice:	Lack of evidence did not observe learners enough to decide between A and B	Evidence of difficulty what it looks like when a learner needs to work more on the practice	Evidence of proficiency what it looks like when a learner is proficient with the practice
Argument that addresses a question or content prompt	Does not make an argument	Makes an argument that does not address the question or content prompt or is vague.	Makes a specific argument that is related and addresses the content prompt
Evidence/data/annotations are used/made/shown to support the argument.	Does not provide any evidence or annotations.	Evidence or annotations provided are vague. Annotations are vague or incomplete Repeats the data but does not use as evidence.	All relevant data is used as evidence and conflicting data is discussed appropriately. Identifies the significant features and patterns in the data.
Reasoning to connect data/evidence to support the argument	There is no reasoning.	Repeats information, data, or argument without justification/statement.	Includes a statement that connects/links/justifies all the evidence to the arguments.