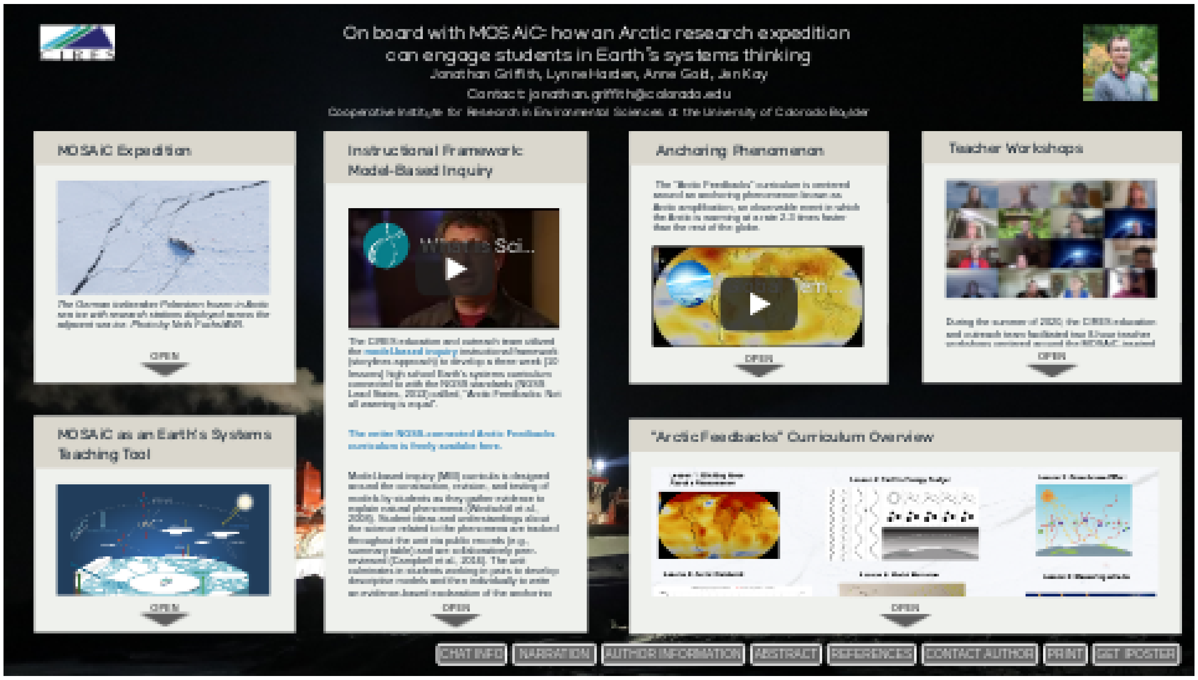
On board with MOSAiC: how an Arctic research expedition can engage students in Earth's systems thinking



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Cooperative Institute for Research in Environmental Sciences at the University of Colorado Boulder




PRESENTED AT:

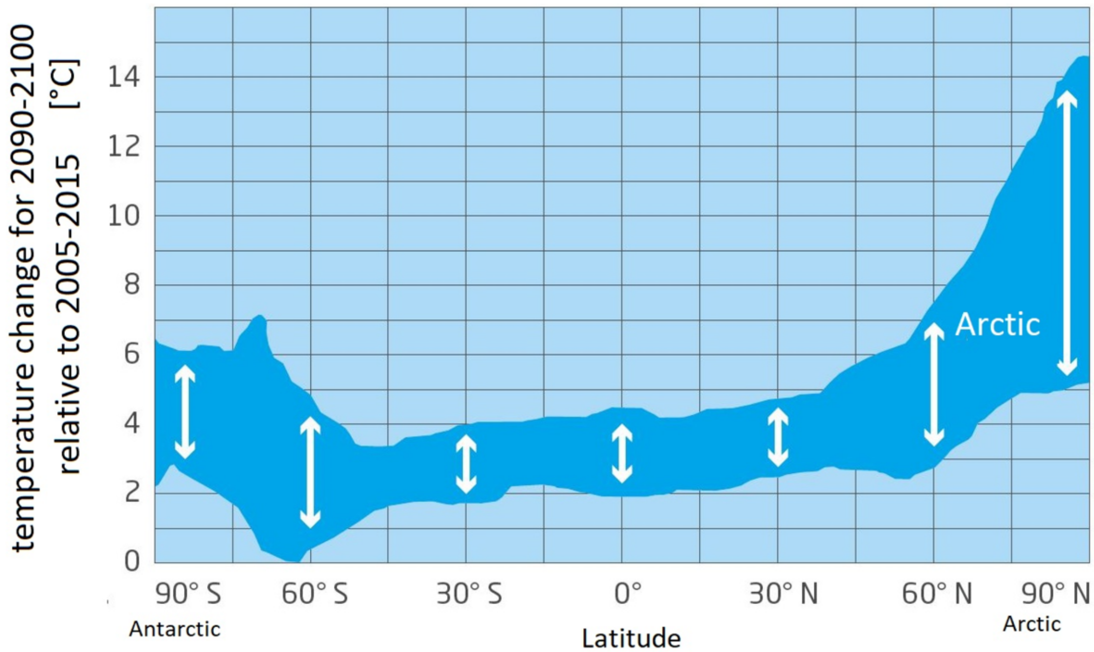
AGU FALL MEETING
Online Everywhere | 1–17 December 2020

MOSAIC EXPEDITION

The German icebreaker Polarstern frozen in Arctic sea ice with research stations deployed across the adjacent sea ice. Photo by Neils Fuchs/AWI.

The 2019-2020 MOSAiC (Multidisciplinary drifting Observatory for the Study of Arctic Climate) expedition is one of the most extensive Arctic research endeavors ever conducted with more than 500 scientists from 20 countries participating in this 140+ million dollar project. Currently, the Arctic is warming twice as fast as the global average (a phenomenon known as Arctic amplification) and due to a lack of observations, there is considerable uncertainty in climate models projecting the Arctic climate of the future (Hodson et al., 2012). The MOSAiC expedition aims to better understand the changing Arctic climate system by gathering data from ground zero (Arctic sea ice) over a full seasonal cycle to augment satellite observation data.

MOSAiC Mixdown podcast: Why do we need more observations (https://www.buzzsprout.com/1009144/3464938-why-do-we-need-more-observations-in-the-arctic) (3:55)



T*he* ***figure*** ***(https://mosaic-expedition.org/science/mission/)*** *above shows projected Arctic warming by the end of the century to be between 5-15°C, a larger range (uncertainty) than any other region on the planet.*

Logistics

In September of 2019, the German research vessel Polarstern set sail from Tromso, Norway for the central Arctic in search of an ice floe (flat piece of ice) with which to attach. Once attached, scientists and crew deployed a network of research stations (cities) on the sea ice adjacent to and up to 50 km away from the Polarstern (engage with **this 360° virtual reality "Tour the MOSAiC Ice Camp" (https://virtualice.byrd.osu.edu/mosaic-dev/)**). Together, the Polarstern, crew, and research instruments drifted with the sea ice along the transpolar current across the Arctic for an entire year gathering important data on all aspects of the Arctic climate system (ocean, ice, atmosphere). The Polarstern freed herself from the sea ice and returned to Bremerhaven, Germany in October of 2020 marking the end of the field portion of the expedition and the beginning of the next phase, data analysis and discovery!

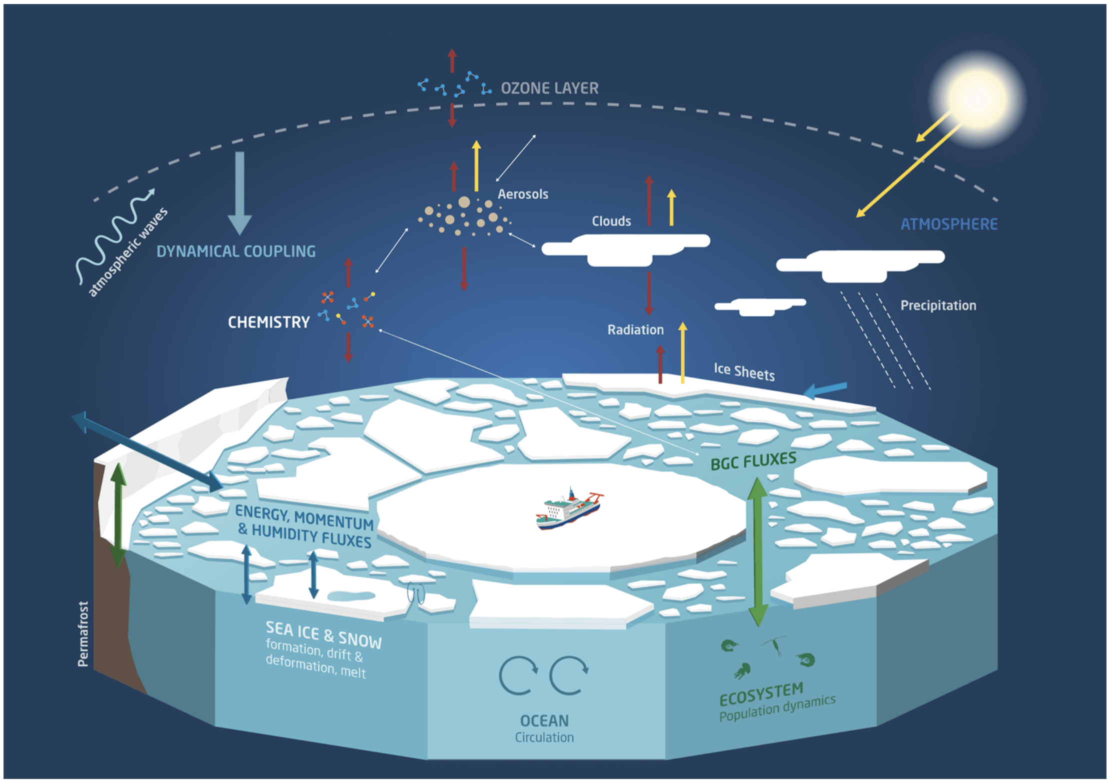
[VIDEO] https://www.youtube.com/embed/o-RdumGRvm4?rel=0&fs=1&modestbranding=1&rel=0&showinfo=0

Watch the ***MOSAiC expedition overview video*** ***(https://www.youtube.com/watch?v=o-RdumGRvm4&feature=emb_logo&fs=1&modestbranding=1&rel=0&showinfo=0&fs=1&modestbranding=1&rel=0&showinfo=0)*** *above!* (3:39)

(https://virtualice.byrd.osu.edu/mosaic-dev/)

*Visit the MOSAiC ice camp in **360° with this immersive virtual reality tour** **(https://virtualice.byrd.osu.edu/mosaic-dev/)** co-produced with the Byrd Polar and Climate Research Center at The Ohio State University.*

MOSAIC AS AN EARTH'S SYSTEMS TEACHING TOOL



***Learn more about the MOSAiC scientific focus areas in this interactive figure developed by the Alfred Wegener Institute.* (https://mosaic-expedition.org/science/scientific-focus-areas/)**

Scientists participating in the MOSAiC expedition seek to better understand the changing Arctic climate system by studying the interconnected components of the system: cryosphere, hydrosphere, biosphere and atmosphere.

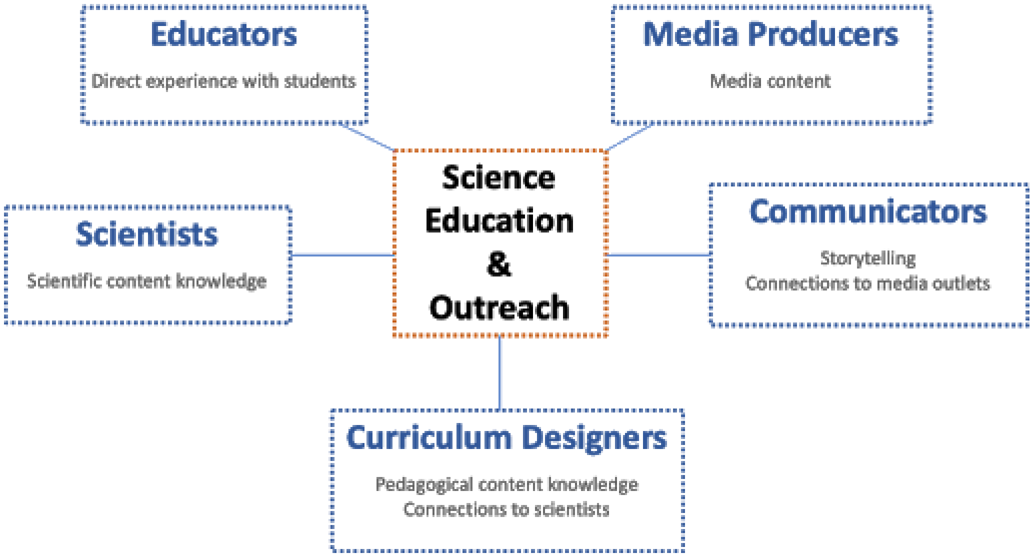
MOSAIC Mixdown podcast: Why is the multidisciplinary aspect important? (https://www.buzzsprout.com/1009144/4671491-why-is-the-multidisciplinary-aspect-important)

Did you know that decling sea ice *(cryosphere)* could be contributing to a rise in Arctic temperatures *(atmosphere)*? Or that algae *(biosphere)* thriving on the underside of sea ice *(cryosphere)* could be involved in the formation of clouds *(atmosphere)*? It's these questions and more that scientists across many disciplines seek to answer.

[VIDEO] https://www.youtube.com/embed/QZ4netlc7LY?rel=0&fs=1&modestbranding=1&rel=0&showinfo=0

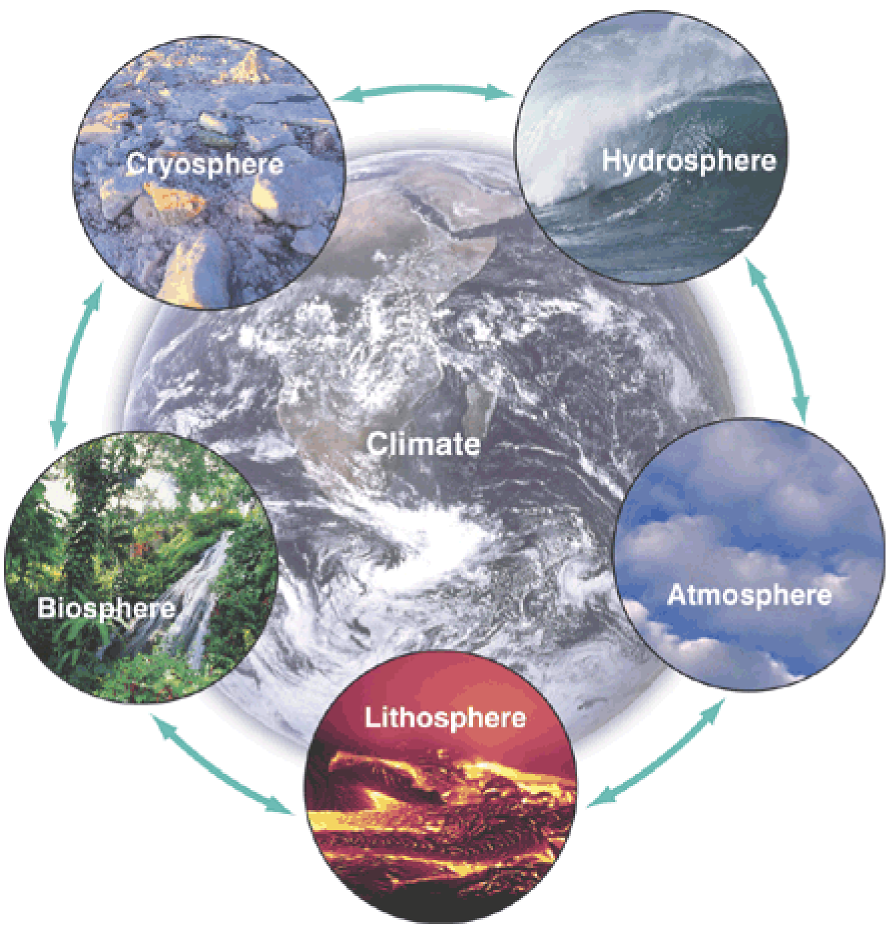
Earth's Systems Educational Resources

The education and outreach team with the Cooperative Institute for Research in Environmental Sciences at the University of Colorado Boulder coordinated the United States effort to connect the public to the MOSAiC expedition. The strength of the MOSAiC expedition and the strength of the education and outreach efforts lie in their collaborative nature. Through the efforts of educators, media producers, scientists, communicators, and curriculum designers (see figure below) a variety of engaging Earth's systems resources were developed which have been consumed by tens of thousands of members of the public, from K-12 students to interested retirees.



Connection to the Next Generation Science Standards

Earth's systems is a major part of the next generation science standards across all grade levels requiring that students develop models to describe the interactions across Earth's spheres. The MOSAiC expedition provides a modern and authentic case study for students to engage with and explore interconnected processes governing the Arctic climate system.



INSTRUCTIONAL FRAMEWORK: MODEL-BASED INQUIRY

[VIDEO] https://www.youtube.com/embed/_3A6EJ6dG1g?rel=0&fs=1&modestbranding=1&rel=0&showinfo=0

The CIRES education and outreach team utilized the **model-based inquiry (https://sites.google.com/view/modelbasedinquiry/home)** instructional framework (storylines approach) to develop a three week (10 lessons) high school Earth's systems curriculum connected to with the NGSS standards (NGSS Lead States, 2013) callled, "Arctic Feedbacks: Not all warming is equal".

The entire NGSS-connected Arctic Feedbacks curriculum is freely availabe here. (https://cires.colorado.edu/outreach/resources/unit/arctic-feedbacks-not-all-warming-equal)

Model-based inquiry (MBI) curricula is designed around the construction, revision, and testing of models by students as they gather evidence to explain natural phenomena (Windschitl et al., 2008). Student ideas and understandings about the science related to the phenomena are tracked throughout the unit via public records (e.g., summary table) and are collaboratively peer-reviewed (Campbell et al., 2016). The unit culminates in students working in pairs to develop descriptive models and then individually to write an evidence-based explanation of the anchoring phenomenon.

Four phases of Model-based inquiry

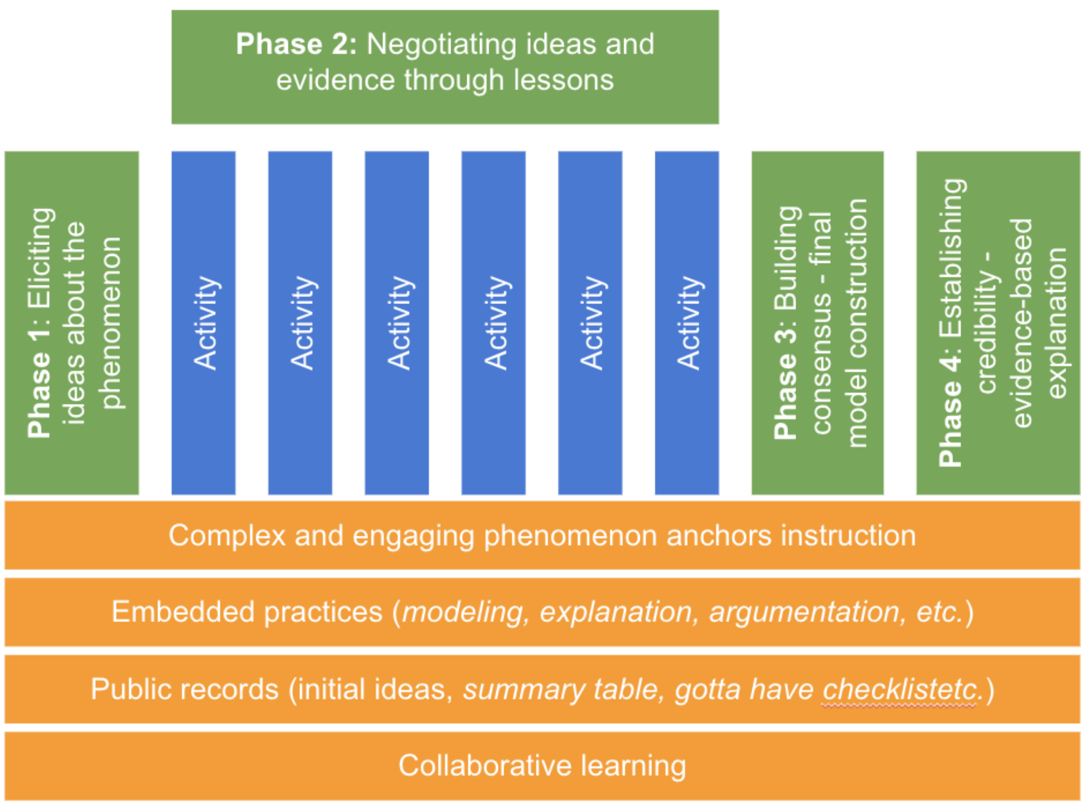
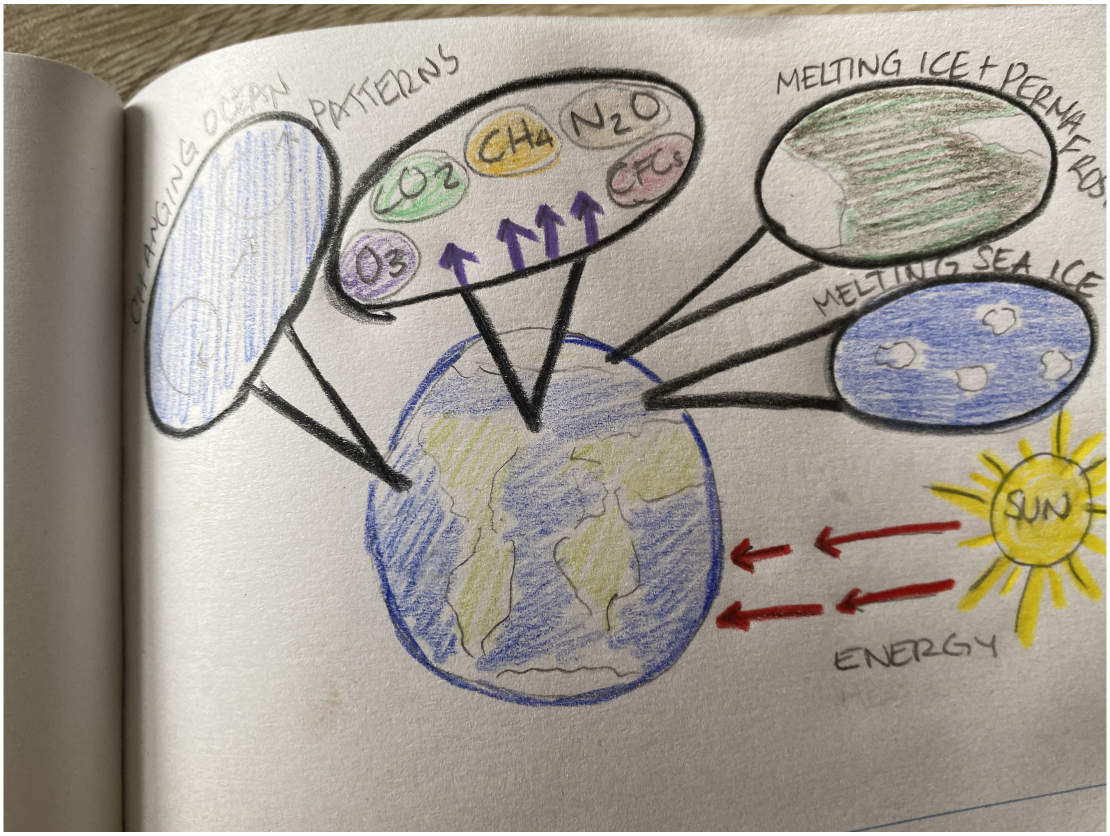


Figure adapted from ***Model-based inquiry (https://sites.google.com/view/modelbasedinquiry/what-is-mbi?authuser=0)***.

Phase 1: Eliciting ideas about the phenomenon, (1-2 days, Lesson 1)

Students are introduced to the phenomenon on the first day and their initial ideas and explanations for the phenomenon are represented in **public records (https://docs.google.com/document/d/1s64rHySFwE4HWynRNx3VOHMP-i0OKuL0mbHkqHEWx28/edit?usp=sharing)** and **initial descriptive models**

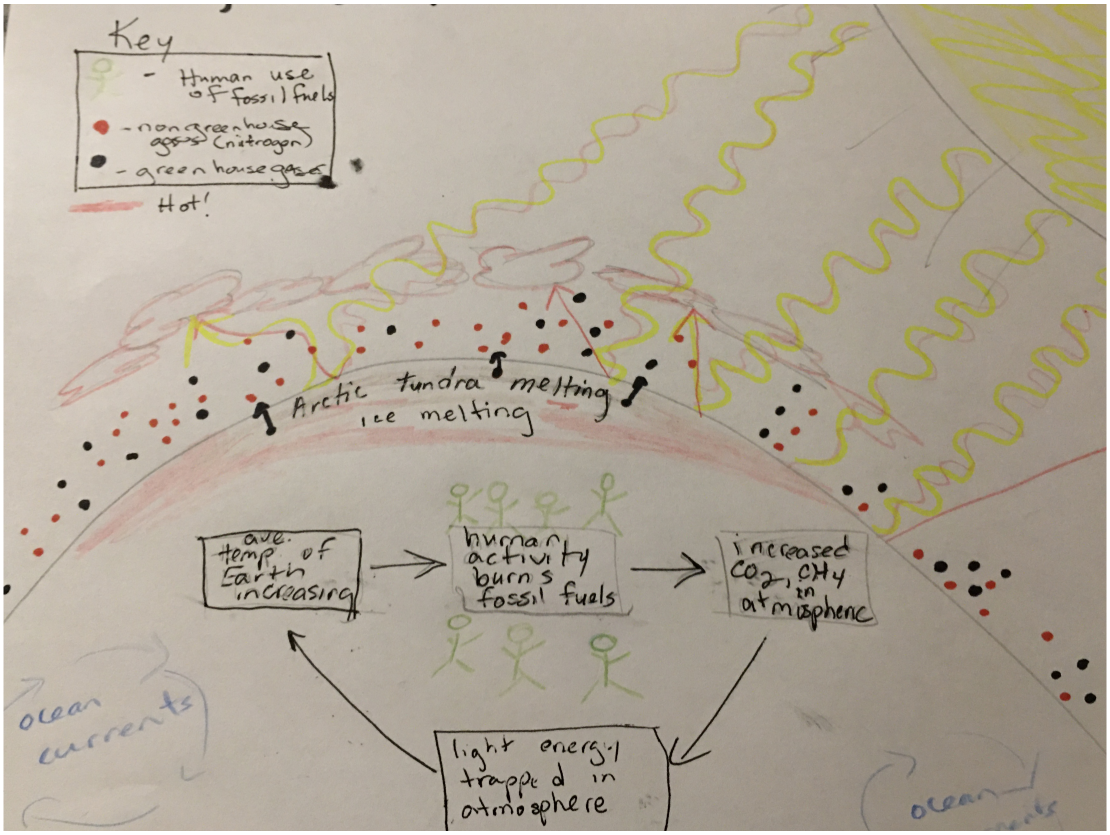
(https://drive.google.com/drive/folders/1o5jGZXnO9KCO1uSoOfQwgNMWVZuXCwgr?usp=sharing).



Initial model example from teacher workshop participant.

Phase 2: Negotiating ideas and evidence through lessons, (7-8 days, Lessons 2-8)

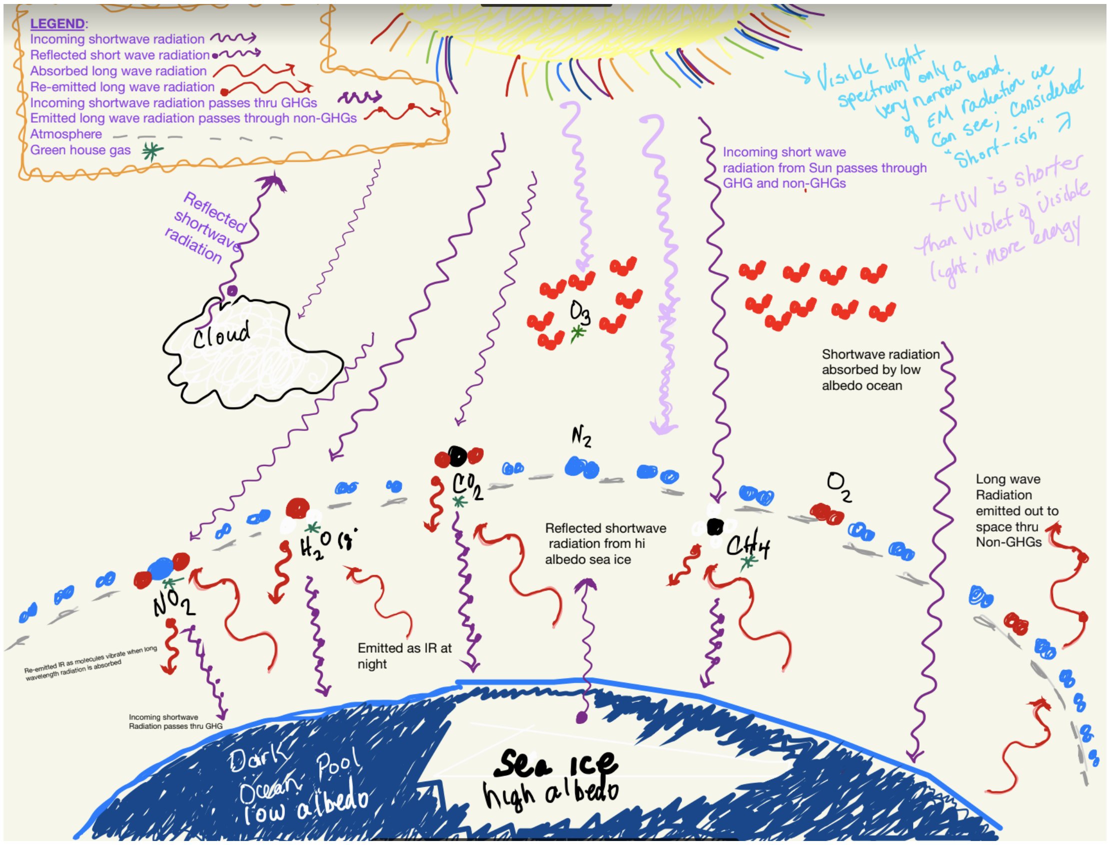
Lessons in phase 2 are designed to support the students on-going changes in thinking. Lessons provide students with learning experiences that relate back to the phenomenon. At the conclusion of each lesson, science concepts and their connection phenomenon are discussed and agreed upon as a class before being recorded in a **summary table (https://docs.google.com/document/d/1bz_dy4V4ImxvEIpyy3TLhjIV2I_ZPBdIZ-XroQvXF9I/edit?usp=sharing)**. Updating the summary table daily is vital as it helps students coordinate science ideas (connect the dots) to build a scientific explanation of the anchoring phenomena. This phase makes up the majority of the unit.



*[Revised model example](https://drive.google.com/drive/folders/1JeUvF8omGn-cxVDX59R1ab7td1oNQ5PY?usp=sharing) **(https://drive.google.com/drive/folders/1JeUvF8omGn-cxVDX59R1ab7td1oNQ5PY? usp=sharing)** from teacher workshop participant.*

Phase 3: Building consensus - final model construction, (1 day, Lesson 9)

Students work in pairs to construct their final descriptive model representing the anchoring phenomenon. Students are encouraged to refer to evidence (e.g., datasets, summary table, etc.) when constructing their finals models. After the final models have been constructed and shared, the teacher facilitates the discussion and development of a "**gotta-have checklist** **(https://docs.google.com/presentation/d/14qHtAc7vTqyRrxoKqFHYaxypkR9z_hVIalpwlVe1JyA/edit? usp=sharing)**", a list of bulleted ideas, concepts, and evidence that the entire class agrees should be present in an accurate scientific explanation of the phenomenon.



Final model example ***(https://drive.google.com/drive/folders/1zfrQoihXtSyLDN4qK3a2BsuppDldF3mV?usp=sharing)*** *from teacher workshop participant.*

Phase 4: Establishing credibility - evidence-based explanation, (1-2 days, Lesson 10)

Students refer to evidence (e.g., gotta-have checklist, datasets, summary table, etc.) and work independently to write an **evidence-based explanation** **(https://docs.google.com/document/d/18hh7d0-1sUIQMhkpoFFTCXxIZ7GWkO6SCwyW1EXCdbE/edit?usp=sharing)** of the phenomenon. An evidence-based explanation incorporates three parts, 1) the story of what happened, 2) important science concepts necessary to explain what happened, and 3) evidence of how we know each part of the explanation (citing specific activities from lessons).

Additional Information

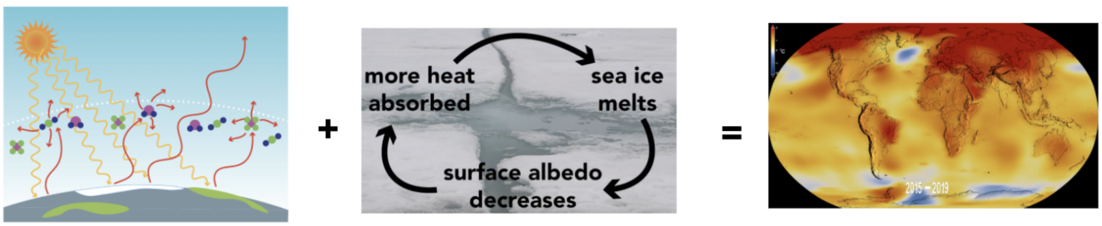
NGSNavigators podcast - Dr. Todd Campbell from the University of Connecticut discusses successful strategies and resources to use when facilitating MBI curricula in your NGSS classroom. **(https://www.ngsnavigators.com/blog/031)** (55:06)

ANCHORING PHENOMENON

The "Arctic Feedbacks" curriculum is centered around an anchoring phenomenon known as Arctic amplification, an observable event in which the Arctic is warming at a rate 2-3 times faster than the rest of the globe.

[VIDEO] https://www.youtube.com/embed/3sqdyEpklFU?rel=0&fs=1&modestbranding=1&rel=0&showinfo=0

Students are first introduced to the phenomenon by watching the Global Temperature Anomalies video above. Student observations as they relate to the video lead to the development of the unit driving question, "Why might the Arctic be warming twice as fast as the rest of the world?" This driving question allows students to investigate Earth's energy budget, the electromagnetic spectrum, the greenhouse effect, and feedback loops. These topics, though common in Earth Science classrooms, become more engaging and accessible when anchored by a phenomenon.



Greenhouse effect Ice-albedo feedback Arctic amplification

Through a series of learning opportunities in which students engaging with online simulations, app-based labs, and authentic Arctic datasets (curated by MOSAiC scientist Dr. Jen Kay), students ultimately come to the understanding that it is an enhanced greenhouse effect caused by human activities that is causing global temperatures to rise, triggering the ice-albedo feedback, a process that amplifies that warming in the Arctic.

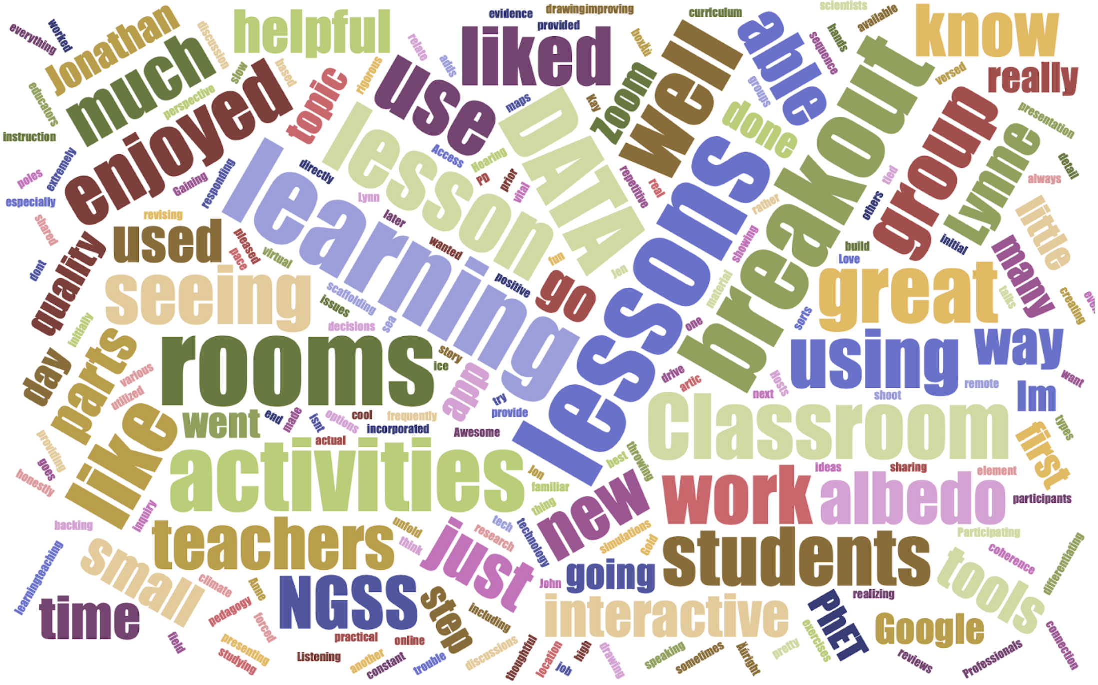
[VIDEO] https://www.youtube.com/embed/3qyT43pbUus?rel=0&fs=1&modestbranding=1&rel=0&showinfo=0

TEACHER WORKSHOPS

During the summer of 2020, the CIRES education and outreach team facilitated two 8-hour teacher workshops centered around the MOSAiC-inspired "Arctic Feedbacks" curriculum. The workshops were facilitated virtually via Zoom where facilitators used main room to introduce tasks that were then completed and reflected upon by participants in breakout rooms. In addition, atmospheric scientists Dr. John Cassano and Dr. Jen Kay joined to discuss their research as it relates to the MOSAiC expedition (see videos below). The workshop culminated in participants constructing final models and written explanations for the anchoring phenomenon (Arctic amplification) just as their students would be asked to do. 100% of participants that completed the post workshop survey (n = 67) said that they would implement parts or all of the curriculum in their classrooms during the 2020-2021 school year.

Testimonials

Prompt: What were the best parts about the teacher workshop?



"I want to give my students relevant and up-to-date learning. I want to be able to show the kids that this is something that is really happening in the world today and is something that will affect their future. This curriculum gives me the means to do this." -*Workshop participant*

Learning Outcomes

To measure the effectiveness of the virtual workshop and curriculum, participants (n=57) were asked to complete a pre and post survey that included climate concept inventory (CCI) multiple choice questions and a series of Likert scale questions (Libarkin et al., 2018). The pre and post survey results are described below:

Preliminary Results

1. Participants gained significant climate content knowledge ($p<0.01$) as a result of the workshop/engaging with the curriculum, and the effect (Cohen's $d = 0.98$) of this intervention (the workshop) was large - thus, the workshop/curriculum was a powerful intervention for increasing climate content knowledge (for what was included in the CCI test).
2. Participants confidence in their climate content knowledge and how well informed they felt about Earth's climate system as a result of the workshop/engaging with the curriculum (see figures below).
3. Taken together (the Likert questions and the CCI questions), we can say that the workshop/curriculum not only increased the educators' content knowledge around climate and Earth's climate system, but it also increased their confidence in their content knowledge.

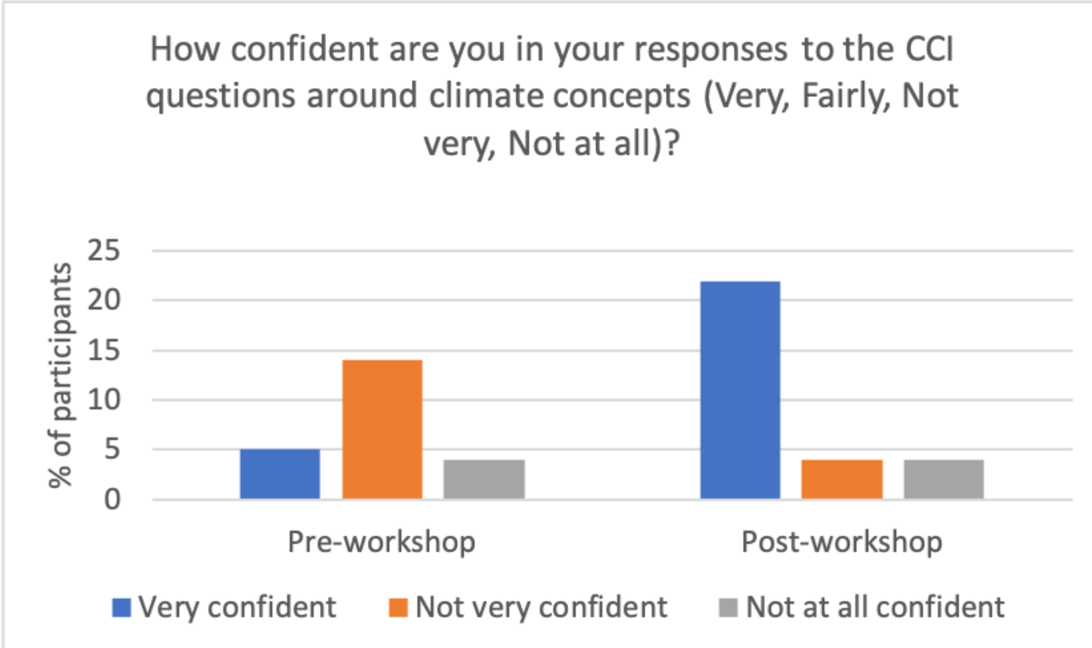


Figure above: Statistically significant difference between pre and post surveys - Very confident increased from 5% pre to 22% post. Not very confident decreased from 14% pre to 4% post. Not at all confident stayed the same at 4% for both.

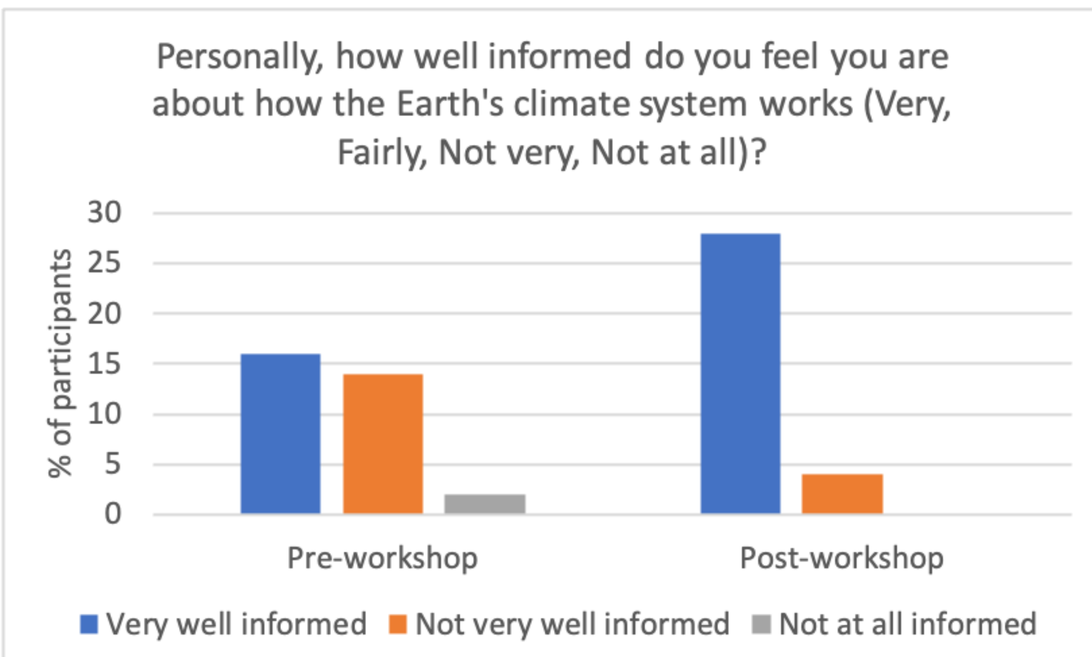


Figure above: Statistically significant difference between pre and post surveys - Very well informed increased from 16% pre to 28% post. Not very well informed decreased from 14% pre to 4% post, and Not at all informed decreased from 2% to 0%.

MOSAiC Scientist Presentations

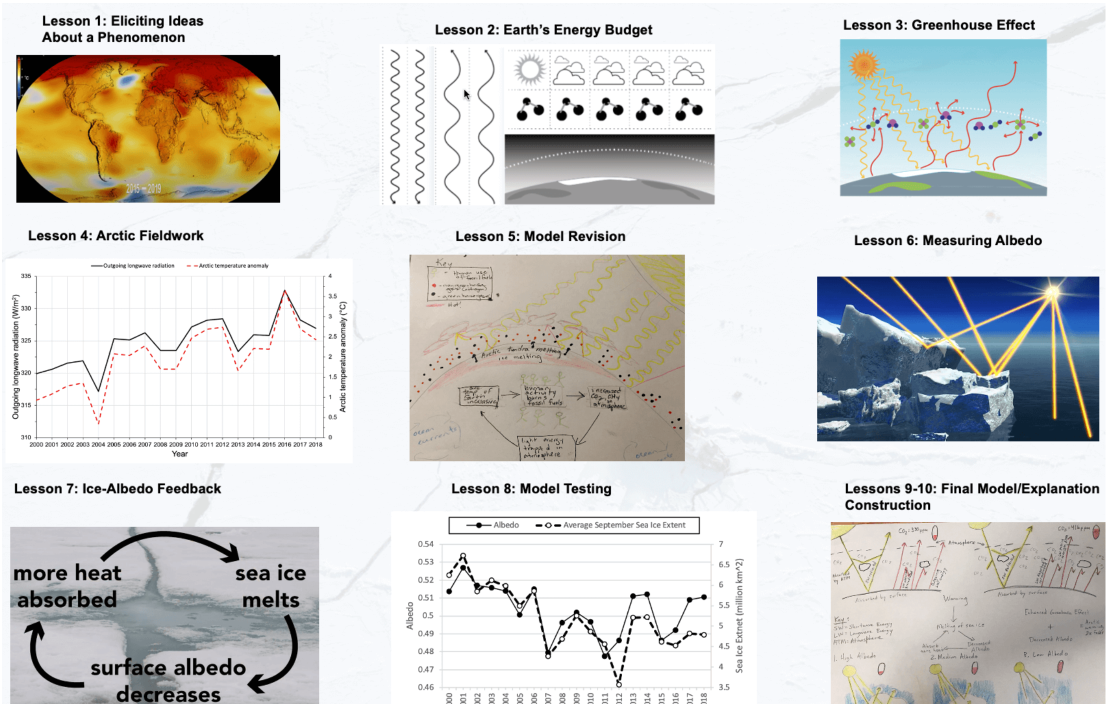
[VIDEO] https://www.youtube.com/embed/7BYhAmCycw0?rel=0&fs=1&modestbranding=1&rel=0&showinfo=0

Atmospheric scientist, Dr. John Cassano/CIRES, describes his experience participating in the MOSAiC expedition.

[VIDEO] https://www.youtube.com/embed/eAnpVusSv2k?rel=0&fs=1&modestbranding=1&rel=0&showinfo=0

Atmospheric scientist and climate modeler, Dr. Jen Kay/CIRES, describes processes contributing the Arctic warming and how she uses observations from the Clouds and the Earth's Radiant Energy System (CERES) satellites to model and understand the Arctic energy budget.

"ARCTIC FEEDBACKS" CURRICULUM OVERVIEW



The image above shows a road map for navigating the "Arctic Feedbacks" curriculum. Students are introduced to the anchoring phenomenon in lesson 1, engage in sense-making activities in lessons 2-8, and demonstrate their learning by constructing a final model and written explanation in lessons 9-10.

- **Arctic Feedbacks Curriculum (https://cires.colorado.edu/outreach/resources/unit/arctic-feedbacks-not-all-warming-equal)**
- **Unit Summary** (https://docs.google.com/document/d/12FgXwkp9p9oQqT6o_CEeys8yDnwusyFJrfR4U8S0R5U/edit)
- **Instructional Calendar** (https://docs.google.com/document/d/10e8p29rDMIrs1DynopnxvfJ89FJTDCTa_jIq7LGLgaw/edit)
- **Curriculum Overview Video** (https://www.youtube.com/watch?v=tMq0RGfPq8I&feature=youtu.be&fs=1&modestbranding=1&rel=0&showinfo=0)

Lesson Descriptions

Lesson 1: Eliciting Ideas About a Phenomenon
(https://docs.google.com/document/d/1MLeT9qiEI9L1Gmt5pOb3qZ3j4IgVqDgMV-9_bUgRL0s/edit)

In this lesson, students work in pairs to construct initial descriptive models and explanations for the unit driving question, “why is the Arctic warming twice as fast as the rest of the world?”

- Driving Question(s):
  - Why should we care about the Arctic?

- Learning Goal(s):
  - Define and describe the geography of the Arctic
  - Elicit student ideas why the Arctic might be warming twice as fast as the rest of the world.
- Standards:
  - ESS2.A: Earth Materials and Systems & ESS2.D: Weather and Climate

Lesson 2: Earth's Energy Budget
(https://docs.google.com/document/d/1B3_h4xp5qxtNrX06PIMVETVET55W0n5667x1y9hneEk/edit)

In this lesson, students will identify and describe properties of the electromagnetic spectrum in the context of Earth's energy budget.

- Driving Question(s):
  - How does Earth maintain the perfect balance of incoming and outgoing energy?
- Learning Goal(s):
  - Identify and describe properties energy in the electromagnetic spectrum
  - Create a conceptual model that represents Earth's energy budget
- Standards:
  - ESS2.D: Weather and Climate

Lesson 3: Greenhouse Effect
(https://docs.google.com/document/d/1O4TANyPd5lXhUVMKBou9bCUI1i7fw5pQbO9wDH62idk/edit)

In this lesson, students explore the relationship between shortwave/longwave energy and atmospheric gases through a simulation and predict how changes in greenhouse gas concentrations will affect global temperatures.

- Driving Question(s):
  - What characteristics define a greenhouse gas?
  - What is the greenhouse effect?
- Learning Goal(s):
  - Identify and describe the relationship between shortwave/longwave energy and atmospheric gases
  - Describe the greenhouse effect using the following vocabulary terms: shortwave energy, longwave energy, greenhouse gases
- Standards:
  - ESS2.D: Weather and Climate

Lesson 4: Arctic Fieldwork
(https://docs.google.com/document/d/1n626MOm77DrMQ7kGXRJUYyY71yZuPHtmrTJsZ99LSr0/edit)

In this lesson, students visit MOSAiC field sites through virtual reality Google Expeditions and interact with actual shortwave and longwave energy datasets from the Arctic to understand how the Arctic energy budget has changed over time.

- Driving Question(s):
  - What scientific instruments are MOSAiC scientists using to study the changing Arctic climate system?
  - How has the amount of incoming shortwave energy and outgoing longwave energy changed over time?
- Learning Goal(s):
  - Identify patterns in shortwave and longwave energy over time.
  - Develop scientific questions related to shortwave and longwave energy datasets.
- Standards:
  - ESS2.D: Weather and Climate

Lesson 5: Model Revision
(https://docs.google.com/document/d/1gHq9_p2KKSOGafHVvIki1EnJgHLC_vMU7KU6CxwEtEo/edit)

In this lesson, students draw on concepts and evidence acquired during the unit to revise their initial models, constructing a new model for the phenomenon, “Why is the Arctic warming twice as fast as the rest of the world?”

- Driving Question(s):
  - Why do scientists continue to gather evidence and revise models of phenomenon?
- Learning Goal(s):
  - Reflect on learning by applying evidence gathered from previous lessons to revise initial models/explanations.
- Standards:
  - ESS2.D: Weather and Climate

Lesson 6: Measuring Albedo
(https://docs.google.com/document/d/1sWO6iOmgBbvVCns3tRMroMLBwA3itRIu5cMwUNUKwfU/edit)

In this lesson, students will use the “Albedo: A Reflectance App” to measure the reflectance (albedo) of different surfaces and come up with a rule to describe the relationship between the color of a surface and its albedo.

- Driving Question(s):
  - What is the relationship between the color of a surface and its albedo?
  - What happens to energy that is not reflected by a surface?
  - How could a decline in sea ice affect the Arctic’s albedo and temperature?
- Learning Goal(s):
  - Describe the relationship between the color and albedo
  - Describe the relationship between albedo and temperature
- Standards:
  - ESS2.A: Earth Materials and Systems

Lesson 7: Ice-Albedo Feedback
(https://docs.google.com/document/d/159LhvMZTQnVXnXoQrkKjq7Qg0bXVChX_DQp00OzRn_s/edit)

In this lesson, students analyze maps to calculate and compare changes in the Arctic’s albedo.

- Driving Question(s):
  - What is a feedback loop?
  - How does a decline in sea ice lead to further melting of sea ice?
- Learning Goal(s):
  - Describe the ice-albedo feedback loop
- Standards:
  - ESS2.A: Earth Materials and Systems

Lesson 8: Model Testing
(https://docs.google.com/document/d/1ASrlnu6ledKnx4I2RSj4AQfIzzASUv8iGnLB1AljWjc/edit)

In this lesson, students will test their models by matching their ideas against real-world data about the phenomenon, Arctic amplification.

- Driving Question(s):
  - Can we use real-world data to confirm or refute our model/understanding of the unit driving question?
- Learning Goal(s):
  - Identify and explain patterns in data
- Standards:
  - ESS2.A: Earth Materials and Systems & ESS2.D: Weather and Climate

Lesson 9: Final Model Construction (https://docs.google.com/document/d/1uAmDZmRews3iw7SIpqScudpwCT-TnZ7Nn1e33UDpy1Q/edit)

In this lesson, students draw on concepts and evidence acquired during the unit to construct final models for the unit driving question, "Why might the Arctic be warming twice as fast as the rest of the world?"

- Driving Question(s):
  - Why do scientists continue to gather evidence and revise models of phenomena?
- Learning Goal(s):
  - Construct a final model that explains why the Arctic is warming twice as fast as the rest of the world
- Standards:
  - ESS2.A: Earth Materials and Systems & ESS2.D: Weather and Climate

Lesson 10: Final Explanation (https://docs.google.com/document/d/1Kif7YXP7qPTo-2ZfxunxTZKMikcxCLDzphJdrWgUbj4/edit)

In this lesson, students work independently to write their final evidence-based explanations for the unit driving question,"Why is the Arctic warming twice as fast as the rest of the world?

- Driving Question(s):
  - Why might the Arctic be warming twice as fast as the rest of the world?
- Learning Goal(s):
  - Construct a written explanation for the unit driving question, why is the Arctic warming twice as fast as the rest of the world?
- Standards:
  - ESS2.A: Earth Materials and Systems & ESS2.D: Weather and Climate

AUTHOR INFORMATION

My name is Jonathan Griffith and I am a member of the education and outreach team with the Cooperative Institute for Research in Environmental Sciences at the University of Colorado Boulder and a professional learning facilitator with OpenSciEd.

Resume/CV (https://drive.google.com/file/d/1WR_QQ3laMOzLlFn7FTTPGppW_wyeFh-p/view?usp=sharing)

ABSTRACT

Why would hundreds of scientists from around the world freeze a ship in Arctic sea ice for an entire year, braving subzero temperatures and months of polar darkness? This may sound like a fictional adventure movie plot, but from September 2019 through October 2020, the MOSAiC (**M**ultidisciplinary drifting **O**bservatory for the **S**tudy of **A**rct**i**c **C**limate) Arctic research expedition did just this. Currently, the Arctic is warming twice as fast as the global average (a phenomenon known as Arctic amplification) and due to a lack of observations, there is considerable uncertainty in climate models projecting the Arctic climate of the future. The MOSAiC expedition aims to better understand the changing Arctic climate system by gathering data from ground zero over a full seasonal cycle to augment satellite observation data. Using the expedition as an engagement hook, scientists and curriculum developers developed a high school earth science curriculum anchored by the phenomenon that climate scientists are actively trying to explain: Arctic amplification. The curriculum follows the model-based inquiry instructional framework where each lesson provides students with learning experiences (e.g., virtual reality tours of MOSAiC field sites, analyzing authentic Arctic satellite datasets) that relate back to the phenomena. Focusing on explaining natural phenomena provides an authentic context for students to learn and apply scientific understanding, which research shows can help engage students in NGSS scientific practices. Here we present an overview of the learning sequence using refinement of mental models throughout the unit and present preliminary results from pre-post assessments from two educator workshops (~100 teachers) that show that participants' understanding of Earth’s climate system improved significantly after engaging with the curriculum. Based on these results, we expect this curriculum to be an important tool in engaging students in Earth’s systems thinking.

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