Metrology and Heat Islands
Companion Lesson to X-STEM All Access Episode: Micro Tech with Macro Effect

Grade Band: Middle School and High School	**Topic:** Engineering, Technology, Environmental Science, Earth Science, Biology
Brief Lesson Description: Students explore the hands-on world of technology and metrology through the study of urban heat islands.	
Performance Expectation(s): HS-ESS2-4: Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate. HS-ESS3-4: Evaluate or refine a technological solution that reduces impacts of human activities on natural systems. MS-PS3-5: Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.	
Specific Learning Outcomes: 1. Understand the importance of measurement in scientific inquiry and engineering design. 2. Conduct precise measurements and compare the accuracy of different measurement tools. 3. Develop advanced metrology skills for environmental monitoring. 4. Explain the mechanisms and factors contributing to urban heat islands. 5. Recognize how different populations experience varied impacts from urban heat islands.	
Narrative / Background Information	
Prior Student Knowledge: -Students have a basic understanding of estimating and measuring. -Students can follow a simple procedure to conduct an investigation.	

Science & Engineering Practices:	**Disciplinary Core Ideas:**	**Crosscutting Concepts:**
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories. Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade off considerations. (HS-ETS1-2) **Developing and Using Models** Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). Use a model to provide mechanistic accounts of phenomena. - ***Connections to Nature of Science*** **Scientific Knowledge is Based on Empirical Evidence** Science arguments are strengthened by multiple lines of evidence supporting a single explanation.	**ETS1.B: Developing Possible Solutions** When evaluating solutions it is important to take into account a range of constraints including cost, safety, reliability and aesthetics and to consider social, cultural and environmental impacts. **(HS-ETS1-3)** **ESS3.C: Human Impacts on Earth Systems** Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. **ESS1.B: Earth and the Solar System** Cyclical changes in the shape of Earth's orbit around the sun, together with changes in the tilt of the planet's axis of rotation, both occurring over hundreds of thousands of years, have altered the intensity and distribution of sunlight falling on the earth. These phenomena cause a cycle of ice ages and other gradual climate changes. *(secondary)* **ESS2.A: Earth Materials and Systems** The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash	**Stability and Change** Feedback (negative or positive) can stabilize or destabilize a system. **Cause and Effect** Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. **Energy and Matter** Energy may take different forms (e.g. energy in fields, thermal energy, energy of motion).

Engaging in Argument from Evidence Engaging in argument from evidence in 6–8 builds on K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed worlds. Construct, use, and present oral and written arguments supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon.	clouds) to intermediate (ice ages) to very long-term tectonic cycles. **ESS2.D: Weather and Climate** The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space. **PS3.B: Conservation of Energy and Energy Transfer** When the motion energy of an object changes, there is inevitably some other change in energy at the same time.	

Possible Preconceptions/Misconceptions:

1. Misconception: Urban heat islands affect only the surface temperature.

Correction: They affect air temperature, ground temperature, and surface temperature, influencing local meteorology and ecosystems.

2. Misconception: Urban heat is solely due to the number of people in cities.

Correction: It is also heavily influenced by infrastructure, materials, and lack of vegetative cover.

3. Misconception: Planting a few trees in urban areas can quickly reverse heat island effects.

Correction: While vegetation helps, the layout, species, density, and ongoing management of green spaces are critical for significant impact.

LESSON PLAN – 5-E Model

ENGAGE:

Show the X-STEM Episode Micro Tech with Macro Effect with Dave Bakker

Have students watch this introductory video about Urban Heat Islands (UHIs). Cities on Fire: The Urban Heat Island Effect

Have students discuss the following questions as a group of 3-4, followed by a class-wide discussion. Alternatively, teachers can opt to have different groups address only some of the questions and report back to the whole class during the class-wide discussion. This video and the ensuing discussions will serve as the starting point for the rest of the lesson.

Discussion Questions

1. ***How do scientists measure urban heat islands? What kind of instruments and tracking are necessary?***
2. ***What are different kinds of measurements related to the video and to heat islands? Why is proper measurement important in scientific endeavors? What kinds of microelectronics do you think are present in these instruments?***
3. ***In cities the temperature differences can be as extreme as 20 °F between urban and rural areas. Why do such significant temperature disparities occur, and what factors contribute to them?***
4. ***Considering the data on temperature differences presented in the video, how can you use simple statistical methods such as calculating the mean and range to evaluate the severity of the urban heat island effect in different parts of a city?***
5. ***The video discusses several adaptation strategies to combat urban heat islands, such as increasing green spaces and retrofitting buildings. Which of these strategies do you think would be most effective in your area and school?***
6. ***How do trees and urban gardens help mitigate the urban heat island effect?***
7. ***Why is it particularly problematic that urban heat islands remain hot during the night, and how does this lack of cooling affect human health?***
8. ***The video suggests that the situation will worsen with climate change, projecting more intense and frequent heat waves. Based on this, how important is it for cities to start planning now for future climate conditions? What should be the priority in these plans?***

EXPLORE:

OPTION ONE: Inquiry-based lab with measurements on campus.

Students will explore metrology and measurement in the science classroom as they learn more about heat islands.

Students will conduct an inquiry-based activity at their schools, measuring and collecting data about temperatures around their school and the impact of heat islands. This activity has lots of flexibility. Teachers can do the entire lab portion in one day or have students collect data over the course of a few days. Students will have a chance to collect, analyze, and interpret real data that they collect themselves. This lab is a great opportunity to have students working outside. Begin by covering the general vocabulary of the lesson.
Here is a list of helpful **Vocabulary**

Inquiry-based Activity:

1. Show students a map of your school's campus. This can either be shown on the screen via google maps, or printed out.
2. ***What do you notice? What do you wonder?***
3. ***How is the campus designed and landscaped?***
4. Explain to students that they will be designing a lab to explore and measure heat islands on their school campus.

Lab Design: Students will need to address the following questions. Teams of 3-4 will answer these questions in writing and show them to the teacher before moving on.

1. ***How will we go about designing our lab?***
5. ***What will be measured? What will be calculated? Note: encourage students to take multiple measurements for each location.***
6. ***How is our campus like a city? How is it organized?***
7. ***What is our testable question? (related to heat islands)***
8. ***What is our hypothesis? *Teachers may want students to craft hypotheses in the following format: IF [Cause] → THEN [Effect] : BECAUSE [Mechanism/Rationale]. Where the cause is generally the independent variable and the effect is the dependent variable. This is also in line with NGSS Cross-Cutting Concept: Cause → (Mechanism) → Effect.***
9. ***What are you holding constant? What is your independent variable? What is your dependent variable?***
10. ***How will you measure and collect data? What will your data table look like?***
11. ***What is your general procedure?***

At this point students are ready to explore and begin!
Teacher Notes:

1. Students can reference back to the campus map as they explore and refine their procedure.
2. Things they might want to explore::
    a. Measuring temperatures with different thermometers and comparing data.
    b. Measuring temperature gradients at different distances:
        i. Horizontal distances from objects, trees, buildings. Tape measures and laser measuring devices come in handy here.
        ii. Vertical distances from the ground up.
    c. Measuring temperatures in different locations/orientations, North/South/East/West
    d. Measuring temperatures in relation to different surfaces:
        i. Abiotic vs Biotic
        ii. Colors (albedo)

Option 2: Option utilizing PocketLab Voyager 2 Sensor

Here are two online labs via PocketLab Notebook. The first lab requires a PocketLab Voyager 2 Sensor, or PocketLab Air / Thermo. Parts of the lab can be done without the sensor. In the lab students will answer a series of questions and view a series of videos related to measuring and Heat Islands. Students will pair their sensors to the PocketLab Notebook activity to record data and analyze data.
What are Heat Islands? **[links have full lab write up and procedure**]
Understanding Human Impacts on Heat Islands

Teacher Notes on Activity:

1. Emphasize proper technique when measuring and share with students the importance of accurate measurements. One area where students often struggle is with how precise to make their measurements. Have students measure to one uncertain digit. Teachers can help students apply this by choosing different types of tools and equipment. (e.g., different degrees of graduated cylinders)

EXPLAIN:
We want students to connect their prior knowledge to new ideas about measurement/metrology and heat islands. .

1. Once students have been given the okay, have them meet with at least one other group to share and discuss their approach.
2. Students are now to go outside and gather their data.
3. Remind students that their measurements and data collection should connect back to their initial question and hypothesis.
4. Once students have gathered their data (either from a single day, or multiple days) they are ready to analyze and graph.
5. Students may need to compile data from a few days and possibly average their results.

GRAPHING:

1. Students are now ready to graph the results of their trials. Teachers can have students graph on pencil and paper or on excel/google spreadsheets, or both. Here is a **LINK** to some handy graph paper that can be printed out for students.

2. The beginning of this video is helpful for those who might need a little help with [Graphing in Excel]

Data Analysis Discussion Questions:

1. ***Describe the method you used for collecting temperature data around the school. How did you ensure that your measurements were accurate and consistent?***
2. ***What type of graph did you choose to represent your data and why? How did you decide on the scale and labels for your axes?***
3. ***Examine your graphs and data tables. What trends or patterns can you observe? Are there any outliers, and if so, how might you explain them?***
4. ***How are your independent and dependent variables related in this study? Did the data support your hypothesis?***
5. ***What differences or similarities did you notice between your data and findings compared to another group's? What factors might explain these differences?***
6. ***After discussing with another group, what new ideas or methods did you learn that could improve your own data collection or analysis?***
7. ***Reflect on your initial hypothesis. Based on the data you collected, would you accept or reject your hypothesis? Provide evidence from your data to support your decision.***

ELABORATE: Applications and Extensions:

In this section students will apply what they've learned to a new, but similar situation. The goal is for them to expand upon knowledge gained earlier in the lesson. Students will conduct a redesign of the campus based on their findings from their outside field work and graphical analysis.

1. Have the class refer back to the map of campus.
2. Students can either draw a sketch of the campus or the teacher can print out copies for groups.
3. Have students add some of their data and findings to specific locations on the campus map.
4. ***What surprised you?***
5. Teams will then create a re-design of the school's campus with the goal of lessening the heat island effect and large temperature gradients. Consider what can be added and what can be deleted from the map to help alleviate high temperatures.

Extension Questions:

1. ***If you were to conduct this lab again, what changes or improvements would you make to your data collection or analysis methods?***
2. ***How did this activity help you understand the concept of heat islands and their impact on urban areas? Can you connect your findings to any real-world scenarios?***
3. ***What skills or knowledge did you gain from designing and conducting your own lab? How does this inquiry-based approach help you learn science more effectively?***

EVALUATE:

Formative Monitoring (Questioning / Discussion):

Participation in discussions and group activities from the sections above will provide teachers with insights into students' understanding.
Teachers should pay close attention to questions posed during discussion and during activities.
Teachers should encourage students to think about how improving measurement techniques can lead to advancements in technology and science.

Summative Assessment (Quiz / Project / Report):

Accuracy and completeness of measurements and data recorded during the lesson.
Discussion and reflection questions embedded into the 5E and SEL sections of the lesson.
End the lesson with a reflection session where students share what they learned about the importance of measurement/metrology and Urban Heat Islands and how they can apply this knowledge in their daily lives and future careers.

Elaborate Further / Reflect: Enrichment:

Students can do further reading, listening, and research on the links and topics below. Teachers can also gain deeper insights and generate interesting class discussions based off of these links. Additionally, students and teachers can explore the Interdisciplinary Connections/Ideas section below.

Here is an Urban Heat Island and Thermal Imaging lab activity from ASU:
[Predicting Temperature Using Infrared Images] + [Thermal Images]
[EPA Urban Heat Island Effect]

SOCIAL EMOTIONAL LEARNING ACTIVITY
CASEL Domain Addressed: Social Awareness Learning Objectives: - Recognize how different populations experience varied impacts from urban heat islands. - Explore the role of social equity in urban planning and environmental justice. - Develop strategies for collective action to mitigate the negative effects of UHIs. This Social and Emotional Learning (SEL) lesson on Urban Heat Islands (UHIs) is designed to enhance students' social awareness by exploring the impacts on communities and encouraging empathy and collective action. The lesson ties into the Social Awareness competency of the SEL framework, focusing on understanding the perspectives of others, particularly those in urban environments disproportionately affected by climate phenomena. Students will understand the societal implications of urban heat islands and develop empathy for communities that are disproportionately affected by urban planning decisions. **Procedure** Show this short news clip: [PBS Urban Heat Islands] 1. ***How do you think living in a heat island affects individuals and families?*** ***2. What feelings arise when you hear people talk about their experiences with extreme urban temperatures?*** Break students into small groups. Each group will view a map of their chosen (or assigned) US city. These maps show the intensity of UHIs in different socioeconomic areas. [Downloadable Urban Heat Island Maps] ***3. What patterns do you notice about your locations and severity of heat islands?*** ***4. Why might some communities be more affected than others?*** Facilitate a discussion on the concept of environmental justice and how it relates to urban heat islands. ***5. What is environmental justice, and why is it important in the context of UHIs?*** ***6. Can you think of any policies or strategies that might help address inequalities related to UHIs?*** ***7. What role can young people play in advocating for and implementing solutions to reduce urban heat?*** ***8. How can we ensure that our action plans are inclusive and beneficial to all community members?*** Assess student engagement and understanding through their participation in discussions and the quality of their responses.. Teachers may use reflection essays to gauge their insights into how social awareness can lead to meaningful change in urban environments.
INTERDISCIPLINARY CONNECTIONS/IDEAS
Geography: Understanding how geographic features influence microclimates within urban settings. Students can explore how the layout of the city, including water bodies, green spaces, and built-up areas, affects the temperature variations observed in UHIs. **Urban Planning and Architecture:** Analyzing how different building materials and urban designs contribute to or mitigate the heat island effect. This connection could lead to discussions on sustainable architecture and the design of cities to enhance livability and reduce environmental impact. **Environmental Science:** Examining the ecological impacts of UHIs on local flora and fauna, as well as broader effects on air quality and weather patterns. This aspect could also include the study of mitigation strategies like green roofs, urban forests, and reflective surfaces. **Public Health:** Exploring how increased urban temperatures affect human health, particularly among vulnerable populations. Discussion points can include heat-related illnesses, the importance of heatwave preparedness, and public health strategies to protect communities during extreme heat events. **Statistics and Data Science:** Applying statistical methods to analyze temperature data collected during the lab. Students can learn about data visualization, correlation studies, and predictive modeling to understand and forecast the impacts of UHIs. **Political Science:** Examining the role of policy in managing urban heat, such as regulations on building materials, and zoning laws.. Students can explore how local, national, and global policies address the challenges of urban heat islands.

Materials Required for This Lesson/Activity	
Quantity	**Description**
1 per group	Thermometers: standard thermometer, digital, and infrared.

1 per group	OPTIONAL: PocketLab Voyager 2 and/or PocketLab Thermo
1 per group	Data log sheets, maps of the school campus and surrounding areas
1 per student	Graph paper, colored pencils for data visualization, computers with spreadsheet software
1 per group	Tape measure, laser tape measure

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