Integrating Chemistry & Earth Science

INTEGRATING CHEMISTRY AND EARTH SCIENCE

EXPLORING HOW CHEMISTRY, EARTH PROCESSES, AND PEOPLE SHAPE THE CITY

A National Science Foundation Funded Discovery in Research K-12 Project

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

BALTIMORE CITY PUBLIC SCHOOLS

NSF

Cary Institute of Ecosystem Studies

INTEGRATING CHEMISTRY AND EARTH SCIENCE (ICE)

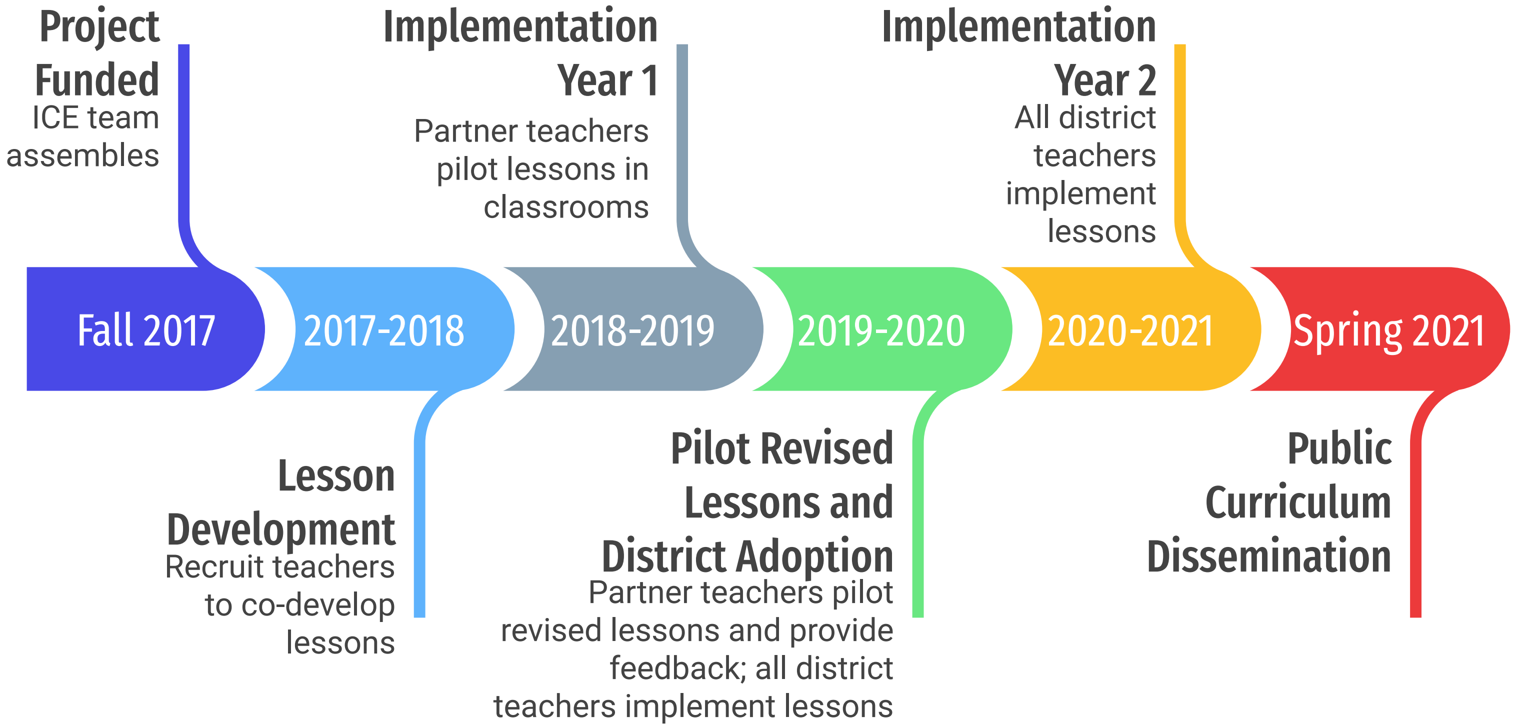
Dear Educators,

The Integrating Chemistry and Earth science (ICE) project is a collaboration between Baltimore City Public Schools (City Schools), Cary Institute of Ecosystem Studies, and George Washington University to infuse Earth science into Baltimore City's high school chemistry course. Funded by the National Science Foundation, ICE brought together experts from Earth science, chemistry and science education to develop an engaging curriculum for students to learn about phenomena in their local environment. ICE lessons cross the Earth-chemistry disciplines, meet NGSS standards in both Physical and Earth/Space sciences, and prepare students to think critically about the world around them.

The Thermochemistry Unit, taught as the 6th of 7 total units in the City Schools' high school Chemistry course, helps students answer the question, "What determines the temperature in Baltimore?" The Urban Heat Island Module presented here contains a subset of lessons from the Thermochemistry unit. Now in its final form, we are pleased to share these activities with a broader audience. Thank you for your interest in these educational materials

For more information, contact: Alan R. Berkowitz, Head of Education, The Cary Institute of Ecosystem Studies (berkowitza@caryinstitute.org).

INTEGRATING CHEMISTRY AND EARTH SCIENCE (ICE) - Project Timeline



INTEGRATING CHEMISTRY AND EARTH SCIENCE (ICE) - Acknowledgements

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INTEGRATING CHEMISTRY AND EARTH SCIENCE

10TH GRADE CHEMISTRY | COURSE OVERVIEW

All high school students in Baltimore City Public Schools (City Schools) are required to complete a three-course sequence of Biology, Chemistry, and Physics in grades 9, 10 and 11. However, with Next Generation Science Standards adoption and implementation, Earth/space science needed to be addressed within City School's curriculum. The Integrating Chemistry and Earth science (ICE) project supported City Schools in creating a new Chemistry curriculum that met the assessment requirements for both chemistry and Earth/space science. This newly revised, seven-unit high school Chemistry curriculum represents a major shift towards providing Next Generation Science Standards-aligned instruction and infusing Earth/space science performance expectations, concepts and practices across the entire curriculum. Within, there are many opportunities for students to explore Earth/space science material including in units 1, 4, 6 and 7 which contain extensive ICE content and within the other units where Earth science is infused as small parts of lessons or individual lesson. We deemed these activities "ICEicles." The topics for these infusions are listed on the following slide along with the overall topics for each of the seven units.

INTEGRATING CHEMISTRY AND EARTH SCIENCE

10TH GRADE CHEMISTRY | COURSE UNITS

Unit topics	ICE/ICEicle topics
Atomic Structure and Patterns*	• The Big Bang Theory and Life cycle of stars
Nuclear Chemistry	• Nuclear fusion in stars and Earth's formation and early history
Combining Atoms	• Properties of water
Chemical Reactions*	• Ocean acidification
Stoichiometry	• Earth as a limiting reactant for energy and mineral resources
Thermochemistry*	• **Urban heat island and related phenomena and Inner Earth heat and processes**
Chemistry and the Life and Death of Baltimore's Mountains*	• Local landforms and rock types, weathering, erosion, water quality, and deposition • Plate tectonics, rock and crustal feature formation with a Baltimore focus

*Earth/space science integration

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THERMOCHEMISTRY | UNIT SUMMARY

The Thermochemistry Unit explores the question “What determines the temperature in Baltimore?” addressing the concepts of temperature, heat energy exchange and budgets, inner Earth structure, and climate.

The Unit addresses the physical properties of heat such as how heat moves, how heat impacts the temperature of substances, and how heat energy is calculated. Students explore the chemical properties of heat such as endothermic and exothermic reactions. The unit also builds an understanding of heat’s role in geological processes such as the structure of the inner Earth, nuclear decay, how energy is transferred within the Earth, and how internal Earth processes impact plate tectonics. The role of solar radiation and the factors that impact its absorption such as albedo and the chemical composition of materials, are key big ideas in the Thermochemistry Unit. Finally, the Unit addresses the influences of urban structures on the behavior of heat energy. The culminating student project includes answering the question: What can we do to minimize the impact of the Urban Heat Island effect in our city and neighborhoods?

The Urban Heat Island module is a subset of lessons from the Thermochemistry Unit. These lessons bring together important concepts from Earth science and chemistry to help students build an understanding of why urban areas have higher temperatures both during the day and at night, than their rural counterparts.

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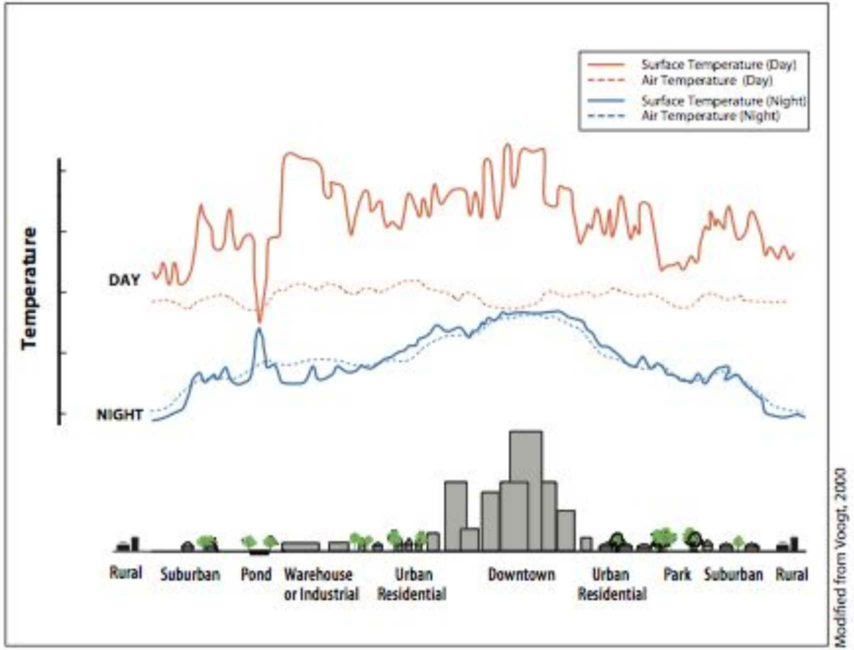
THERMOCHEMISTRY

ANCHORING PHENOMENON: Urban Heat Islands - a zone of heat in a cooler landscape.

DRIVING QUESTION: What Determines the Temperature in Baltimore?

DESIGN CHALLENGE: Propose solutions that your neighborhood could use to decrease the UHI's dangerous temperatures and/or their impacts during the summer.



Source: Reducing Urban Heat Islands: Compendium of Strategies, www.epa.gov

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THERMOCHEMISTRY | UNIT LESSON SEQUENCE

1. **Thermal Exploration: exploring temperature in the schoolyard**
2. Chemical Reactions: reactions that cause temperature change
3. Conservation of Thermal Energy: interactions between water at different temperatures
4. Heat Capacity: how different materials react to heat
5. Calorimetry (2 Days): how thermal energy, heat, and mass are related
6. Hand Warmers I: the chemical reactions that cause hand warmers to generate heat
7. Thermal Energy in Chemical Systems: how energy moves
8. Predicting Temperatures (2 Days): using lab results to predict temperatures
9. Hand Warmers II: student designed hand warmers using claims, evidence, and reasoning

10. Inside Earth (2 Days): radioactive decay and gravitational collapse; Earth's internal temperature

Urban Heat Island Module (lessons 1 and 11–17)

11. **Convection: how heat is transferred within fluids**
12. **Plate Tectonics: convection in the Earth's mantle**
13. **Conduction: how heat is transferred between objects that touch**
14. **Solar Radiation (2 Days): how solar radiation behaves when it reaches Earth**
15. **Thermal Radiation (2 days): specific heat, heat capacity, albedo**
16. **Heat Waves and Urban Heat Islands (UHI): using real data to understand UHIs**
17. **Reducing the impacts of Urban Heat Islands: mitigating the UHI effect**

18. Earth's Energy Balance Review: prepare for Unit exam

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THERMOCHEMISTRY | TARGETED PERFORMANCE EXPECTATIONS

HS-ESS1-1: **Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy that eventually reaches Earth in the form of radiation.** [Clarification Statement: Emphasis is on the energy transfer mechanisms that allow energy from nuclear fusion in the sun's core to reach Earth. Examples of evidence for the model include observations of the masses and lifetimes of other stars, as well as the ways that the sun's radiation varies due to sudden solar flares ("space weather"), the 11-year sunspot cycle, and non-cyclic variations over centuries.] [Assessment Boundary: Assessment does not include details of the atomic and sub-atomic processes involved with the sun's nuclear fusion.]
HS-ESS2-3: **Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection.** [Clarification Statement: Emphasis is on both a one-dimensional model of Earth, with radial layers determined by density, and a three-dimensional model, which is controlled by mantle convection and the resulting plate tectonics. Examples of evidence include maps of Earth's three-dimensional structure obtained from seismic waves, records of the rate of change of Earth's magnetic field (as constraints on convection in the outer core), and identification of the composition of Earth's layers from high-pressure laboratory experiments.]
HS-PS3-3: **Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*** [Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.] [Assessment Boundary: Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.]
HS-PS3-4: **Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).** [Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.]

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THERMOCHEMISTRY | NGSS DIMENSIONS

Science and Engineering Practices (SEP)
Constructing Explanations and Designing Solutions. Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade off considerations. **Developing and Using Models.** Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. **Planning and Carrying Out Investigations.** Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.

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THERMOCHEMISTRY | NGSS DIMENSIONS

Disciplinary Core Ideas (DCI)
ESS1.A: **The Universe and Its Stars**. The star called the sun is changing and will burn out over a lifespan of approximately 10 billion years.
ESS2.B: **Plate Tectonics and Large-Scale System Interactions.** The radioactive decay of unstable isotopes continually generates new energy within Earth's crust and mantle, providing the primary source of the heat that drives mantle convection. Plate tectonics can be viewed as the surface expression of mantle convection.
PS3.B: **Conservation of Energy and Energy Transfer.** Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).
PS3.D: **Energy in Chemical Processes and Everyday Life.** Nuclear Fusion processes in the center of the sun release the energy that ultimately reaches Earth as radiation. (secondary)

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THERMOCHEMISTRY | NGSS DIMENSIONS

Crosscutting Concepts (CCC)

Energy and Matter. In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.

Scale, Proportion, and Quantity. The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.

Systems and System Models. When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models.

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THERMOCHEMISTRY | MODELING TASKS FOR STUDENT SENSE MAKING

Throughout the ICE curriculum, lessons bring together disciplinary core ideas, crosscutting concepts, and science and engineering practices to support three-dimensional teaching and learning.

Within the Thermochemistry Unit and the Urban Heat Island module, particular emphasis is placed on supporting students' development of model-based explanations of the UHI phenomenon. The modeling tasks within the module prompt students to illustrate their understanding of how energy moves into, out of, and within the urban system. Additionally, students are able to highlight how heat energy interacts with natural and human-made elements of the urban system leading to the UHI phenomenon.

The students' models also make their thinking visible so teachers are able to build upon the current understanding of their students and document the changing complexity of their models.

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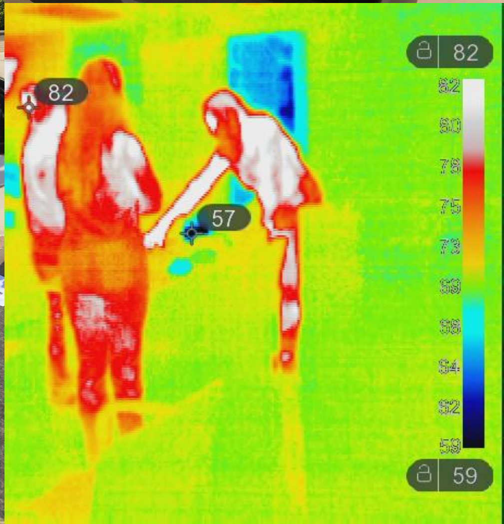
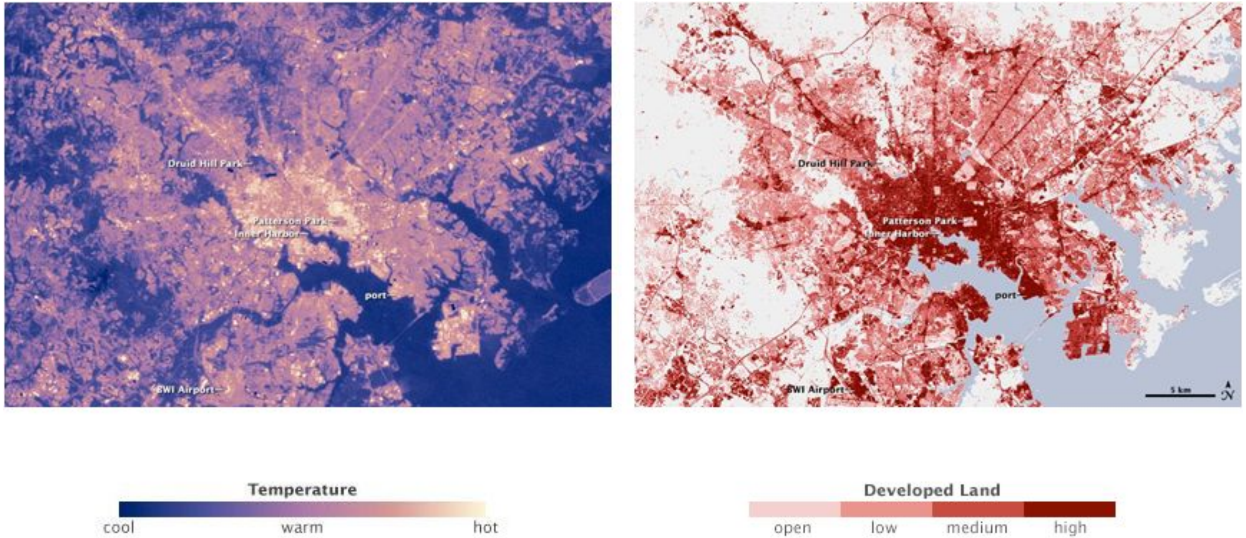
URBAN HEAT ISLAND MODULE
OVERVIEW



URBAN HEAT ISLAND MODULE

The Urban Heat Island Module includes 8 lessons derived from the Thermochemistry Unit of Baltimore City Public School's high school chemistry course. These lessons guide students in learning about and developing an understanding of how Urban Heat Islands form and what we can do to reduce their presence and effects. Activities include hands on explorations of heat in the school yard, investigating the pathways and processes that influence heat transfer, absorption, storage and reflection, and analyzing real, local data from a heat wave in Baltimore City.

Baltimore metro land surface temperatures (August 2001) and corresponding developed land image demonstrating the effect of human-made materials on surface temperature. I.e. the Urban Heat Island Effect



Left image: land surface temperature in the Baltimore region, August 2, 2001. Right image: developed area, January 1-December 31, 2001.

Source: Zhang et al. 2008

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URBAN HEAT ISLAND MODULE | LESSONS

1) Thermal Exploration of the Schoolyard

2) Convection

3) Plate Tectonics

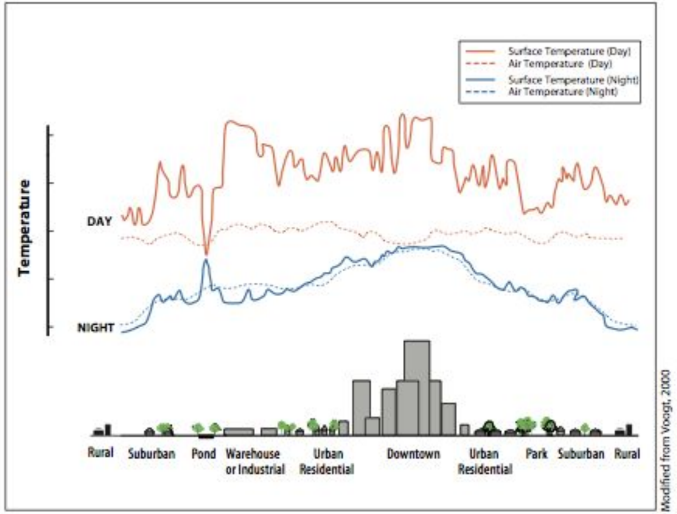
4) Conduction

5) Energy from the Sun (two days)

6) Thermal Radiation (2 days)

7) Heat Waves and Urban Heat Islands

8) Reducing the Urban Heat Island



Source: Reducing Urban Heat Islands: Compendium of Strategies, www.epa.gov

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URBAN HEAT ISLAND

Lesson 1: Thermal Exploration of the Schoolyard	Lesson 2: Convection
Driving Question: What determines the temperature of the objects around the school?	**Driving Question:** How is heat transferred within fluids, such as water bodies or the Earth's interior?
Summary: Students use infrared thermometers to explore and record temperatures of different surfaces in the schoolyard. They develop an initial heat model explaining heat energy pathways and processes at the scale of the Earth and their neighborhood. Go To Lesson	**Summary:** Students explore the process of convection with the goal of understanding: 1) the general behavior of fluids, 2) the outer core, mantle, bodies of water, and the atmosphere all behave like fluids, 3) heat energy is transferred in fluids by diffusion, conduction, and convection/advection, and 4) where gravity is at work, cooled/more dense materials move downwards into the fluid forming convection cells. Go To Lesson

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URBAN HEAT ISLAND

Lesson 3: Plate Tectonics	Lesson 4: Conduction
Driving Question: How does convection affect the surface of the Earth?	**Driving Question:** What happens when two objects, at different temperatures, touch?
Summary: Students examine global earthquake and volcano data to develop an understanding that convection within the Earth's mantle is the mechanism behind plate tectonics, earthquakes, and volcano formation. Go To Lesson	**Summary:** Students utilize a computer simulation to study the process of conduction and compare the conductivity of different materials. Go To Lesson

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URBAN HEAT ISLAND

Lesson 5: Energy from the Sun (2 Days)	Lesson 6: Thermal Radiation (2 Days)
Driving Question: What happens to solar radiation when it reaches the Earth?	**Driving Question:** How does Earth's surface cool?
Summary: Students understand that hot objects (like the sun) emit shortwave (light) radiation that can travel through a vacuum and anything that is transparent. This radiation can either be reflected or absorbed by surfaces. The percentage of reflected radiation is the "albedo." Absorbed radiation will increase the temperature of the surface of the object. This heat energy is then released as long wave (infrared) radiation.	**Summary:** Students understand that materials differ not only in how much energy they can reflect, but also in how much absorbed energy is needed to increase their temperature (Specific Heat). This property also influences the rate at which materials lose heat when exposed to a cooler medium. he stored heat is referred to Heat Capacity. The Specific Heat/Heat Capacity of building materials in an urban area influence the temperature of the city in terms of excess heat stored in structures. The differences in Heat Capacity of materials create temperature differences across day and night.
Go To Lesson	Go To Lesson

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URBAN HEAT ISLAND

Lesson 7: Heat Waves and Urban Heat Islands	Lesson 8: Reducing the Urban Heat Island
Driving Question: How does the temperature in Baltimore City compare to the temperature in Baltimore County?	**Driving Question:** How can we reduce the impacts of the Urban Heat Island effect?
Summary: Over the next two lessons students will study the Urban Heat Island effect as it applies to Baltimore and its surrounding region and propose possible solutions for neighborhoods within Baltimore City. Go To Lesson	**Summary:** Students will develop proposed solutions to the Urban Heat Island effect for neighborhoods within Baltimore City and present them to the class. Go To Lesson

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SOURCES

Grooms, J., Fleming, K., Berkowitz, A.R., and Caplan, B. (2021). Exploring modeling as a context to support content integration for chemistry and Earth science. *Journal of Chemical Education*, 98(7), 2167-2175.

Reducing Urban Heat Islands: Compendium of Strategies, www.epa.gov

Zhang, Ping, Marc Imhoff, Robert Wolfe, and Lahouari Bounoua presented the research on December 18, 2008, at the fall meeting of the American Geophysical Union. NASA images by Robert Simmon, based on data from the National Land Cover Database and Landsat 7. Caption by Holli Riebeek.