Infrared Light and Infrared Astronomy

The Next Generation Science Standards (NGSS)-aligned NASA EMS/IRA curriculum module was written by SETI Institute staff for 10-hour classroom delivery by instructors participating in the Astronomy Activation Ambassadors (AAA) program. Instructors intending to implement any portion of the curriculum should keep the following points in mind:

- Before teaching the curriculum, AAA teachers receive 6 months of focused professional development, an all-day in-person training workshop, and a week-long STEM immersion experience at a NASA astronomy research facility. The curriculum is written for fully trained AAA teachers.
- The curriculum is based on a series of hands-on student activities. Materials and equipment needed for those activities are listed in the lesson plans.
- The curriculum materials are not in final form; they are still undergoing revision. Independent product review has not yet been completed.

NGSS definitions and conventions are employed herein. **Please note that portions of specific standards not addressed in this particular curriculum module are indicated with ~~strikethroughs~~.**

Unit Goals and Objectives
Overarching Storyline: Astronomers know a great deal about the Universe, from the chemical composition of distant gas clouds, to the life cycles of stars, histories of Solar System bodies, formation of galaxies, and origin of the Universe. Astronomers have unraveled almost all of these mysteries by careful and close examination of electromagnetic (EM) radiation. The EM spectrum includes everything from X-rays to radio waves, and is collected by instruments that have been carefully engineered to detect specific wavelengths. Astronomers can use both representative color images and spectra to interpret this information and investigate the objects or processes in question.
Essential Questions: • How do we know (what is the evidence to support the idea) that there is more "light" beyond what our eyes can see? • What are the different ways we can detect and record infrared (IR) light data? • What are some properties of visible light and how does do they compare with properties of IR light? • How do astronomers use IR light to better understand objects in the universe?
Established Goals (Performance Expectations): • Plan an astronomy investigation that would yield infrared spectra. • Explain how scientists know and understand a science research finding from infrared observations using text, a model, and evidence.

Infrared Light and Infrared Astronomy

Content and Skill Standards for the Unit (3-Dimensional Learning)
Students will build upon these prior Middle School Performance Expectations (PEs) and Disciplinary Core Ideas (DCIs): **PE MS-PS4-2 Waves and their Applications in Technologies for Information Transfer** Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials. [Clarification statement: Emphasis is on both light and mechanical waves. Examples of models could include drawings, simulations, and written descriptions.] **PE MS-PS4.B Electromagnetic Radiation** When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light.
Students will build their understanding toward the following DCIs: **PS4.B Electromagnetic Radiation** Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave~~ of changing electric and magnetic fields or as particles called photons~~. The wave model is useful for explaining many features of electromagnetic radiation while the particle model explains other features. **PS4.A Wave Properties** Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory~~ and sent over long distances as a series of wave pulses~~. **PS4.C Information Technologies and Instrumentation** Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them. **PS4.B Electromagnetic Radiation** Atoms of each element emit and absorb characteristic frequencies of light. These characteristics allow identification of the presence of an element, even in microscopic quantities. **ESS1.A The Universe and Its Stars** The study of stars' light spectra and brightness is used to identify compositional elements of stars. ~~their movements, and their distances from Earth.~~

Focal Science and Engineering Practices (SEPs) for the Unit

Asking Questions
- Ask questions that can be investigated within the scope of the school laboratory, research facilities, or field (e.g., outdoor environment) with available resources and, when appropriate, frame a hypothesis based on a model or theory.
- Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information.

Developing and Using Models
- Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism, or system in order to select or revise a model that best fits the evidence or design criteria.

Constructing Explanations
- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.
- Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion.

Engaging in Argument from Evidence
- Evaluate claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments.
- Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence.

Obtaining, Evaluating, and Communicating Information
- Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

Focal Crosscutting Concepts (CCCs) for the Unit

Patterns
- Empirical evidence is needed to identify patterns.

Stability and Change
- Much of science deals with constructing explanations of how things change and how they remain stable.

Connections to Engineering, Technology, and Applications of Science for Grades 9–12

Interdependence of Science, Engineering, and Technology
- Science and engineering complement each other in the cycle known as research and development (R&D).

Connections to the Nature of Science for Grades 9–12

Scientific Investigations Use a Variety of Methods
- Scientific investigations use a variety of methods, tools, and techniques to revise and produce new knowledge.

Scientific Knowledge Is Based on Empirical Evidence
- Science arguments are strengthened by multiple lines of evidence supporting a single explanation.

Scientific Knowledge Is Open to Revision in Light of New Evidence
- Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation.

Science Is a Human Endeavor
- Technological advances have influenced the progress of science and science has influenced advances in technology.

Days 1-2: Filters and Wavelengths

Targeted Idea: 'Parts of light' can be blocked by filters or substances.

Overview of Days 1-2:

Students are given an opening probe and asked to select an answer that most closely matches their ideas, and write a response explaining their current thinking. Students are given the opportunity to explore light passing through various color filters (with differing degrees of light/color absorption) to gather data and support an explanation/model of properties of visible light an how humans detect light. They then evaluate their own explanation/model against a sample student model. The sample student model presents them with a tentative model that they can evaluate in terms of merits and limitations and then refine to explain further observations.

The classroom activities are supported by homework: finding substances that block or partially filter LED lights and reading/answering questions about a Science Case Study. They return to the classroom to share substances, their understandings, and questions about the Case Study in classroom discussions.

***The probe is not a moment to instruct**, but rather an opportunity to make the teacher aware of various conceptions held by students, and to make the students aware of the breadth of ideas held by their peers. They will have plenty of experiences to revise these viewpoints.*

Students are building their understanding toward these DCIs during Days 1-2:

PS4.B Electromagnetic Radiation
Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave ~~of changing electric and magnetic fields or as particles called photons~~. The wave model is useful for explaining many features of electromagnetic radiation while the particle model explains other features.

PS4.A Wave Properties
Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory ~~and sent over long distances as a series of wave pulses~~.

PS4.C Information Technologies and Instrumentation
Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them.

Students are building their skills in / understanding of these SEPs during Days 1-2:

Asking Questions
- Ask questions that can be investigated within the scope of the school laboratory, research facilities, or field (e.g., outdoor environment) with available resources and, when appropriate, frame a hypothesis based on a model or theory.
- Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information.

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- Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism, or system in order to select or revise a model that best fits the evidence or design criteria.

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- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.

Obtaining, Evaluating, and Communicating Information

- Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

Middle School PEs/DCIs relevant to Days 1-2:

MS-PS4-2 Waves and their Applications in Technologies for Information Transfer
Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials. [Clarification statement: Emphasis is on both light and mechanical waves. Examples of models could include drawings, simulations, and written descriptions.]

MS PS4.B Electromagnetic Radiation
When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light.

Day 3: Beyond the Visible

Targeted Idea: There is invisible light in the EM spectrum.

Overview of Day 3:

Students examine photos of a toaster behind a black garbage bag (one taken with a regular camera and one with an IR camera). After viewing NASA videos regarding the EM spectrum and infrared light, students continue talking about their own mental models of visible and invisible light. Students are also introduced to the IR camera and get their first glimpses of themselves and their classroom in the infrared.

The purpose of this section is to introduce students to a larger unit concept (visible light is a small portion of the EM spectrum that can be detected with instruments) and to the focus of the day (different wavelengths of light can pass through some everyday objects but not through others).

When students look at two images of a plastic bag over a toaster, they should notice that the infrared camera can "see" the toaster, even if something (like a plastic bag) blocks visible light reflected from it from reaching a camera. This reinforces the idea that not all wavelengths of light are visible to the human eye, nor detectable with all instruments.

Students may hold the belief that if an object is opaque to visible light, no other wavelengths of light will pass through it. Conversely, students may hold the belief that if an object is transparent to visible light, it will be transparent to all wavelengths of light. If your students seem to be having trouble with these ideas, show them that an opaque plastic bag does not block the IR signal from a remote control from turning on a television. It may help them to know that the remote control emits infrared light (that's how it signals the television), and that the infrared light passes through the plastic bag in the same way that heat from the toaster passed through the plastic bag and was recorded by the camera.

Students are building their understanding toward these DCIs during Day 3:

PS4.B Electromagnetic Radiation
Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave ~~of changing electric and magnetic fields or as particles called photons~~. The wave model is useful for explaining many features of electromagnetic radiation while the particle model explains other features.

PS4.A Wave Properties
Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory ~~and sent over long distances as a series of wave pulses~~.

PS4.C Information Technologies and Instrumentation
Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications,

scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them.

Middle School PEs/DCIs also relevant to today's work:

MS-PS4-2 Waves and their Applications in Technologies for Information Transfer
Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials. [Clarification statement: Emphasis is on both light and mechanical waves. Examples of models could include drawings, simulations, and written descriptions.]

MS PS4.B Electromagnetic Radiation
When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light.

Students are building their skills in / understanding of these SEPs during Day 3:

Asking Questions

- Ask questions that can be investigated within the scope of the school laboratory, research facilities, or field (e.g., outdoor environment) with available resources and, when appropriate, frame a hypothesis based on a model or theory.
- Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information.

Obtaining, Evaluating, and Communicating Information

- Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

Days 4- 5: Detecting the Invisible

Targeted Idea: We can sense light, beyond what our eyes can see, using various detectors and devices. Some of this light may be blocked by filters and other substances.

Overview of Days 4-5:

Just as our ears cannot hear all wavelengths of sound, our eyes cannot see all wavelengths of light. We can use devices to detect this light.

Students explore a discrepant event using a remote control and smart phone cameras. They are asked to discuss their group observations and generate a tentative explanation for why the smart phones could detect light that their eyes cannot. Following this, students use a photocell detector circuit to collect evidence that there is additional "light" transmitted beyond the visible region of the spectrum. The focus here is the collection of data, and that they will use evidence to construct an explanation that "invisible light" exists, and that we can detect this light with instruments other than our eyes.

Students watch the teacher demonstrate how the same detector recognizes "unseen light" beyond the red end of the spectrum. The students draft a Claim/Evidence/Reasoning paragraph to support the statement that that light exists beyond the visible spectrum, and that we can detect this light with instruments.

Students are building their understanding toward these DCIs during Days 4-5:

PS4.B Electromagnetic Radiation
Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave~~ of changing electric and magnetic fields or as particles called photons~~. The wave model is useful for explaining many features of electromagnetic radiation while the particle model explains other features.

PS4.A Wave Properties
Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory~~ and sent over long distances as a series of wave pulses.~~

PS4.C Information Technologies and Instrumentation
Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them.

Middle School PEs/DCIs also relevant to today's work:

MS-PS4-2 Waves and their Applications in Technologies for Information Transfer
Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials. [Clarification statement: Emphasis is on both light and mechanical waves. Examples of models could include drawings, simulations, and written descriptions.]

MS-PS4.B Electromagnetic Radiation

When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light.

Students are building their skills in / understanding of these SEPs today:

Engaging in Argument from Evidence

- Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence and challenging ideas and conclusions, responding thoughtfully to diverse perspectives, and determining what additional information is required to resolve conflicts.
- Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence.
- Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence.

Obtaining, Evaluating, and Communicating Information

Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

Day 6: How do astronomers use images in research?

Targeted Idea: Photos can provide a great deal of information about objects in the Universe. We can measure light or look at images from other wavelengths to try to get a bigger picture.

Overview of Day 6:

Astronomy is unlike other sciences in that investigators cannot change the variables of an experiment or collect physical materials to measure properties of the objects under study (with a few exceptions, such as the Moon and Earth). Astronomers are almost entirely dependent on studying the light from objects. A variety of tools are used to collect this light, to receive the data from these instruments, and to process the data. After which, investigators can analyze and interpret the images. Astronomers can compare the images to other similar objects to look for patterns; other times, they make measurements on the photos and plot the brightness data. Investigators can maximize the study of objects by collecting data in multiple wavelengths of the EM spectrum.

In this activity, students examine a variety of astronomical images. They practice respectfully providing critiques on the scientific arguments of peers. In groups, they make and defend a claim based on evidence. They begin with easy to interpret optical images, and eventually move toward examining IR images both printed and from the IR camera.

Students are building their understanding toward these DCIs:

PS4.A. Wave Properties
Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory~~ and sent over long distances as a series of wave pulses.~~

PS4.C Information Technologies and Instrumentation
Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them.

Middle School PE/DCI also relevant to today's work:

MS-PS4-2 Waves and their Applications in Technologies for Information Transfer
Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials. [Clarification statement: Emphasis is on both light and mechanical waves. Examples of models could include drawings, simulations, and written descriptions.]

MS-PS4.B Electromagnetic Radiation
When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light.

Students are building their skills in / understanding of these SEPs and CCCs today:

SEPs

Engaging in Argument from Evidence

- Evaluate claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments.
- Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence.

Constructing Explanations

- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.
- Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion.

CCCs

Patterns

- Empirical evidence is needed to identify patterns.

Days 7-8: How do astronomers use spectra to investigate objects in the Universe?

Targeted Idea: Tools can break light into its component parts called spectra. Every substance has its own unique spectral signature; finding that signature means that this substance is present.

Overview of Days 7-8:

Astronomers use a variety of tools to examine the light from objects in the Universe. One essential tool in astronomy is the diffraction grating, which has been modified and improved over time. Gratings split (diffract) light into a spectrum by sending light of different wavelengths into very slightly different directions. Astronomers study the spectra of objects to look for the presence of a particular substance- each one has a known signature.

Students start this day by tying up some lose ends from Day 6. They begin by discussing Circumnuclear Ring Case Study, using the Case Study Focus questions as a guide. They are then asked to consider the similarities and differences in how the astronomers used the image data.

The students are reminded of the wavelength model of light introduced on Day 2. The students are asked to recall (and consult) the data that they collected on Day 1 (the blue filter let through light that was green, not blue. They are given a green LED and white LED with a blue filter. They are asked to collect more data by observing blue filtered - green light and blue filtered - white light through the spectroscopes. They are also asked to review data depicting the spectrum of the filters as a graph. The data show light emitted from the green light and passing through the blue filter actually includes some green light. The data show light emitted from the white light and passing through the blue filter actually includes some green and red light. Students add to their Explanations with model and evidence, to illustrate how we "see" infrared images and how we see white light through a blue filter and spectroscope (this includes the viewing infrared images through an IR camera, and the GAM Filter Spectra Data sheet.)

The students observe a spectrum from an incandescent lamp and emission spectrum from a CFL lamp, with spectroscopes and record their observations. They use this data, in combination with Solar and Planetary Atmospheric spectra, to make evidence supported statements about the chemical composition of the atmospheres of the Sun, Mars, Earth and Venus. In preparation for homework and activity on Day 9, students are presented with a CCC guide.

Students are building their understanding toward these DCIs:

PS4.B Electromagnetic Radiation
Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation while the particle model explains other features.

PS4.C Information Technologies and Instrumentation
Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them.

PS4.B Electromagnetic Radiation
Atoms of each element emit and absorb characteristic frequencies of light. These characteristics allow identification of the presence of an element, even in microscopic quantities.

ESS1.A The Universe and Its Stars
The study of stars' light spectra and brightness is used to identify compositional elements of stars. ~~their movements, and their distances from Earth.~~

Middle School PEs/DCIs also relevant to today's work:

MS-PS4-2 Waves and their Applications in Technologies for Information Transfer
Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials. [Clarification statement: Emphasis is on both light and mechanical waves. Examples of models could include drawings, simulations, and written descriptions.]

MS-PS4.B Electromagnetic Radiation
When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light.

Students are building their skills in / understanding of these SEPs and CCCs today:

<u>SEPs</u>

Asking Questions
- Ask questions that can be investigated within the scope of the school laboratory, research facilities, or field (e.g., outdoor environment) with available resources and, when appropriate, frame a hypothesis based on a model or theory.
- Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information.

Developing and Using Models
- Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism, or system in order to select or revise a model that best fits the evidence or design criteria.

Constructing Explanations
- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.

Obtaining, Evaluating, and Communicating Information

- Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

Engaging in Argument from Evidence

- Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence and challenging ideas and conclusions, responding thoughtfully to diverse perspectives, and determining what additional information is required to resolve conflicts.
- Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence.
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CCCs

Patterns

- Empirical evidence is needed to identify patterns.

Day 9: What are some ways of thinking that scientists use when doing research?

Targeted Idea: Scientists may consider one or more Crosscutting Concepts (CCCs) in their approach to a research question. The CCCs are mental tools students can use to help them understand a phenomenon from a scientific point of view.

Overview of Day 9:

Students gather into their groups and discuss the assigned Science Case Study through the lens of the Crosscutting Concepts. In discussion, the students should think about the different approaches taken by the scientists; for example, did they try to determine if an object is changing or stable, or did they look at many objects at once to search for similarities (a pattern)? The groups reference the support document as they discuss their Case Study for the Crosscutting Concepts. Groups then present highlights of the discussion points. This is an opportunity to review all of the Case Studies, discuss the various approaches that scientists may take, and discuss the general question of "What are scientists looking for when they study the Universe at multiple wavelengths? The class then overviews the unit organizer and does a final reflection on the Fancy Cameras Probe before receiving the final assignment.

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<u>CCCs</u>

Patterns
Empirical evidence is needed to identify patterns.

Stability and Change
Much of science deals with constructing explanations of how things change and how they remain stable.

Day 10: How do scientists know what they know?
Overview of Day 10: *In this final day of the Infrared Light and Infrared Astronomy unit, students will present and discuss their final assignment.* **Students are demonstrating their understanding toward these DCIs today:** **PS4.B Electromagnetic Radiation** Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave ~~of changing electric and magnetic fields or as particles called photons~~. The wave model is useful for explaining many features of electromagnetic radiation while the particle model explains other features. **PS4.A Wave Properties** Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory ~~and sent over long distances as a series of wave pulses~~. **PS4.C Information Technologies and Instrumentation** Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them. **PS4.B Electromagnetic Radiation** Atoms of each element emit and absorb characteristic frequencies of light. These characteristics allow identification of the presence of an element, even in microscopic quantities. **ESS1.A The Universe and Its Stars** The study of stars' light spectra and brightness is used to identify compositional elements of stars. ~~their movements, and their distances from Earth.~~

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- Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion.

Engaging in Argument from Evidence

- Evaluate claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments.
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CCCs

Patterns

- Empirical evidence is needed to identify patterns.

Stability and Change

- Much of science deals with constructing explanations of how things change and how they remain stable.

Infrared Light and Infrared Astronomy

Materials and Resources

Materials:
 	
Button battery with black electrical tape on one side, 1 per student
5 mm LEDs , one of each color: white, green, red, blue, per small group,
5 mm LED, one per student for homework
Set of three filters (red, green, blue), per small group
Large sheets of white paper, per small group
Set of colored (ROYGBV) pencils, crayons, or markers, per small group
Black garbage bag
Small sheet of Plexiglas
Various digital cameras (e.g. smart phone cameras, regular digital cameras, webcams)
Various remote controls, 1 per small group
Squares of black plastic (garbage bag)
Color copies of photos, Day 6 Images to Print (suggestion: laminate or put into protective sleeves)
Spectroscope, 1 per student
Photocell detector circuit (multiply this by the number of groups):
    Solar cell
    Amplifier/Speaker
    Audio Cable with 1/8” mini-plug on one end
    Mini-pin X pin adapter
    2 jumper cables with alligator clips on both ends
    9 volt battery for Amplifier/Speaker
    Optional: Fan and/or comb
 	
For classroom demonstrations:
    Overhead projector or slide projector
    Masking tape
    Two pieces of 8” x 10” black construction paper
    Holographic diffraction grating
    IR Camera
    Incandescent lamp
    CFL lamp
    Light base with rheostat
    Optional: transmitter circuit
 	
Handouts:
 	
Fancy Cameras
Sample Student Model A
Case Study Focus Questions Organizer
Unit Graphic Organizer
Science Case Study – Pluto Occultation Visible
Light Spectrum Review
EM Spectrum Review
SOFIA mission lithograph

Science Case Study – Jupiter "First Light" Image
CER Handout
Science Case Study – M2-9 Planetary Nebula
Science Case Study – Milky Way Circumnuclear Ring (CNR)
Orion lithograph
GAM Filter Spectra Data Day 7
Absorption Spectral Data Day 8
Sample Student Model B
Student Support Guide to Examine Science Case Studies for Crosscutting Concepts
Infrared Discovery Matrix
Final Assignment

Resources:

Data projector
Internet access
PowerPoint File
Online videos
Large Graphic Unit Organizer per class
Day 6 Teacher Support Notes
Optional: Additional teacher-chosen resources as appropriate.

Student Misconceptions

On "Invisible Misconceptions" by Sarah Scoles

[Originally published in the smallerquestions.org blog, 2011.]

Libarkin, et al. (2011) published an article in the *Astronomy Education Review* about students', and teachers' misconceptions about light – both visible light and higher- and lower- energy light (such as infrared and ultraviolent) that are invisible to our narrow-minded eye-lenses.

Sensibly, we think of light as something we can see, because light is how we see (although, as I will discuss later, even this idea is not intuitive). But that view of light neglects most of the electromagnetic spectrum.

[Anything] made of photons is light. This includes radio waves, microwaves, visible light, infrared radiation, ultraviolet rays, X-rays, and gamma rays. Just because our eyes are not 200-feet across and we can't see radio waves does not mean that they are not, fundamentally, the same phenomenon as the light that comes out of your lamp.

However, many students and teachers (and clerks and historians and brewmasters and dogs) don't think about light as including the invisible electromagnetic radiation. And that makes sense. After all, you don't often encounter a situation in which your interaction with the world would change if you knew more about the photons zipping around you.

What are the common misconceptions? Let me start by saying that most misconceptions about light are based on semi-logical, commonsense interpretations of experiences. In this study, a student believed that cats' eyes could be seen in complete darkness, because they had seen cats' eyes in, for example, a dark basement. However, they could see the cats' creepy eyes because of ambient light coming from the warm, welcoming, un-creepy upstairs.

So that's one misconception: that objects can be seen in the absence of light. Not true! Put your hand in front of your face in a cave.

For ultraviolet radiation, students believed that it:

- only came from the Sun
- would allow them to see objects if it were shone on them
- was not an electromagnetic wave

For infrared radiation, students believed that:

- they didn't really know what it was at all
- they didn't know why "red" was in the name

Why is it important to know that light is light is light? Because then you possess a more full understanding of the universe, of course. And you will be a happier and more fulfilled person.

Actually, it's important because most of the light spectrum is *not* visible, and many interesting processes that occur in the universe are completely invisible to your pathetic eye-holes. If students don't understand that the X-rays shot out from the accretion disks of black holes are basically the same as their car's headlights, but with more energy, that signals that they do not understand what *any* kind of light truly is--not just that they don't understand what invisible light is.

Astronomy, and chemistry and physics and biology, all require an understanding of the different flavors of photons. To think only of visible light as "light," and not to really understand what "light" is, is pretty discriminatory, and this is the twenty-first century, and we have laws against that.

Let's get some action items: What needs to be done? In order for commonsense misconceptions, which have a firm mental footing, to be dispelled, they have to be confronted directly. That's why studies such as this one are important: you can't address misconceptions if you don't know what they are. False ideas about light will only change if correct ideas are not only presented, but presented in a convincing, inquiry-based way that allows students to reconstruct their worldview to fit the new evidence. Simply saying, "Yo, X-rays are photons, too," is not enough and will not be incorporated into life after the midterm.

REFERENCE

Libarkin, J., Anila, A., Crockett, C., Sadler, P. (2011). Invisible Misconceptions: Student Understanding of Ultraviolet and Infrared Radiation. *Astronomy Education Review*. *10* (1) DOI: 10.3847/AER2011022 Paper No. 153-0.

INVISIBLE MISCONCEPTIONS: STUDENT UNDERSTANDING OF ULTRAVIOLET AND INFRARED RADIATION. ASGHAR, A., LIBARKIN, J. C., & CROCKETT, C. D., Science Education Department, Harvard College Observatory, 60 Garden St. MS-71, Cambridge, MA 02138; Geological Society of America 2001 Annual Meeting conference abstract 26065.

Although student understanding of visible light and the mechanisms associated with vision and color have been extensively researched, preconceptions about non-visible light remain unstudied. In an attempt to ascertain student understanding of ultraviolet and infrared radiation, a questionnaire was disseminated to 300 grade 6-12 students, 25 teachers, and eight scientists. A

discussion with six teachers and in-depth interviews with two scientists and eleven students were also conducted. Widespread preconceptions include: 1) Ultraviolet radiation is a type of visible light coming from the Sun, often described as very bright. A few students also described a connection between ultraviolet light and the ozone layer; 2) Students typically held negative associations with ultraviolet radiation, including its dangerous or deadly potential, especially with relation to skin cancer; 3) Humans can see certain objects in the presence of ultraviolet radiation only; 4) All types of ultraviolet radiation, just like visible light, can penetrate glass; 5) The relationships between visible light, ultraviolet radiation, sunburns, and skin cancer as expressed by students demonstrate confusion. Sunburn is often associated with visible light; and 6) Students did not have a developed concept about infrared radiation. Although students demonstrated knowledge of infrared, for instance the military use of infrared goggles, they did not have a clear understanding of what the term infrared means. In summation, preliminary data indicates that students of all ages have alternative views of light, most of which are based on their perceptual and life experiences. Additionally, teachers and high school physics students, even those in honors physics, have an incomplete view of ultraviolet and infrared radiation.
GSA Annual Meeting, Boston, MA, November 5-8, 2001 Session No. 153: Geoscience Education II: K-12, Teaching Strategies Hynes Convention Center: 310 8:00 AM-12:00 PM, Thursday, November 8, 2001 © 2001 The Geological Society of America (GSA), all rights reserved.

There's More to Light Than Meets the Eye

by Debra Fischer (U.C. Santa Cruz) & George Musser (ASP)

Humpty-Dumpty White Light

It is difficult to do experiments with K12 students which demonstrate that light involves electric and magnetic fields. Most experiments with electromagnetic radiation study the different wavelengths of visible light. Visible light ranges from 400 nanometers (400 billionths of a meter, corresponding to violet light) to 700 nanometer (red light). The classic demonstration is to make a rainbow, or spectrum, out of white light. The Exploratorium's *Science Snackbook* has other demonstrations that involve mixing colors of light.

Experiments with ultraviolet and infrared light reinforce the idea that electromagnetic radiation extends beyond the visible wavelength range. Experiments with ultraviolet light, in particular, are visually impressive. For advanced students, these experiments can show how light reveals the structure of atoms.

Infrared Light and Infrared Astronomy

Fluorescence with ultraviolet light

Light just beyond the violet edge of the visible spectrum is called *ultraviolet* light. As anyone who has been sunburned knows, ultraviolet photons carry *more* energy than the visible variety. You should protect your eyes by wearing UV-absorbing goggles. Another safe alternative is a light-viewing box, available from scientific supply houses or easy to build yourself. In such a box, the UV light is directed away from the eyes toward the black interior of the box, where it is absorbed and safely emitted at longer wavelengths.

The best UV light sources produce both long-wavelength (300-400 nanometer "black light") and short-wavelength (less than 300 nanometer) light. Fluorescent minerals or dyes, which absorb the UV light and emit it as visible light, create a spectacular demonstration. If you switch the UV light from long-wavelength to short-wavelength, you will see a difference in the color (wavelength) of the emitted light. The phenomenon of fluorescence involves the structure of atoms (see Inside an Atom, below).

Blocking UV light

Visible light penetrates glass. We can see it! But UV light does not. Put a fluorescent mineral inside a light box containing a UV source. Then cover the mineral with a glass jar. Is the rock still fluorescent? How quickly does the fluorescence turn off? Does it make a difference if the UV light is long-wavelength or short-wavelength? Other materials, such as a plastic cup or UV-absorbing goggles, can also be tested to see whether they block UV light.

Infrared light

Light just beyond the red edge of the visible spectrum is called *infrared* light. Its photons carry less energy than those of visible light. Our hands are better detectors of IR light than our eyes. Things that emit in the IR feel warm: fire, electric heaters, Sun-baked pavement.

The ASP's Project ASTRO activities handbook, *The Universe at Your Fingertips,* describes an experiment to test whether there is light below the red edge of the visible range. This experiment involves three thermometers, which measure the temperature of the air where the experiment is being done. Break sunlight into a spectrum using a prism and place the thermometers at three points in the spectrum: one in the violet range, one in the yellow range, and one just barely beyond the red end. What do the thermometers read?

In the Dark

It is easy to have misconceptions about a topic as abstract, yet misleadingly common sensical, as light. Drawing out these misconceptions is an important first step to rebuilding students' knowledge. Students commonly have trouble understanding that the visible window is just one small part of a continuum of electromagnetic radiation (see Dreams of Fields, below). The reasons may include:

- X-rays and ultraviolet radiation are hazardous. Visible and infrared are life-saving. So how can they all be the same type of radiation?
- We see visible light. Therefore, it must be different from other radiation we can't see.

Infrared Light and Infrared Astronomy

Another source of confusion is the different results students get when mixing colors of light, as opposed to mixing colors of pigments. Mixing red, green, and blue light makes white light because these are the wavelengths that comprise white light. By contrast, mixing red, green, and blue paints creates black: the absence of light and color. This happens because the red paint absorbs all colors except red light; the green and blue pigments absorb the red. Only when we confront our misconceptions can we can begin to replace them with facts.

Inside an Atom

Light lets us peek inside the atom -- if we know how to look. According to the simple Bohr model, an atom consists of a nucleus around which electrons buzz in orbits. Each electron orbit represents a discrete energy level; the lowest energy levels are those closest to the nucleus. It takes energy to move up to a higher level.

A photon of light provides the energy that an electron needs to climb up a level. If the photon comes close enough to an atom, it can be absorbed by the atom, pushing the electron up (see diagram below). Depending on how much energy the photon contains, the electron might move up one, two, a few, or many energy levels. If the energy is great enough, the electron may go flying out of the atom altogether.

Atoms are good at absorbing energy, but not so good at holding on to it. Within a few billionths of a second, the electron comes bumping back down to a lower level. Each bump is a step from a higher energy orbit to a lower energy one. At each step, the atom must spit out a photon whose energy equals the energy difference between the two levels.

The key thing is that the atom does not have to release a single photon of light. It can, and often does, release light in a whole series of steps. In this case, the total energy from all the steps must equal the energy of the initially absorbed light. Because there are several outgoing photons, each individual photon is lower in energy -- therefore, longer in wavelength -- than the incoming photon. That's how atoms can turn ultraviolet light into visible light.

Emission from an atom: The Bohr model of the atom gives a rough idea of what happens when an atom absorbs or emits light. The Bohr atom looks like a miniature solar system: a nucleus surrounded by electrons in various orbits. In the top case, a photon of short-wavelength light is absorbed by the atom, causing one of its electrons to jump farther away from the nucleus. If this electron falls back down to its original position, it emits a photon of the exact same wavelength. In the bottom case, the electron does not fall to its original position, but rather to an intermediate position. In this case, it emits a photon of lesser energy (longer wavelength).

Dreams of Fields

Opposites attract; like repels. What would pop songs and love sonnets do without the metaphors of magnets? Most of us have played with fridge magnets or compasses; we have seen magnetic poles with the same polarity repel each other and magnetic poles with opposite polarity attract each other. It all depends on the invisible magnetic fields.

Although the concept of a field is abstract, it is easy to envision when you try to push two like magnetic poles together. The magnetic fields penetrate space. They contain energy -- the ability to do work. Slide two magnets with the same polarity toward each other on the surface of a table until they are uncomfortably intimate. If you let go of the magnets, they will scoot away from each other. The energy in the magnetic field is doing work on the magnets.

An analogous situation exists for electric charges. Similar charges repel; opposite charges attract. As with magnetic poles, electric charges are accompanied by electric fields that penetrate space. A negatively charged electron is pulled by the electric field of a positive charge and repelled by the field of a negative charge. Electric fields become even more interesting when they penetrate materials, such as metal wires. There they exert a force that causes the electrons to move through the wire -- the phenomenon of electricity.

But that's not all. Perhaps the most amazing property of electric and magnetic fields is the way they interact with each other. If you take a magnet and plunge it through a loop of wire, an electric field is created. We know an electric field is created because it forces the electrons in the wire to move; we can measure the resulting current. In fact, this is the principle used by electric generators in power stations.

Likewise, moving charges create a magnetic field. To observe this, build a simple circuit with a piece of wire and a battery. Connect one end of the wire to the positive terminal of a 9-volt battery and the other to the negative terminal. Place a compass next to the loop of wire and watch the compass needle move as you connect and disconnect the wire from one of the battery terminals. An important ingredient in both of these experiments is the variation of the fields. Static, unchanging magnetic fields don't spawn electric fields, and steady electric fields don't create magnetic fields.

Once created by a moving magnet or changing electric current, a field can break free of its source. It departs and sails through space like a thought without a thinker. And that is what we call *light.* Light and other forms of electromagnetic radiation contain both electric and magnetic fields that oscillate in strength. A change in the electric field creates a magnetic field. In return, the oscillating magnetic field creates an electric field. The two fields become entwined in a cyclical dance, each one pushing and then being pulled by the other.

Incredibly, no energy is lost in this process. In a vacuum, an electromagnetic wave would travel forever without losing any energy. It disappears only when it is absorbed by matter -- for instance, a hand that intercepts sunlight and becomes warm. This process of transporting energy is called *radiation.*

At the time this article was written, Debra Fischer was an astronomy graduate student at the University of California, Santa Cruz. She is now a professor at Yale University.

