Open Source Radio Telescopes

Loop Antenna Lesson Plan

Correlated with West Virginia Science Content Standards

Version 1.0

Written by Ellie White

A Note to Teachers

As science teachers, you have an extremely powerful influence on our world – you are inspiring and training the next generation of young minds to approach the world around them with curiosity and interest in how things work and why things are the way they are. The goal of Open Source Radio Telescopes (OSRT) is to help you in your mission to make science exciting, fun, and accessible to your students while teaching them important concepts they'll need to succeed in their education, their future jobs, and their daily lives. As scientists, engineers, educators, and students in the field of Radio Astronomy, we've seen how astronomy has the power to engage and inspire students and people of all ages to get involved in the quest to understand our Universe – and we have sought to foster this sense of wonder by creating lesson plans and instructions to allow students to build their own radio telescopes so that they can uncover the secrets of the invisible universe for themselves, all while learning extremely important concepts about how the Earth and its systems work, what it means to be an engineer, how computers can be used in science and in our jobs, and how science and technology profoundly impact our everyday lives. At OSRT, we hope that by giving you the resources to introduce your students to these vital STEM concepts through the exciting lens of radio astronomy, we can work with you to help students find their passions and gain the confidence and critical thinking skills they'll need to pursue careers in STEM and related fields. I hope you and your students enjoy learning about radio astronomy and making discoveries about our Universe along the way. Thank you for all you do for your students and for the future of our children and our world – with the tools of science and technology by our side, we can change the world together. Wishing you the best of luck on your journey into the invisible cosmos, and if I can be of assistance in any way (answering questions, providing information, etc.) please don't hesitate to contact me at white728@marshall.edu.

Ellie White

14 October 2018

Co-Director, Open Source Radio Telescopes

Acknowledgements

This lesson plan has been long in the making, and owes its existence to a number of talented, kind, and helpful people who I've had the privilege and pleasure of working with over the past months and years that I've been a part of Open Source Radio Telescope's mission. I'd like to thank and recognize the many mentors, coworkers, and fellow radio astronomy enthusiasts who have contributed significantly to the development of this lesson plan and to OSRT's evolution in general.

Many thanks to:

Deana White, for her detailed, thorough, and insightful edits and review of this lesson plan, and for her invaluable suggestions and encouragement throughout the course of this project.

Dr. Mindy Backus, for her insights and for coordinating the pilot program to test these lesson plans in WV classrooms.

J.D. Nelson, Bob Simon, and Steve White for their contributions to the design of the loop antenna project and the development of the loop antenna kits.

Sue Ann Heatherly, for her wisdom and for providing the assessment tool to evaluate the effectiveness of these lesson plans.

Christine Plumley, Mike Holstine, and Dr. Karen O'Neil for their support in bringing the loop antenna kits to fruition.

Dave Sheehan and Dr. Jon Saken of Marshall University for their support in loaning supplies to allow students and teachers to get the most out of this learning experience.

Sophie Knudsen, for her inspiration and contributions to OSRT's goals.

Dr. Glen Langston, Marcus Leech, Dr. Kevin Bandura, Pranav Sanghavi, and Eve Klopf for their dedication to bringing radio astronomy and STEM education to students of all ages.

Evan Smith, Co-Director of OSRT, for the dedication and effort he has put into bringing OSRT into being.

Dr. Richard Prestage, Co-Director and original founder of OSRT, for his vision in bringing OSRT to fruition. I cannot thank him enough for his years of mentorship and for teaching me that "there is no such thing as a stupid question."

And to our partners and sponsors:

NooElec, for their generous donation of electronics equipment in support of OSRT's cause.

The Green Bank Observatory, for coordinating the production of the loop antenna circuit boards and kits.

Marshall University, for collaborating on a pilot program to test the loop antenna lesson plans and kits in elementary through high-school science classrooms.

<table>
<tr><th colspan="3">LOOP ANTENNA LESSON PLAN 1</th></tr>
<tr><td>Content Area:
Physical Science</td><td>Lesson Topic:
Light and Sound Waves and Their Properties</td><td>Length (timing) of Lesson:
40 minutes</td></tr>
<tr><th colspan="3">INSTRUCTIONAL OUTCOMES</th></tr>
<tr><td colspan="3">WV Standard(s):

S.4.GS.6
S.6.PS.1
S.6-8.L.4,
S.HS.PS.20
S.9-10.L.4
S.11-12.L.4
S.HS.P.19</td></tr>
<tr><td colspan="3">Learning Objective(s):

Students will be able to understand the difference between light waves and sound waves. They should also be able to understand and diagram the components of a wave (frequency, wavelength, amplitude, energy, wave speed), and the relationships between each of these components.</td></tr>
<tr><td colspan="3">Formative Assessment:

Students' contributions to class discussion about the topic (asking insightful questions, giving answers or making comments that suggest an understanding of the material), the quality and accuracy of the wave diagrams they create will provide a measure of students' mastery of the subject.</td></tr>
<tr><th colspan="3">PREPARATION</th></tr>
<tr><td colspan="3">Materials/Resources:
You will need:
- A Slinky spring toy
- Wave diagram: Definition of a Wave
- Construction paper
- Colored pencils, crayons, and/or markers
- String
- Glue</td></tr>
</table>

- Loop Antenna Lesson Plan Overview (incl. in Loop Antenna Lesson Plan Attachment A)
- Reference on types of waves (for instructor's use): Categories of Waves
- Reference on parts of a wave (for instructor's use): The Anatomy of a Wave
- Reference on the wave equation (for instructor's use): The Wave Equation

INSTRUCTIONAL PROCEDURES

*Highlight **BLUE** for materials/**GREEN** for technology
*Highlight **PINK** for instructional strategies
*Highlight **YELLOW** for discipline-specific academic language/vocabulary

		Procedural Steps	Questions	Differentiated Instruction
Activating Strategy/ Introduction	Time 10 mins	1. To start off the unit, go over the Overview provided with the lesson plan with your students. 2. Introduce the concept of a wave by discussing questions 1-3 (listed to the right) with your class. 2. After going through these questions, further discuss the differences between sound and light waves. Explain that in addition to sound waves requiring a medium (a material, like air) while light waves don't, sound waves move differently from light waves. Explain to students that light waves wiggle side to side, while sound waves travel forward or backward. 3. To demonstrate this difference, ask for two student volunteers to do a hands-on activity. Lay the Slinky on its side on the floor and have one student hold each end. Have them hold the ends of the Slinky far enough apart that there is some slight tension in the spring. Then, making sure that the rest of your class can see the Slinky's movements, have one of the two students wiggle their end of the Slinky from left to right, at a speed such that a snakelike curve	1. What do you think a wave is? *Suggested answers: something that moves up and down, something that carries energy.* 2. What types of waves can you think of? *Suggested answers: Ocean waves, sound waves, light waves, waves of material, as in a flag, etc.* 3. What do you think is the difference between a light wave and a sound wave? (Guide students by asking if light can travel in outer space, then ask if sound can travel in space). *Suggested answers: Sound requires a medium (like air) to travel in, while light can travel in a vacuum, where there's nothing.* 4. What difference do you notice between the transverse waves and the longitudinal waves that you	It is up to the instructor to assess the classroom and determine how to adapt the lesson to best reach all of her/his students.

		travels through the spring. Explain to students that this is an example of a transverse wave. Next, have one of the two students give the Slinky repeated pushes toward the other student, which should cause the Slinky to undergo repeated compressions. Tell students that this is an example of a longitudinal wave (refer to Categories of Waves for helpful diagrams/definitions of transverse and longitudinal waves if need be). Now, discuss question 4 with your students and explain that while the particles in a transverse wave wiggle in a direction perpendicular (at right angles) to the direction that the wave is travelling in, while the particles in a longitudinal wave move back and forth in the same direction as the wave is travelling in. Emphasize that light is considered a transverse wave, while sound is a longitudinal wave. Also explain to students that a light wave is made of energy, while a sound wave is created by compressions of air similar to the compressions you saw in the Slinky.	demonstrated with the Slinky? (Possibly prompt students with the leading question, does the wave wiggle in the same direction as it travels?) *Suggested answers: For the transverse wave, the Slinky wiggles in a direction perpendicular to the direction of motion, while for the longitudinal wave, the Slinky wiggles in the same direction of motion)*	
Core Instruction	Time 20 mins	1. Explain to students that in this lesson, we will be focusing on the properties of light waves because understanding light waves will be useful later on in this unit. Discuss question 1, then draw or show a diagram of a wave (similar to the wave diagram shown here: Definition of a Wave). 2. Explain the components of a wave as follows, being sure to point to the appropriate part of the wave on the diagram as you go: - A peak of a wave is where the wave reaches its maximum height in its cycle. - A wave's trough is where the wave reaches minimum height in its cycle. - Wavelength is the distance from one point in the wave's cycle to the same point in its next cycle; for example, the	1. What did the transverse wave look like? *Suggested answers: a snake, an S, wiggly, lumpy, etc.* 2. Does light have a speed, or does it just travel instantaneously? If it does have a speed, how fast do you think it travels? *Suggested answers: Light has a speed. It travels at ~300 million meters per second, or ~671 million miles per hour. Tell students it would take us about 1.5 seconds to get to the Moon from Earth if we could travel at light speed.*	

		distance between two peaks is one wavelength, as is the distance between two troughs. - Amplitude is the distance from the middle of the wave to a peak or trough; in other words, the amplitude is half the distance from the peak to the trough. The greater the amplitude a wave has, the more energy it carries. - The frequency of a wave is the number of waves that passes by a point in one second. Frequency is measured in Hertz (Hz); 1 Hz means that one wave passes per second, while 10 Hz means that ten waves pass per second. - The period of a wave is the amount of time it takes for a wave to complete one cycle (a cycle is the portion of a wave between two crests or troughs). It is the reciprocal of the frequency (1/frequency), and is measured in seconds. \\ -The velocity of a wave is how fast the wave travels from one point to another. 3. Explain to students that in light waves, there is a relationship between wavelength, frequency, and the speed of light. Discuss questions 2 and 3 with your class. Then explain that as wavelength gets bigger, frequency gets smaller, and vice versa. This means that wavelength and frequency have an inverse relationship, which can be seen in the equation: $f = c / \lambda$ $\lambda = c / f$ (where f = frequency, λ = wavelength, and c = the speed of light). Work through a few simple examples of this formula to show students how it works, like:	3. Is the speed of light always the same? *Suggested answer: No. Light travels at a constant speed in a vacuum (like outer space), but when it has to travel through materials it gets slowed down.*	

		a) If I know that the speed of light is 300,000,000 meters per second and the wavelength of light is 150,000,000 meters, what is the frequency? (2 Hz) b) If we know that the speed of light is 300,000,000 meters per second and the frequency is 300 Hz, what is the wavelength? (1,000,000 meters) 4. Have students put their new knowledge to use by creating a diagram of a wave. Display the diagram of a wave that you showed earlier for reference, and provide construction paper, writing instruments, glue, and string to your class. Instruct them to glue a length of string onto a sheet of construction paper in the form of a wave, and use the writing instruments to label the parts of the wave discussed earlier in the lesson. Encourage them to decorate their diagrams creatively, while making sure to accurately represent a wave diagram. Later, once the diagrams have dried, you may decide to display them in the classroom if possible as a reminder of how waves work.		
Closure	Time 10 mins	Before the end of class, perhaps recap the main points covered, make sure to answer any remaining questions students have, and encourage them to read more about waves if they are interested in doing so. Unless students are not finished with their diagrams, have them leave the diagrams on their desks or in some designated area to dry.		

Contingency	Time	If students have not completed their wave diagrams, encourage them to finish at home and bring them to class later in the week. On the other hand, if you have extra time, perhaps allow all of your students to take turns pairing up to try the Slinky experiment instead of just one pair.		

LOOP ANTENNA LESSON PLAN 2		
Content Area: Physical Science	Lesson Topic: The Electromagnetic Spectrum	Length (timing) of Lesson: ~50 mins

INSTRUCTIONAL OUTCOMES

WV Standard(s):

S.6-8.L.3, S.6-8.L.4, S.6-8.L.12, S.6-8.L.13, **S.6-8.L.16**, **S.6-8.L.19**
S.9-10.L.3, **S.9-10.L.4**, **S.9-10.L.12**, **S.9-10.L.13**, **S.9-10.L.16**, **S.9-10.L.19**
S.11-12.L.3, S.11-12.L.4, S.11-12.L.12, S.11-12.L.13, S.11-12.L.16, S.11-12.L.19

Learning Objective(s):

Students will be able to name the different types of light that make up the electromagnetic spectrum (radio, infrared, optical, UV, X-rays, and gamma-rays), and should understand how these types of radiation come into play in everyday life. They should learn about natural and artificial sources of these different types of radiation. Students should also be able to rank the types of light that make up the electromagnetic spectrum by their energy – e.g., radio waves have the lowest energy while gamma-rays have the highest energy.

Formative Assessment:

Students' involvement in class discussion about the topic (asking insightful questions, giving answers or making comments that suggest an understanding of the material), their contributions to the electromagnetic spectrum map, and their participation in the infrared experiment will provide a measure of students' mastery of the subject.

PREPARATION

Materials/Resources:
For the electromagnetic spectrum map, you will need:
- A 3'x7' sheet of white butcher paper
- Images of an optical light spectrum and various items that emit or detect different types of radiation, printed on cardstock (incl. in Loop Antenna Lesson Plan Attachment B)
- Key that explains which of the above images go where (incl. in Loop Antenna Lesson Plan Attachment A)
- Other similar images collected from magazines or the Internet by the instructor (optional)

- Yardstick
- Scissors
- Double-stick tape
- Template 1 (incl. in Loop Antenna Lesson Plan Attachment A)

For the electromagnetic spectrum map, you may want to do some preparation beforehand, and draw a scale for the spectrum on the butcher paper. To do this, follow the template included in Attachment A, and draw the lines onto the butcher paper as shown, dividing the horizontal line into 6 roughly equal parts using the yardstick. Do not write the types of radiation (radio, microwaves, etc.) on the paper yet, though, as this will be done during class. Use double-stick tape to affix a cardstock printout of the visible light spectrum (included in Attachment B) in the center of the butcher paper as indicated on the template. Before class you may want to tape this paper up to your whiteboard or some other prominent location that students can see easily for demonstration purposes. In addition, you will want to cut out the items from Attachment B that you printed on cardstock as indicated above, then keep the cut-out items handy for the lesson.

For the John Herschel infrared experiment, you will need:

- Lab report forms, 1 for each student (incl. in Loop Antenna Lesson Plan Attachment A)
- A shoebox
- A white sheet of paper
- 3 mercury thermometers
- Black construction paper
- A prism
- Tape

For the infrared experiment, you may wish to prep the experiment prior to class to save time for discussion with students. To prepare this experiment, refer to the images found here: http://coolcosmos.ipac.caltech.edu/cosmic_classroom/classroom_activities/herschel_example.html. As you can see, you will need to tape a white sheet of paper to the inside bottom of the shoebox. You may also want to wrap the bulb ends of the thermometers in black construction paper to increase heat absorption (note that it is better not to paint the ends of the thermometers' bulbs as indicated in the link so that the thermometers can be reused later) and then tape the thermometers to each other (see example in the link above) so they are as close together as possible and will appropriately span the length of the spectrum produced by the prism. The rest of the experiment procedures will need to be done with the class, as explained below. Make sure that during class prior to doing this experiment, the thermometers are in a shaded area of the classroom so they will all read at the same temperature when you begin the experiment.

INSTRUCTIONAL PROCEDURES

*****Highlight **BLUE** for materials/**GREEN** for technology
*Highlight **PINK** for instructional strategies
*Highlight **YELLOW** for discipline-specific academic language/vocabulary

		Procedural Steps	Questions	Differentiated Instruction
Activating Strategy/ Introduction	Time 20 mins	1. Begin by discussing questions 1 and 2 with students. Then remind them that in our last lesson, we learned that light can be described as a wave. Now go over questions 3 and 4 with class. 2. After discussing these questions with your students, emphasize to them that yes, in fact, there are invisible colors – invisible types of light that extend beyond the red and violet sides of the visible spectrum, and that these types of light just have wavelengths that our eyes can't detect. Now, using the prepared poster with the visible light spectrum in the middle as a guide, discuss question 5 with your students. As they give suggestions for types of invisible light, guide them toward the correct location of where each kind of light belongs in the spectrum (refer to Template 1). Make sure that by the end of the discussion you have added radio, microwaves, infrared, ultraviolet, x-rays, and gamma rays to the poster in the proper order as shown in Template 1. 3. Now emphasize to students that as you go from left to right on the spectrum graph, the wavelength goes from big to small, while the frequency goes from small to big. Remind students that higher frequency means more energy, and ask them what they think happens to the energy in the electromagnetic spectrum as you go from left to right – i.e., are radio waves or gamma rays more energetic? Explain that since the types of radiation to the right of the graph have higher frequencies, they also have more energy. Therefore, UV, X-rays, and gamma rays are	1. Have you ever seen a rainbow? If so, where did you see it? *Answer is open-ended.* 2. What do you think a rainbow is? What does it come from? *Suggested answer: Rainbows come from splitting up white light into different colors*. 3. Why are the colors of the rainbow all different? If necessary, prompt students by asking, what is light made of? Could there be something different about blue waves of light versus red waves of light? What are the parts of a light wave? *Suggested answer: Colors are different because different colors of light have different wavelengths (or frequencies, either is correct).* 4. Do you think there could be colors that we can't see, extending from the red and violet ends of the spectrum? *Suggested answer: Yes* 5. Can you name any types of invisible light? Suggested answers: radio, microwave, infrared, ultraviolet, x-rays, gamma-rays. As students name them, ask them where they think each of these types of light falls relative to the	It is up to the instructor to assess the classroom and determine how to adapt the lesson to best reach all of her/his students.

		more energetic than radio waves, microwaves, and infrared light. 4. To reinforce this learning with a hands-on activity, retrieve the cardstock pictures you cut out beforehand. Now, (referring to the provided key), hold up one of the cardstock images and invite one of your students to come to the board and tell you where they think this item belongs on the electromagnetic spectrum. Once they hit upon the right answer, have them attach their picture to the right section of the spectrum with double-stick tape. Repeat this exercise with each of your students, going through the room until you have used up all of your images.	visible spectrum – to the left of red, or to the right of violet, etc.)	
Core Instruction	Time 20 mins	1. Now that you have explored what the electromagnetic spectrum looks like, go over question 1 with your students. Tell them that we are now going to repeat an experiment done by a famous scientist named John Herschel, who lived during the 1800s and was the first person to ever find out that there are types of light that we can't see. To give a little extra historical background, you could explain that John Herschel was the son of William Herschel and the nephew of Caroline Herschel, a brother and sister duo of astronomers who made great contributions to science, including discovering several comets. Now discuss question 2 with your students. 2. Pass out lab report forms to each of your students and explain that in this experiment, we are going to be creating a rainbow with a prism and using thermometers to measure the temperatures of the blue end of the spectrum, the red end of the spectrum, and the space right next to the red end of the spectrum. Explain that in science, a hypothesis is a guess that scientists make based on what	1. How do you think scientists know that there are other kinds of light that aren't visible? *Suggested answer: By doing experiments!* 2. What do you think it would have been like to be the first person to ever realize that there are types of light that we just can't see? *Suggested answers: open-ended.*	

		they already know, and the purpose of an experiment is to prove or disprove that hypothesis and learn something new about the world in the process. Have students write down what they think will happen in this experiment. 3. Instructing students to keep their lab reports and pencils with them, have them follow you outside to a sunny area where you can perform the experiment. Set the shoebox on the ground and hold the prism so that the edge is touching the cardboard box. Rotate the box and prism until you are able to cast a rainbow on the inside of the box. Once you have achieved this, tape the prism in place. Then, place the three taped-together thermometers inside the box so that one thermometer lines up with the blue light, one lines up with the red, and one is adjacent to the red but just outside the rainbow itself. (Note that if your thermometers are too long to fit in a shoebox, you can just set them on the ground on a white sheet of construction paper and hold the prism in position so that it casts the rainbow onto them.) Leave this setup alone for 1-5 minutes to let the thermometers adjust; while this is happening, instruct students to summarize the steps of this experiment in the "Methods" section of their lab report. Now have each of your students inspect the thermometers (leaving them in place) and write down the temperature for each one in the "Results" section of the lab report (labelling them "Blue Thermometer, Red Thermometer, Mystery Thermometer"). Now return to the classroom to discuss your results.		
Closure	Time 10 mins	1. Have students compare their results with their hypotheses. The experiment should have resulted with the blue thermometer having the lowest temperature, the red thermometer having a slightly higher temperature, and the mystery thermometer having the highest temperature. If		

		this was not the case, explain to students that this was what was supposed to happen, but in the real world experiments are fraught with error which can mean that results don't always turn out perfectly. Emphasize that this is not a bad thing, it simply gives us ideas about how we can improve our observations. Discuss with students what we could have done to make this experiment better or more accurate. 2. Next, explain to students that the result (or expected result) of the mystery thermometer having the highest temperature indicates that there is another type of light we cannot see hitting the thermometer in this region, and that this type of light is infrared. 3. Have students write down their conclusions from the experiment in their lab report's "Conclusions" section – depending on the outcome of the experiment, it could be about what could have been done differently to obtain better results, or it could be about how this experiment proves the existence of invisible light, or both. 4. Finally, tell class that next week we will be exploring how these different invisible kinds of light have an effect on our understanding of the Universe. After answering any remaining questions, encourage them to be on the lookout for examples of how invisible light appears in their everyday lives.		
Contingency	Time	If students can't finish their lab report conclusions during the remaining minutes of class, have them bring the reports		

		home to complete and bring them in to class later in the week. If it is rainy/cloudy, save the John Herschel experiment for another day and perhaps spend more time going over the historical backdrop of Herschel's time period (the 1800's) and what was going on in other fields of science at that time.		

LOOP ANTENNA LESSON PLAN 3		
Content Area: Physical Science	Lesson Topic: Astronomy Across the Spectrum	Length (timing) of Lesson: ~45 mins
INSTRUCTIONAL OUTCOMES		
WV Standard(s): **S.6.PS.2** **S.6-8.L.2**, **S.6-8.L.4** **S.9-10.L.2**, **S.9-10.L.4** **S.HS.PS.24** **S.11-12.L.2**, **S.11-12.L.4** **S.HS.P.23**		
Learning Objective(s): Students will learn about the astronomical objects that emit different kinds of light and the kinds of telescopes (optical, radio, x-ray, etc.) that can be used to study them.		
Formative Assessment: Students' involvement in class discussion about the topic (asking insightful questions, giving answers or making comments that suggest an understanding of the material), their contributions to the further development of the electromagnetic spectrum map, and their participation in the astronomy matching game activity will provide a measure of students' mastery of the subject.		
PREPARATION		
Materials/Resources: For the matching game and the continued work on the electromagnetic spectrum map, you will need:		

- Double-sided tape
- Images of different kinds of telescopes and astronomical objects printed on cardstock (incl. in Loop Antenna Lesson Plan Attachment B)
- Key that explains which of the above images go where (incl. in Loop Antenna Lesson Plan Attachment A)
- Scissors
- Electromagnetic Spectrum map from Lesson 2
- Video about astronomy across the spectrum: https://www.youtube.com/watch?v=XpjlY-KU0Eg
- Projection device or screen to show video
- Optional reference material (for instructor's use): https://imagine.gsfc.nasa.gov/science/toolbox/multiwavelength1.html

To prepare for Lesson 3, you may wish to cut out the images of astronomical objects and telescopes from the cardstock prior to class to save time.

INSTRUCTIONAL PROCEDURES

*Highlight **BLUE** for materials/**GREEN** for technology
*Highlight **PINK** for instructional strategies
*Highlight **YELLOW** for discipline-specific academic language/vocabulary

		Procedural Steps	Questions	Differentiated Instruction
Activating Strategy/ Introduction	Time 10 mins	1. Begin Lesson 3 by briefly recapping what was covered in Lesson 2 – remind students that in our last lesson we learned that many objects on Earth emit invisible light, and that this invisible light can show us things that visible light can't. Now discuss questions 1-2 with your students to get them warmed up to the subject. 2. Making sure that the Electromagnetic Spectrum map is still prominently displayed in your classroom, discuss question 3 with your students. Now tell them to think about what it means if the energy of an electromagnetic wave gets higher, and discuss question 4. 3. Now link these concepts together by telling students that the higher the frequency of the electromagnetic radiation	1. Do you think that objects in space (like galaxies, planets, etc.) only give off visible light? *Suggested answer: No* 2. Do you think we could learn more about the Universe by observing it in the other kinds of light that we learned about in our last lesson? What do you think we could learn by observing these other kinds of light? *Suggested answer: Yes (open-ended). Tell students that today we are going to learn about the answer to this question.*	It is up to the instructor to assess the classroom and determine how to adapt the lesson to best reach all of her/his students.

		that an astronomical object emits, the hotter and more energetic it is. To reinforce this concept, discuss question 5 with students. 5. Emphasize to students that since objects at different frequencies have different temperatures, this means that if we want to learn about objects that are hot, cold, and in-between, we must observe space at all of these different frequencies to get a complete understanding of our Universe. Tell them that when astronomers use lots of different types of electromagnetic radiation to observe the Universe, they are doing something called Multi-Wavelength Astronomy – they are looking at astronomical objects in several different wavelengths (which is the same thing as saying they are looking at several different frequencies).	3. What do you remember about what happens when the frequency of electromagnetic radiation gets bigger and wavelength gets smaller? (If necessary, prompt students by asking, what happens to the energy? *Suggested answer: The energy of the radiation gets higher.* 4. What happens to the temperature of an object when the energy gets higher? *Suggested answer: it gets hotter*. 5. What kind of light do you think the coldest objects in outer space emit? What about the hottest objects? *Suggested answers: Coldest objects emit radio waves, hottest objects emit gamma rays.*	
Core Instruction	Time 25 mins	1. To build on the concepts just discussed, tell students that you are now going to play a game. Tell them it will be similar to the exercise you did in the previous lesson to figure out where different things belonged on the spectrum, but today you will do it in a more exciting way. Explain to them that the rules of this game are that you (the teacher) will hold up an image of an astronomical object or telescope and will tell them something about it. The students' job is to be the first "scientist" to properly classify the object and figure out where it belongs on the spectrum. Divide the room up into teams (however many seems appropriate to your class size) and tell each team to come up with an astronomy-inspired name. Write the team names on the whiteboard (or in some other prominent		

		location if the map is covering the whiteboard), and tell students that you will be keeping score. The rules are that the first student to raise their hand gets to call out where they think it belongs, and if they are correct, their team gets a point and they get to stick the object to the map in its proper location. If not, then another student gets a chance to give their suggestion. 2. In playing this game with students, refer to the key for hints to give them about what each astronomical object is like. Read Hint #1 first, and if no students raise their hands, then read the other hint(s). If necessary, repeat the idea that hotter and more energetic objects give off higher frequency radiation, and remind them that higher frequency radiation is to the right of the map while low frequency radiation is to the left of the map. When students do raise their hands, call on the student that raised her/his hand first and invite her/him to tell the class where they think the object belongs. Note that if a few students are dominating the discussion, after giving them a few chances to answer questions make sure to include quieter students and encourage them to participate as well. 3. At the end of the game (after all of the cards have been taped to the map), tally up all the points and announce the team rankings. Congratulate all students for their great contributions to multi-wavelength astronomy. Before moving on, emphasize one other important point to students – while radio waves and microwaves are two different parts of the spectrum, when scientists refer to “radio astronomy” they often lump microwaves and radio waves into the same categorty. So if you hear “radio astronomy,” think “radio and microwave astronomy”!		

Closure	Time 10 mins	1. Now that you have done this exercise, reinforce what you have learned today by watching the linked video, which talks about multi-wavelength astronomy and the various telescopes that are used to observe in the different parts of the electromagnetic spectrum, with a focus on radio astronomy. 2. If students are confused about the last part of the video (which talks about how radio telescopes work), tell them that you will be learning more about this in coming lessons and try to answer any questions they have about this, encouraging them to look up the answer if they want to learn more. 3. Close class by reminding them that the important thing to take away from today is that Multi-Wavelength Astronomy means looking at objects in the Cosmos in many different parts of the electromagnetic spectrum. Tell them that we will soon focus on learning about how one particular part of the electromagnetic spectrum is used to make great astronomical discoveries: radio waves.		
Contingency	Time	If the rules of the game above do not seem well-suited to your classroom, feel free to make adaptations as you see fit (i.e. playing as individuals instead of as teams if your classroom is very small, etc.). Other adaptations can be made as necessary.		

<table>
<tr><th colspan="3">LOOP ANTENNA LESSON PLAN 4</th></tr>
<tr><td>Content Area:
Physical Science</td><td>Lesson Topic:
History of Radio Astronomy</td><td>Length (timing) of Lesson:
~50 mins</td></tr>
<tr><th colspan="3">INSTRUCTIONAL OUTCOMES</th></tr>
<tr><td colspan="3">WV Standard(s):
S.6-8.L.4, S.6-8.L.12, S.6-8.L.13, S.6-8.L.18, S.6-8.L.19
S.9-10.L.4, S.9-10.L.12, S.9-10.L.13, S.9-10.L.18, S.9-10.L.19
S.HS.PS.24
S.11-12.L.4, S.11-12.L.12, S.11-12.L.13, S.11-12.L.18, S.11-12.L.19
S.HS.P.23</td></tr>
<tr><td colspan="3">Learning Objective(s):

Students will learn about Karl Jansky’s discovery of cosmic radio waves, and about the contributions of pioneer radio astronomers Grote Reber and Ruby Payne-Scott. Students will also learn about the major role of West Virginia’s Green Bank Observatory in the history of radio astronomy.</td></tr>
<tr><td colspan="3">Formative Assessment:

Students’ involvement in class discussion about the topic (asking insightful questions, giving answers or making comments that suggest an understanding of the material) and the quality of their radio-astronomy news articles will provide a measure of students’ mastery of the subject.</td></tr>
<tr><th colspan="3">PREPARATION</th></tr>
<tr><td colspan="3">Materials/Resources:
- Access to computers for students to research radio-astronomy related topics
- Slides with images of early radio astronomy history (incl. in Loop Antenna Lesson Plan Attachment C)
- Link to timeline of the Green Bank Observatory: https://greenbankobservatory.org/timeline-green-bank-observatory/
- Projector or screen to display images and timeline</td></tr>
<tr><th colspan="3">INSTRUCTIONAL PROCEDURES</th></tr>
<tr><td colspan="3">*Highlight <u>BLUE</u> for materials/<u>GREEN</u> for technology
*Highlight <u>PINK</u> for instructional strategies</td></tr>
</table>

*Highlight **YELLOW** for discipline-specific academic language/vocabulary				
		Procedural Steps	**Questions**	**Differentiated Instruction**
Activating Strategy/ Introduction	Time 20 mins	1. Introduce this lesson by reminding students that in our last lesson, we learned that astronomers can discover a lot about the universe by looking at celestial objects using different types of electromagnetic radiation. Discuss question 1 with students. Explain to students that for a very long time, astronomers only observed what they could see with the naked eye or with an optical telescope, and only in recent years have astronomers been able to investigate other forms of light from space. 2. For steps 2-4, project the included slides on the wall for students to see. Now, tell students the story of Karl Jansky. Karl Guthe Jansky was an engineer at a telephone company called Bell Labs in the early 1930's, and he was working on radio communications. In his work, he had been assigned to investigate a problem: there was a lot of static in the signals the company was receiving. So Jansky built his own antenna, nicknamed "Jansky's Merry-Go-Round" because it turned around on Model-T Ford wheels (here, pull up the timeline from the Green Bank Observatory website and flip to the slide about Karl Jansky, projecting this so that students can see it). With this funny-looking antenna he was able to figure out that while some of the static he was seeing came from thunderstorms, it took him a long time to figure out what the rest of the static was coming from. Discuss questions 2-4 with your students. 3. Since Karl Jansky was an engineer, his job wasn't to investigate radio signals from space, his job was to improve radio communications. So it was up to others to pick up	1. Do you think astronomers always knew that they could observe the Universe in invisible light? Why or why not? *Suggested answers: No, because they didn't have the technology, or they didn't know the invisible light was there, etc.* 2. Where do you think the strange signal was coming from? *Suggested answers: outer space, the Milky Way, specifically.* 3. How do you think Jansky knew that these signals were coming from the Milky Way? If necessary, prompt students by asking, how long does it take the Earth to turn so that if we looked at the sky, we'd see the same point again? *Suggested answer: He knew that these signals were coming from the Milky Way because their pattern repeated every ~24 hours.* 4. If you were Karl Jansky, how would you feel if you were the first person to ever discover radio waves coming from space? *Suggested answers: open-ended.*	It is up to the instructor to assess the classroom and determine how to adapt the lesson to best reach all of her/his students.

		where he left off. In 1937, one young, resourceful electrical engineer named Grote Reber read about Jansky's discovery of cosmic radio waves and found that no one was doing any follow-up work to study this strange new invisible universe. So, Reber took it upon himself to build a giant radio dish in his backyard. He did all of the construction himself and paid for the materials out of his own pocket, simply because he was curious and determined to learn something new about the Universe around him. Reber made the first radio maps of the Sun and of the Milky Way, and for about 10 years he was the only radio astronomer in the world. 4. Explain to students that radio astronomy really took off during and after World War II. Discuss question 5 with students. Then introduce them to another pioneer of radio astronomy: Ruby Payne-Scott. Tell students that Payne-Scott was the world's first female radio astronomer; she worked as a research physicist in Australia during WWII and participated heavily in many military projects, but perhaps what she is most remembered for are her contributions to the field of astronomy. Payne-Scott discovered two new types of solar bursts and played a major role in the world's first astronomical radio interferometer measurements (an astronomical radio interferometer is a radio telescope that instead of being made of one antenna, is composed of several antennas working together). Payne-Scott's work paved the way for the future of solar research and technology in radio astronomy, but she was not fully recognized for her work at the time. In fact, Payne-Scott lost her research job because in Australia at the time, married women were not allowed to work in these fields, and when inspectors discovered that she was secretly married, she was forced to resign and give up her retirement earnings. Discuss questions 6-7 with students.	5. Why do you think radio astronomy really took off during WWII? What kind of technology from the war do you think might have been applied to radio astronomy? *Suggested answers: Radio astronomy took off because lots of new technology was being developed during the war; radar technology in particular was applicable to radio astronomy.* 6. If you were Ruby Payne-Scott, would you have persevered despite the injustices women in the 20th century faced when they pursued careers in male-dominant fields? What do you think inspired Payne-Scott to keep going despite the many setbacks and frustrations she faced? *Suggested answers: open-ended. She cared about her work, she was curious about how the Universe works, she liked a challenge.* 7. What kind of impact do you think Payne-Scott's discovery of different types of solar bursts had on science? *Suggested answers: we now more fully understand the inner workings of the Sun.* 8. In Green Bank in the year 1960, Frank Drake performed the first-ever scientific search for intelligent extraterrestrial life using Green Bank's	

		5. Now pull up the link to the timeline on the Green Bank Observatory's website and project it for the students to see. Before going through the timeline's slides, explain to students that the Green Bank Observatory is a radio astronomy observatory located in our own state, in Pocahontas County near the border between Virginia and West Virginia. Tell them that the Green Bank Observatory was the first official radio astronomy observatory in the United States, then begin to flip through the timeline slides. You do not need to read all of them, as there are several, but discuss any slides you think your students will find interesting. One particular slide that might warrant further discussion would be the slide labeled "Project Ozma," which discusses the first ever scientific search for intelligent extraterrestrial life (extraterrestrial life means life that inhabits other worlds besides Earth). If you go over this slide, be sure to discuss question 8 with students.	oldest telescope, the 85-foot Tatel Telescope. Do you think there is intelligent life elsewhere? Why or why not? *Suggested answers: open-ended.*	
Core Instruction	Time 25 mins	1. After going through this material, tell students that we are now going to do an activity. Ask each student to select a person or discovery in the history of radio astronomy to focus on, and tell them that they are going to take the role of a reporter writing a news article about this discovery or person. If students are not sure which person / discovery to choose, invite them to flip through the slides on the GBO timeline to find an idea they like. 2. Tell students to use the internet to look up information about the person or discovery they selected, and to carefully keep track of their sources (where they got their information). Also, briefly discuss what constitutes a reliable source and what does not: i.e., a random blog or discussion site is not a reliable source of information,		

		whereas for example a NASA website is likely to be accurate and useful. 3. Encourage students to be creative in their writing. Tell them that while you expect them to use factual, well-sourced information in their article, they are free to additionally include some interpretive elements like an imagined interview with the radio astronomer(s) they are researching. Make sure to tell them that since they are writing a news article, they should include the five W's: "who, what, where, when, and why."		
Closure	Time 5 mins	1. Near the end of the class period, if students are still not finished with their articles, encourage them to take the beginnings of the articles they've written home and complete them there, and have them bring the articles in later in the week for review.		

Contingency	Time	If students finish their articles with time to spare before the end of class period, have them read their articles to the class so that they can share what they've learned with their classmates.		

LOOP ANTENNA LESSON PLAN 5		
Content Area: Physical Science	Lesson Topic: Earth's Atmosphere and Ionosphere	Length (timing) of Lesson: ~50 mins
INSTRUCTIONAL OUTCOMES		
WV Standard(s): **S.5.GS.8** **S.6.PS.2** **S.6-8.L.4** **S.9-10.L.4** **S.11-12.L.4**		
Learning Objective(s): Students will learn about the layers of the Earth's atmosphere and the ionosphere. Students should be able to name the different layers and their order, and what effect they have on weather. Students will also learn about the atmosphere's effect on electromagnetic radiation's ability to be transmitted into space or received from space.		
Formative Assessment: Students' involvement in class discussion about the topic (asking insightful questions, giving answers or making comments that suggest an understanding of the material) and the quality of their atmospheric layer diagrams will provide a measure of students' mastery of the subject.		
PREPARATION		
Materials/Resources: - White construction paper - Drawing materials (colored pencils, crayons, and/or markers) - Rulers (1 per student) - Slides for lesson 5 (incl. in Loop Antenna Lesson Plan Attachment C) - Projector - Template for atmospheric layers diagram (incl. in Loop Antenna Lesson Plan Attachment A) - Reference on atmospheric layers, for instructor's use: https://scied.ucar.edu/atmosphere-layers - Reference on the ionosphere, for instructor's use: http://solar-center.stanford.edu/SID/activities/ionosphere.html		

INSTRUCTIONAL PROCEDURES

*Highlight **BLUE** for materials/**GREEN** for technology
*Highlight **PINK** for instructional strategies
*Highlight **YELLOW** for discipline-specific academic language/vocabulary

		Procedural Steps	Questions	Differentiated Instruction
Activating Strategy/ Introduction	Time 20 mins	1. Introduce the topic by reminding students that in our last lesson, we learned about important discoveries in radio astronomy and the scientists who made them. Discuss question 1 with students as a lead-in to today's lesson. Tell students that because radio waves are really big (they have long wavelengths), they can travel through a lot of things. But sometimes the atmosphere (the layer of air around the Earth) can still have an effect on radio waves, so it is important to learn about the atmosphere so we can understand how it impacts radio astronomy. 2. Now, project the slide with the atmospheric layers and tell students that the atmosphere has 5 different layers, then discuss each one in turn: - The troposphere is the lowest layer of our atmosphere, and it extends to 6.2 miles (10 km) above sea level. This is where weather happens, and where most clouds are formed. - The stratosphere is the next-lowest layer of the atmosphere, extending from 6.2 miles (10 km) above sea level to about 31 miles (50 km) above sea level. The ozone layer is located in the stratosphere, and this is also where jets fly. - The next layer of the atmosphere is called the mesosphere, and it extends from 31 miles (50 km) to 53 miles (85 km). This is where most meteors burn up as they enter the atmosphere, so if you have ever watched a	1. What natural phenomenon do you think could create some problems for radio astronomers? (If students need prompted, give them a hint: What do you have to look through to see the stars?) *Suggested answers: the Earth's atmosphere and weather.* 2. Do you know what an ion is? Can you guess? (Give hints like: Think about an atom – what are atoms made of?) *Suggested answer: an ion is an atom that has been separated from its electron(s).* 3. Now do you have a guess as to what might be in the **ion**osphere? *Suggested answer: ions, and the electrons that were knocked loose from their atoms.* 4. Do you think really long radio waves can penetrate the ionosphere? Why or why not? *Suggested answer: Really long radio waves (therefore, really low frequency radio waves) cannot penetrate the ionosphere, though medium-length and shorter wavelength*	It is up to the instructor to assess the classroom and determine how to adapt the lesson to best reach all of her/his students.

		meteor shower, now you know that this happens in the mesosphere! -The second-to-highest layer is called the thermosphere, and it extends from 53 miles (85 km) to somewhere between 311 to 621 miles (500 to 1000 km) from the ground (this variation is due to the fact that the amount of energy striking this layer from the Sun can change). Many satellites are actually in orbit in the thermosphere. - Finally, the outermost layer of the atmosphere is appropriately called the exosphere. It extends from the edge of the thermosphere and out into space; scientists say this layer could extend anywhere from 62,000 miles (100,000 km) and 120,000 miles (190,000 km); at this point it is hard to tell what is still part of the atmosphere and what is actually space! 3. Now tell students that while these layers describe the atmosphere, there is a series of regions within these atmospheric layers called the ionosphere. Discuss questions 2-3 with students, then explain to them that the ionosphere is located in parts of the mesosphere and thermosphere ranging from 46 to 621 miles (75-1000 km) above sea level. It is a region where the Sun's energy has stripped atoms of their electrons, and it has 3 layers itself: the D layer (which is the lowest), the E layer (which is in the middle), and the F layer (which is the highest). Discuss question 4 with students. 4. Explain to your class that the fact that the ionosphere can reflect really long radio waves can come in handy in some cases. Explain that the U.S. military uses very long wavelength (also, very low frequency, abbreviated to VLF) radio waves to communicate with their submarines. These VLF communication signals bounce off the ionosphere –	*radio waves can penetrate this layer. Explain to students that long wavelength radio waves cannot get through the ionosphere because the loose electrons in this region absorb or reflect the radio waves so they cannot enter or escape the Earth.* 5. If a signal bounces off a lower layer of the ionosphere, does it travel a longer distance to get to its destination, or a shorter distance? *Suggested answer: shorter.* 6. Do you think a radio wave that travels a short distance is stronger, weaker, or the same strength as a radio wave that travels a long distance? *Suggested answer: Stronger*	

		because they can't penetrate it and travel out into space. They can then propagate (or travel) very long distances on Earth, so that submarines far away from the radio transmitter can still pick up the signal. Amateur radio astronomers can make use of this property of the ionosphere as well. Show students the slide with the diagram of the ionosphere, and tell them that generally, the VLF radio signals bounce off the upper layers of the ionosphere (the E or F layers), but when solar activity (such as a solar flare) disturbs the ionosphere, the signals bounce off the D layer instead. Discuss question 5-6 with your students, then emphasize that since the VLF signal bounces off a lower layer of the ionosphere when solar activity is occurring, it travels a shorter distance, and therefore the signal we receive from the VLF station is stronger when there are solar flares going on. Tell students that in future lessons in this class, we are going to be building our own radio telescope to monitor the signal strength of the VLF submarine communication signal in hopes that we might detect some solar activity.		
Core Instruction	Time 20 mins	1. To reinforce the topics discussed in this lesson, do an activity with your students – tell them that we are now going to create illustrated diagrams of the layers of the Earth's atmosphere and ionosphere. 2. First, pass out white construction paper, rulers, and drawing instruments, and instruct students to use their rulers and draw lines measured as follows (note that the paper should be oriented portrait-wise; refer to template if necessary): - Draw solid line 1" from the bottom of the page - Draw another solid line 2.5" from the bottom of the page - Draw a dotted line 3.25" from the bottom		

		-Draw a solid line 4” from the bottom -Draw another solid line 7.5” from the bottom, and draw a dotted line just slightly below this one. 3. Now, tell students to write the word “Troposphere” in the lowest division of the paper, “Stratosphere” in the second division, “Mesosphere” in the next division, “Ionosphere” between the 2 dotted lines, “Thermosphere” in the second-to-top division, and “Exosphere” in the uppermost division (again, refer to template for guidance). 4. Finally, instruct students to decorate each layer appropriately – i.e., draw clouds in the troposphere, jets in the stratosphere, meteors in the mesosphere, satellites in the thermosphere, etc.		
Closure	Time 10 mins	1. Once students have completed their diagrams, tell them that you are going to do one final activity. Explain that we are each going to invent a mnemonic to remember the 5 layers of the atmosphere and the ionosphere; give them an example like: “This Small Martian Is Truly Excited” (T stands for troposphere, S = stratosphere, M = mesosphere, I = ionosphere, T = thermosphere, E = exosphere). After students have invented their mnemonics, have them write their mnemonic down on the back of their diagrams.		

Contingency	Time	If students do not have enough time to finish their diagrams, encourage them to bring them home to complete them and bring the diagrams back into class once they are done.		

LOOP ANTENNA LESSON PLAN 6		
Content Area: Physical Science	Lesson Topic: Electricity and Magnetism	Length (timing) of Lesson: ~50 mins
INSTRUCTIONAL OUTCOMES		
WV Standard(s): **S.6-8.L.3, S.6-8.L.4, S.6-8.L.12, S.6-8.L.13**, **S.6-8.L.16**, **S.6-8.L.19** **S.9-10.L.3**, **S.9-10.L.4**, **S.9-10.L.12**, **S.9-10.L.13**, **S.9-10.L.16**, **S.9-10.L.19** **S.HS.PS.14**, **S.HS.PS.19** **S.11-12.L.3, S.11-12.L.4**, **S.11-12.L.12**, **S.11-12.L.13, S.11-12.L.16**, **S.11-12.L.19** **S.HS.P.7, S.HS.P.16**		
Learning Objective(s): Students will learn about the differences between electricity and magnetism, and how they interact. They will also gain an understanding of Faraday's Law.		
Formative Assessment: Students' involvement in class discussion about the topic (asking insightful questions, giving answers or making comments that suggest an understanding of the material), their participation in building the loop antenna, and the quality of their lab reports will provide a measure of students' mastery of the subject.		
PREPARATION		
Materials/Resources: - Projector - Slide to go with lesson 6, showing a visual demonstration of Faraday's Law (incl. in Loop Antenna Lesson Plan Attachment C) - Bar magnet(s) - Galvanometer, ammeter, or digital multimeter - Lab report forms, 1 for each student (same template as for Lesson 2, incl. in Loop Antenna Lesson Plan Attachment A) - "Small Loop Antenna Instruction Manual" (incl. in Loop Antenna Lesson Plan Attachment D)		

- Magnet wire
- PVC pipe pieces (for building loop structure)
- Masking tape (or regular tape)
- Wire cutter
- Wire stripper
- String
- Reference for instructor on Faraday's Law experiment: https://www.education.com/science-fair/article/faraday-experiment-current-generated-magnet/

INSTRUCTIONAL PROCEDURES

*Highlight **BLUE** for materials/**GREEN** for technology
*Highlight **PINK** for instructional strategies
*Highlight **YELLOW** for discipline-specific academic language/vocabulary

		Procedural Steps	Questions	Differentiated Instruction
Activating Strategy/ Introduction	Time 10 mins	1. Remind students that in our last lesson, we learned about the Earth's atmosphere and ionosphere. Re-emphasize the point that by observing the signals from submarine communication stations, we will be able to detect solar activity, and tell students that today we will be building the first part of the radio telescope that will allow us to do that. And tell them that before we do that, we need to learn some things about electricity and magnetism that will help us understand how our radio telescope can actually pick up radio waves. 2. First, explain to students that electricity is a form of energy created when electrons flow; also explain that electrons (which are negatively charged) flow because they are attracted by a positive charge ahead of them. Remind students that objects with a negative electric charge are attracted to positively charged objects, while like charges repel. Discuss question 1 with students. Now explain that magnetism is the force between objects with magnetic	1. What examples of electricity can you think of in everyday life? *Suggested answers: open-ended. Some possibilities are: electricity is what powers my house (explain that the electricity that powers your house is a result of electrons travelling through the wires in your household objects), or static shock (explain that static electricity is what happens when electrons – which have a negative charge – jump to a surface with a net positive charge), etc.* 2. From this description, do you notice anything in common between electricity and magnetism? *Suggested answer: both involve the attraction of*	It is up to the instructor to assess the classroom and determine how to adapt the lesson to best reach all of her/his students.

		fields; i.e. the attraction between the north and south poles of two magnets, and how north poles of two magnets repel (same with two south poles). Discuss question 2 with students. 3. Now tell students that in fact, electricity and magnetism are very closely related. Explain that when there is a magnet near a conductive wire (if something is conductive, that means electricity can travel through it), this induces, or causes, a current (a flow of electrons) to travel through the wire. Explain to students that this relationship between electricity and magnetism was discovered by physicist Michael Faraday in 1831, and therefore the relationship is known as Faraday's Law of Induction. Project the slide with the GIF demonstrating Faraday's Law so that students can gain a visual understanding of this. 4. Tell students that you understand they may be wondering how this relates to radio astronomy. Discuss questions 3-4 with students. Now explain that scientists often call different forms of light "electromagnetic radiation" because light is composed of moving electric and magnetic fields. This means that radio waves have a magnetic field! Now, discuss question 5 with students.	*opposite charges, and the repellence of like charges.* 3. Do you remember what another name for light is? *Suggested answer: electromagnetic radiation.* 4. What do you notice about the words "electromagnetic radiation"? *Suggested answer: it contains parts of the words "electricity" and "magnetism".* 5. With Faraday's Law in mind, now that you know radio waves have magnetic fields, what do you think would happen if a radio wave passed a coil of wire? (Provide hints like, "What happened in the video when the magnet went near the wire?") *Suggested answer: the radio wave will induce (or cause) an electric current to start flowing in the wire.*	

Core Instruction	Time 30 mins	1. To reinforce the topics discussed in this lesson, tell students you will now build the first step in your solar-flare-detecting loop antenna radio telescope. Explain that once you build the large loop of wire, you will test Faraday's Law by using a magnet and an electric-current detector to see if running a magnet over the wire will really induce a current. But first, hand out lab reports (the same format as the ones used in lesson 2) and have students record their hypotheses about what will happen in this experiment. 2. Next, follow the instructions in Chapter 1, "Building the Loop Antenna" (pg. 3-4) of the included "Small Loop Antenna Instruction Manual." Make sure that all of your students are involved in some aspect of the construction process. 3. Once you have finished constructing the loop antenna (including stripping the coating off of the last few inches of wire), connect the two loose ends of the wire to the two alligator clips attached to the digital multimeter (an instrument which, among other things, can measure electric current) and switch the power on. Turn the knob on the multimeter to the micro-amp setting (labeled "µA"). Have students write down the procedure that was followed in this experiment (winding the loop of wire, plugging in the digital multimeter, observing the multimeter's readings) in the "Methods" section of the lab report. Then, have them write down the reading that the multimeter gives without doing anything to disturb it (as a control, to see how it compares to what we'll do next) – this should also be recorded in the "Results" section. Now, have one student wave the magnet inside the loop, and have the others watch the multimeter to see how it changes. Have them record the multimeter readings in their lab reports and		

		make note of what types of motions the magnet was undergoing when they took the reading. Note that if you are not using a multimeter, or if you need more information than given above, there are many helpful resources and videos available online on how to use digital multimeters, galvanometers, and ammeters.		
Closure	Time 10 mins	1. Now have students compare the results of the experiment with their hypotheses. Did the digital multimeter show a change when the magnet was moving in the center of the loop antenna's wire coil? Or was it hard to tell? If there was no noticeable difference, brainstorm with students about why this might be true – ideas include the magnet was too weak, the multimeter wasn't sensitive enough, etc. Have students write down their thoughts on this in the "Conclusions" section of their lab report. 2. Explain to students that in coming days, we will get to see how the antenna detects the magnetic fields from radio waves. Tell them that in our next lesson, though, we will be exploring how radio waves impact many of us in our daily lives through their practical uses.		

Contingency	Time	If students do not have enough time to finish their lab reports, this can be assigned as homework. Also, if loop antenna construction takes too long, then this lesson can be split over two days.		

LOOP ANTENNA LESSON PLAN 7		
Content Area: Physical Science	Lesson Topic: Radio Communication	Length (timing) of Lesson: ~50 mins
INSTRUCTIONAL OUTCOMES		
WV Standard(s): **S.6-8.L.2, S.6-8.L.4, S.6-8.L.12, S.6-8.L.13, S.6-8.L.18, S.6-8.L.19** **S.9-10.L.2, S.9-10.L.4, S.9-10.L.12, S.9-10.L.13, S.9-10.L.18, S.9-10.L.19** **S.HS.PS.24** **S.11-12.L.2, S.11-12.L.4, S.11-12.L.12, S.11-12.L.13, S.11-12.L.18, S.11-12.L.19** **S.HS.P.23**		
Learning Objective(s): Students will learn about how radios work, and why radio waves are used in communication. Students will also gain an understanding of how radio waves propagate.		
Formative Assessment: Students' involvement in class discussion about the topic (asking insightful questions, giving answers or making comments that suggest an understanding of the material), the accuracy of their Morse Code messages, their participation in the radio station scavenger hunt activity, and the quality of their news broadcasts (if this activity is performed) will provide a measure of students' mastery of the subject.		
PREPARATION		
Materials/Resources: - Paper (for writing Morse Code messages) - Pencils - Morse Code keys – 1 for each student (incl. in Loop Antenna Lesson Plan Attachment A) - AM/FM handheld radio - Timer - Radio Astronomy News Article assignments from Lesson 4 (for optional activity described in the "Contingency" section)		

- Sound recording device, like a cell phone (also for optional activity)				
INSTRUCTIONAL PROCEDURES *Highlight **BLUE** for materials/**GREEN** for technology *Highlight **PINK** for instructional strategies *Highlight **YELLOW** for discipline-specific academic language/vocabulary				
		Procedural Steps	**Questions**	**Differentiated Instruction**
Activating Strategy/ Introduction	Time 25 mins	1. Tell students that up to now, we have been focusing mainly on the astronomical applications of radio waves, but today we are going to talk about how radio can be used in everyday life. Discuss question 1 with students. 2. Explain to students that radio transmitters are the devices that are used to create a radio signal that can travel out to distances of several miles away, so that radio listeners can tune in to the stations that are being transmitted even if they aren't right next to the transmitter. Now discuss question 2 with students. Explain to students that there are a number of ways that information can be transmitted through a radio wave. Discuss the three different ways of encoding information in a wave that are listed below (note that the word "modulation" just means adding information to a radio wave): - Amplitude Modulation (AM): remind students of the two different options they might see on a radio: AM and FM. Explain that AM stands for Amplitude Modulation, and this just means that the information in the signal is communicated by changing the amplitude of the radio wave: i.e., when sound gets louder, amplitude gets bigger, etc.).	1. When you tune in to a radio, do you think that the radio is picking up sound waves or electromagnetic waves? *Suggested answer: electromagnetic waves, specifically, radio waves.* 2. How do you think radio waves are able to contain the voices and sounds that you hear when you tune in to a music or news station? What do you think we could change about the waves to indicate that there is information in them? *Suggested answers: parts of radio waves that you could change to encode information would be to vary the amplitude of the wave, or the frequency of the wave, or just turn the wave on and off.*	It is up to the instructor to assess the classroom and determine how to adapt the lesson to best reach all of her/his students.

		- Frequency Modulation (FM): when frequency modulation is used, this means that the radio waves just get squashed together or spread apart a little bit in a pattern that conveys the sound pattern that is recorded. - On/Off modulation: in this kind of modulation, the radio signal is just turned on and off in a coded pattern – the most well-known example of this kind of modulation is Morse Code, which uses dots and dashes to convey letters and numbers. 3. To get a feel for one of the modes of modulation, hand out the Morse Code translation keys, paper, and pencils to your students and tell them to write a message in Morse Code to give to one of their classmates. After students have written their messages, have them exchange messages with the person next to them – make sure each student gets a message from someone else. Then have the students decode the message they received. If you like, have students practice tapping out their messages so they can hear what a Morse Code transmission might sound like if it were converted from radio waves to sound.		
Core Instruction	Time 30 mins	1. Now that you have gone over how radio waves convey information, do another activity with your students. Split your classroom up into teams of equal numbers of students, and assign numbers to each team. Now explain that you are going to have a radio station speed scavenger hunt – tell students that each group will get to take a turn with a handheld radio, and their job is to find, say, 4 radio stations as fast as they can (when you actually do this activity, instead of 4 radio stations, make sure the number of radio stations each team is supposed to find is equal to the number of members in a team, so that each student gets a turn to tune in to a radio station). Tell the teams that	1. What do you think the numbers on the radio dial indicate (not the volume dial)? *Suggested answer: the frequency that the radio is tuning in to.*	

		each will get a turn to participate, and that you will give the first team the handheld radio and time them to see how long it takes them to tune in to their assigned number of radio stations (within a team, each station they tune to must be different, i.e. two students in the same team cannot both tune in to channel 97.9). 2. Now begin! Starting with team 1, give them the radio, count down 3,2,1, then start timing. Make sure each student tunes in to a station, and once all are done, stop the timer. Write down their time, then repeat this for the remaining teams. At the end of the game, announce the times for each team. 3. Since students have now been familiarized (or re-familiarized) with the features of a radio, discuss question 1 with them. 4. Now discuss the parts of a radio, and how each part works together to receive, decode, and play back the message encoded in the radio waves. Refer to the various parts of the handheld radio that you just used as you discuss the inner workings of the radio. First explain that when the radio waves from the transmitter encounter the handheld radio's antenna (point to the antenna), it causes the electrons in the antenna to wiggle back and forth, similar to what happened in our loop antenna experiment in the last lesson. The wiggling electrons generate a current, which flows through the electronic parts in the radio, and then causes the speaker to vibrate in the same pattern contained in the radio wave's modulation (or encoding), so that we can hear sounds coming through the radio.		

Closure	Time 5 mins	1. Make sure students understand the steps of how a radio works, and address any questions they have about this. 2. Finally, lead in to the next section by saying something along the lines of, in our next lesson, we will learn how we can actually use electronics to “tune” a radio telescope to particular frequency channels like we could tune in to channels on the handheld radio using the knob. “Stay tuned until next time…!”		
Contingency	Time	If you have more time, or if you would prefer this activity to one of the other activities in this lesson, you can have students modify their radio astronomy news articles into the format of a short radio broadcast, and use a sound recording device to record them reading their broadcasts in their best radio host voices.		

LOOP ANTENNA LESSON PLAN 8		
Content Area: Physical Science	Lesson Topic: Circuits and Electronic Components	Length (timing) of Lesson: ~50 mins

INSTRUCTIONAL OUTCOMES

WV Standard(s):

S.6-8.L.4
S.9-10.L.4
S.11-12.L.4
S.HS.P.17, S.HS.P.18

Learning Objective(s):

Students will learn how simple circuits work, and explain how the flow of electrons makes electricity. They will also learn about what capacitors, inductors, resistors, amplifiers, and batteries do, and will be able to understand how circuits can be used to make a radio telescope work.

Formative Assessment:

Students' involvement in class discussion about the topic (asking insightful questions, giving answers or making comments that suggest an understanding of the material), their engagement with the investigation of the loop antenna circuit board, and the quality and logic of their "schematics" will provide a measure of students' mastery of the subject.

PREPARATION

Materials/Resources:

- Circuit board for the loop antenna (made by the Green Bank Observatory)
- Ham-It-Up Upconverter (manufactured by NooElec)
- Construction paper
- Drawing supplies (colored pencils, crayons, and/or markers)

INSTRUCTIONAL PROCEDURES *Highlight **BLUE** for materials/**GREEN** for technology *Highlight **PINK** for instructional strategies *Highlight **YELLOW** for discipline-specific academic language/vocabulary				
		Procedural Steps	**Questions**	**Differentiated Instruction**
Activating Strategy/ Introduction	Time 25 mins	1. Remind students that in our last lesson, we learned about how radios work. Tell your class that today, we will be learning about electric circuits and how their different parts work together to perform tasks, like improving the signal you detect with a radio or radio telescope. 2. Discuss question 1 with your students. Tell them that each of the parts they mentioned that the flashlight needed to have represents the components (or parts) of a simple circuit. Explain that a circuit is a closed loop of wire and components in which electrons flow. Like the flashlight, the simplest circuit consists of a power source (e.g. battery), a load (e.g. a light bulb), and wiring to connect the components. 3. Explain to students that the people who design circuits are called electronics technicians or electrical engineers (electrical engineers are more often involved in designing circuit systems, while technicians are often the ones who fabricate, or put together, the circuits and electronics). Tell them that in order to make circuits that actually work and make sense, these people will make a very detailed, step-by-step drawing called a schematic. Schematics are full of funny symbols and numbers, but engineers and technicians understand them and can use them as instruction guides to create a real, working circuit.	1. Think about simple electronic object in your house, say a flashlight. What parts does the flashlight need to work? *Suggested answers: a battery (power source), a light bulb (load), wire to connect the parts, a switch, etc.*	It is up to the instructor to assess the classroom and determine how to adapt the lesson to best reach all of her/his students.

		4. To reinforce the idea of what a schematic accomplishes, have students pick some kind of process or system that they understand and draw their own schematic to illustrate it. Pass out construction paper and drawing instruments and tell students to create their "schematics" in the form of a flowgraph, enclosing each individual step in a box or circle and drawing lines with arrows between the boxes to indicate the order of the steps.		
Core Instruction	Time 20 mins	1. After completing the schematic exercise above, discuss question 1 with students. Now go over with your students the different types of components that could be used to build a circuit (some of which they may have mentioned in discussion): -Resistors are components that reduce the flow of electric current through a circuit. This is necessary in cases where, for example, too much current flow would harm another component (i.e. would burn out a light bulb), so the resistor controls the current to prevent any problems like this. -Capacitors are components that act sort of like temporary batteries. While a circuit is running, they accumulate charges on their metal plates, and when the circuit needs extra charge, the capacitor can provide it. Another property of capacitors is that they function as high-pass filters (which means they let high-frequency signals through, but block low-frequency signals. -Inductors are coils of wire wrapped around a core of air or some other material, and they store magnetic charge. The loop antenna we built is an example of a giant inductor. Another property of inductors is that they can act as low-pass filters (which means, opposite to capacitors, they only let low frequencies through, but block high frequencies.)	1. Have you heard of any other types of components that make up electronic circuits? *Suggested answers: any of these are correct: resistors, capacitors, inductors, amplifiers, etc.* 2. What do you think happens when an inductor (which is a low-pass filter), and a capacitor (which is a high-pass filter) are connected to the same circuit? *Suggested answer: the circuit blocks out all but a very narrow range of frequencies where the two filters don't overlap. Remember, the inductor blocks high frequencies and the capacitor blocks low frequencies. It's ok if you need to guide students to this answer.* 3. Of the components we've learned about today, which one (excluding inductors and capacitors) might really come in handy when dealing with faint signals in radio astronomy? (Hint:	

		-Amplifiers (also called operational amplifiers, or op-amps) are used to strengthen signals that flow through the circuit, sort of like an amp plugged into an electric guitar makes the guitar sound louder. 2. Now explain to students that many of these components play a big part in making radio telescopes like our loop antenna work. After discussing question 2, tell students that the filtering capabilities of inductors and capacitors means that if you choose the right values of inductors and capacitors to go in the same circuit, you can figure out how to let only a very narrow range of frequencies pass through your circuit – this is very useful when you just want to tune in to one frequency. A real-world example of this is in the radio we experimented with in our last lesson – when you turned the knob to tune in to a particular frequency, you were actually changing the values of the components in the radio's circuits and therefore changing what frequency the radio could receive. Next, discuss question 3 with students. 4. Summarize the preceding discussion by saying that in order to optimize the signal that travels to a circuit from a radio telescope, it needs to have inductors and capacitors to tune the incoming signal, and amplifiers to make the signal strong enough that we can get useful information out of it. Now, pass the printed circuit board (which has the Green Bank Observatory's logo on it) around the room (being sure to remind students to treat it with care to avoid breaking any of the components) and tell students that the capacitors are the small, mushroomy-looking components and the amplifiers are the black rectangular components. Remind them that when the loop antenna is connected to the circuit, it serves as the inductor. Now pass the upconverter circuit around to students, and explain that its	which components make signals stronger?) *Suggested answer: amplifier*	

		function is to change the frequency of the signal that comes out of the circuit board so it is compatible with the device that reads the signal into the computer, which we will discuss next time. *Note that in this lesson you will not be connecting the loop antenna to the circuit board and upconverter – you will be doing this in Lesson 10.		
Closure	Time 5 mins	1. Answer any questions students have about how circuits work and how they relate to the loop antenna project, and then tell them that in our next lesson, we will learn about the next place the signal goes after it passes through the circuit board.		

Contingency	Time	Instructor can determine how to adapt the lesson above if any difficulties arise.		

<table>
<tr><th colspan="3">LOOP ANTENNA LESSON PLAN 9</th></tr>
<tr><td>Content Area:
Physical Science</td><td>Lesson Topic:
Analog-to-Digital Conversion and Sampling</td><td>Length (timing) of Lesson:

~50 mins</td></tr>
<tr><th colspan="3">INSTRUCTIONAL OUTCOMES</th></tr>
<tr><td colspan="3">WV Standard(s):

S.6.PS.3
S.6-8.L.4
S.9-10.L.4
S.11-12.L.4
S.HS.P.20</td></tr>
<tr><td colspan="3">Learning Objective(s):

Students will learn how natural analog signals (like radio waves) can be read into a computer and transformed into a digital signal by a process of sampling. They will also gain an understanding of digital sampling and the Shannon-Nyquist Sampling Theorem.</td></tr>
<tr><td colspan="3">Formative Assessment:

Students’ involvement in class discussion about the topic (asking insightful questions, giving answers or making comments that suggest an understanding of the material), their engagement with the investigation of the software defined radio, and the quality and accuracy of their Pointillist paintings will provide a measure of students’ mastery of the subject.</td></tr>
<tr><th colspan="3">PREPARATION</th></tr>
<tr><td colspan="3">Materials/Resources:

- Software defined radio dongle (RTL-SDR)
- White construction paper or cardstock
- Rulers (one per student)
- Drawing supplies (colored pencils, crayons, and/or markers)
- Printouts of famous Pointillist paintings (incl. in Loop Antenna Lesson Plan Attachment B)</td></tr>
</table>

INSTRUCTIONAL PROCEDURES *Highlight **BLUE** for materials/**GREEN** for technology *Highlight **PINK** for instructional strategies *Highlight **YELLOW** for discipline-specific academic language/vocabulary				
		Procedural Steps	**Questions**	**Differentiated Instruction**
Activating Strategy/ Introduction	Time 30 mins	1. Remind students that in our last lesson, we learned how circuits can be used to optimize the signal we detect with our loop antenna radio telescope. Tell them that in this lesson, we will be learning how the wiggling electrons in a circuit board get transformed into something our computers can process and understand. 2. Discuss questions 1-2 with students. Then explain that taking repeated measurements at fixed intervals (meaning you take measurements with an equal amount of time between each one) like we talked about with the temperature example is called sampling. Tell students that sampling is used by scientists in a lot of different ways – science revolves around making measurements and comparing them, and scientists must know how frequently they need to make their measurements (i.e., take samples) in order to get data that will help them answer their questions. Tell students that the number of samples that are taken in a given amount of time or space is called "sampling density" – if you are sampling something (like temperature) that changes in time, the number of samples per hour or samples per second is an indicator of sampling density. On the other hand, if you are a surveyor and are measuring the height of the ground above a reference level every so often, then how many measurements (or samples) that you make every meter (or kilometer) is your sampling density.	1. If you wanted to keep track of how the value of something (like the temperature outside) changes through the day, what would you do? *Suggested answer: check the temperature of it every so often.* 2. Let's say you made a graph of the temperature measurements you took through the day. If, for some reason, you wanted to know really precisely what the temperature was at some time – say 2:06:36 pm, for example, would it be better if you had taken just a few temperature measurements, say one per hour, or if you had taken a whole lot of temperature measurements, say one per second? *Suggested answer: one per second.* 3. After looking at these two Pointillist paintings, what would you compare the dots to? *Suggested answer: measurement samples.* 4. Which of these paintings has a higher sampling density, do you think?	It is up to the instructor to assess the classroom and determine how to adapt the lesson to best reach all of her/his students.

		3. To reinforce the idea of samples and sampling density, we will now do an activity with Pointillist paintings. Explain to students that Pointillism was a style of art that arose in the late 1800's. Artists made Pointillist paintings by applying small, individual dots of color to a canvas. Now show your students the two Pointillist paintings labelled 1 and 2 – perhaps pass them around the room so that students can study each one. Discuss questions 3-4 with students. 4. Now, tell students that we will make our own Pointillist art to illustrate the concept of sampling. Give each student a sheet of white construction paper, a ruler, and drawing tools. Instruct them to sketch a faint, general (but not too detailed) outline of a drawing on their paper. Then, tell them to use the ruler to draw faint lines dividing up their page into three equal parts, going over their outline (does not matter whether they divide it heightwise or lengthwise). Next, tell students to use the colored pencils, crayons, or markers (whichever were provided) to create an image by filling in their outline with dots like the Pointillist painters did. But before they begin, give them the following instructions: in one of the three sections of their paper, the dots are to have a low sampling density; in another of the sections the dots should have a medium sampling density, and in the remaining section of their paper, the dots should have a high sampling density. 5. Once students have completed their images (or once time is up), have them study each other's pictures and make observations about the difference between a high sampling density and low sampling density. Discuss question 5 with students. (At the end of class, you may wish	*Suggested answer: painting 2, because the dots are closer together than in painting 1.* 5. What do you notice about the difference between images with high sampling density and low sampling density: which one has more detail? *Suggested answer: the images with high sampling density (more dots) have more detail than the images with lower sampling density.*	

		to hang up the Pointillist drawings students have made as a reminder of what you've learned about sampling density).		
Core Instruction	Time 15 mins	1. Now explain to students that one very common way that sampling is used is to turn analog (or, real-world) signals into digital (number-based) signals that a computer can understand. Tell them that this process – converting analog signals into digital signals – is called analog to digital conversion. Discuss question 1 with students. 2. Explain to students the difference between an analog signal and a digital signal: - An analog signal is continuous, meaning it is not broken up into little parts. Think about time, for example – while you can measure time in parts like seconds, time itself is not jumpy or interrupted, it flows smoothly from one moment to the next. - A digital signal, on the other hand, is discrete: it *is* broken up into little parts, often called bits. Digital signals are represented by numbers. Tell students that we can use sampling to convert an analog signal into a digital signal by measuring the value of the analog signal at set time intervals. These measurements (or samples, which are represented by numbers) form the new digital signal. 3. Now take out the SDR dongle. Tell them that this device is called a Software Defined Radio (SDR) dongle and that it functions as an analog to digital converter – it samples (or measures) the analog signal coming from our radio telescope's circuit board and upconverter (which is	1. How do you think analog to digital conversion might come in handy in our radio telescope project? *Suggested answer: converting the signal from the circuit board into a signal in our computer, or something along those lines.* 2. Do you think it's better if the software defined radio dongle takes measurements (samples) of the analog signal really frequently, or just every once in a while? (Remember the Pointillist paintings!) *Suggested answer: better if it samples more often so that we can keep more details about the signal.*	

		measured in volts), and sends those digital samples to software in the computer for further processing. Pass the SDR around the room for students to inspect. 4. Discuss question 2 with students. Now tell them that in fact, there is a formula that tells us how often the software defined radio dongle (or any analog to digital converter) must sample a signal in order to get enough detail out of it, and this formula is called the Shannon-Nyquist Sampling Theorem (sometimes just called the Nyquist Sampling Theorem). What this formula states is simply that if you have a signal with a given frequency (like a radio wave with a frequency of 10 Hz, for example), then you must take samples at more than twice that frequency – for the 10 Hz signal, this means you must sample at least 20 times per second to get enough detail about the signal. Go through a few examples with students to reinforce this concept: - If we wanted to sample a 50 Hz signal properly according to the Shannon-Nyquist Theorem, how many samples per second would I need to take? *100* - If we wanted to sample a 24 kHz signal properly, how many samples per second would we need to take? *48k (48,000)*		
Closure	Time 5 mins	1. Answer any further questions students have about sampling and how it relates to the loop antenna project, and then tell them that in our next lesson, we will learn about what happens to the signal from the antenna now that it has entered the realm of the computer.		

Contingency	Time	If students are unable to finish their Pointillist paintings in the time allotted, assign this as homework.		

LOOP ANTENNA LESSON PLAN 10		
Content Area: Physical Science	Lesson Topic: Basics of Programming	Length (timing) of Lesson: ~50 mins

INSTRUCTIONAL OUTCOMES

WV Standard(s):

S.6-8.L.4
S.9-10.L.4
S.11-12.L.4

Learning Objective(s):

Students will learn what a computer program is and what it does, and about its most basic parts.

Formative Assessment:

Students' involvement in class discussion about the topic (asking insightful questions, giving answers or making comments that suggest an understanding of the material), the quality of their computer algorithms, and their engagement with the investigation of the GNURadio flowgraph and starting to run the antenna will provide a measure of students' mastery of the subject.

PREPARATION

Materials/Resources:

- Paper (for algorithm activity)
- Pencils (also for algorithm activity)
- Small Loop Antenna data collection sheets, 1 for each student (incl. in Loop Antenna Lesson Plan Attachment A)
- Access to a computer that is connected to the Internet and can be allowed to run for several days without being turned off.
- Small Loop Antenna Instruction Manual (incl. in Loop Antenna Lesson Plan Attachment D)
- The loop antenna (constructed in Lesson 6)
- All of the additional loop antenna equipment listed in Chapter 3 (pg. 7) of the Instruction Manual
- A very small flathead screwdriver
- Software needed to run loop antenna observations, as explained in the Instruction Manual
- Projector (optional)

To prepare for today's lesson, you will probably want to make sure to download and test the necessary software for the small loop antenna on the computer you will be using to run the observations; to do this, follow all of the detailed steps given in Chapter 2 of the Small Loop Antenna Instruction Manual.
INSTRUCTIONAL PROCEDURES *Highlight **BLUE** for materials/**GREEN** for technology *Highlight **PINK** for instructional strategies *Highlight **YELLOW** for discipline-specific academic language/vocabulary

		Procedural Steps	Questions	Differentiated Instruction
Activating Strategy/ Introduction	Time 20 mins	1. Tell students that today, we will finally assemble the rest of our antenna and begin to observe with our Small Loop Antenna radio telescope! But before we begin, we need to learn a few things about computer programming so that we understand what happens to the digital samples we learned about in our last lesson, and how they get turned into a data graph that we can understand. 2. First off, discuss question 1 with students. Then tell them that one way to think of a computer program is like a recipe: it is a collection of words that tells the computer what to do, how to do it, and what order to do it in. The people who write computer programs (also called computer code) are called, not surprisingly, programmers. Discuss question 2 with students. Explain that computer code can't be written in plain English or any other spoken languages because these languages can be confusing and ambiguous. Discuss question 3, then tell students that there are several languages that computers do understand, however, and they include the languages: Python, C++, Java, HTML, Scratch, and many others.	1. What do you think a computer program is? Suggested answers: open-ended. 2. When programmers write code, do you think they write it in English? *Suggested answer: Not exactly. Computer programs are written in specific computer "languages". While these languages may contain some English words, they are arranged in a way that doesn't make sense the way normal English does; rather, they are arranged in ways that make sense to the computer.* 3. Can you think of some English words that have more than one meaning? *Suggested answers: "right" (can mean "correct," or the opposite of left), "rose" (can mean to get up, or a kind of flower), etc.*	It is up to the instructor to assess the classroom and determine how to adapt the lesson to best reach all of her/his students.

		3. Now that students understand why code has to be written in computer languages to avoid the ambiguity of English, explain that programs also tend to follow a consistent structure, or sequence of steps called an algorithm. Discuss question 4. 4. Now tell students that we are going to do an activity, somewhat similar to the one we did when we were learning about schematics, but this time, we are not going to draw flowgraphs – instead, we are going to write out a series of very, very specific instructions that we think are absolutely foolproof to misunderstanding. Pass out paper and pencils to your students, then tell them to pick a simple process (like making a cup of tea, for example), and write out a series of very detailed and unambiguous step-by-step instructions on how to do it. Tell them to imagine that they are writing this down for an incredibly literalist robot who takes everything you say seriously (for the middle school age range, and if you are familiar with this show, it may be helpful to reference the character "Bobert" from the "Amazing World of Gumball" cartoon who follows every order he is given to the letter). 5. Once they have completed their instructions, have students exchange instructions with their classmates (making sure each student gets a set of instructions from someone else), and tell them read the instructions in the mindset of a "literalist robot", and tell the "programmer" (the student who wrote the instructions) of any ambiguities or parts of their instructions that could be misinterpreted. Tell students that finding holes in their programs and fixing them in this way is called "de-bugging", because you are removing the "bugs" (or problems) from your program.	4. Can you think of anything we've learned about recently that reminds you of a computer algorithm? *Suggested answer: a schematic diagram; like algorithms in computer programs, schematics involve writing things down in logical, orderly steps.*	

Core Instruction	Time 25 mins	1. Once students have completed the program-writing activity above, show them (either on the computer screen, or via projector) an example of a real-world program (the "Loop-Antenna-Data-Graphing.py" program you downloaded before class), and discuss with students what the lines of code could mean. Now show them the GNU Radio software flowgraph you also downloaded before class, and analyze what each block could be doing. Emphasize to students that the digital samples created by the SDR dongle we discussed in our last lesson are processed through this flowgraph, and explain that the purpose of the flowgraph is to perform digital signal processing (DSP) steps on the samples. Also explain that the flowgraph processes and saves the data gathered from the antenna to a file, and that the program we looked at a moment ago opens this data file and graphs the samples so that we can see what the antenna has detected. 2. After thoroughly analyzing and discussing the flowgraph and Python program, tell students you are now going to become radio astronomers – you are about to begin setting up the loop antenna for its first observing run (radio astronomers call this setup process "commissioning the antenna"). Pass out the data collection sheets to your students, then move on to the next step. 3. Place the antenna somewhere off to the side of the room where no one will trip on it, but it is still easily accessible (it will need to be in the same location for several days, so be mindful of that). Have students help you follow the instructions in Chapters 3-4 of the Small Loop Antenna Instruction Manual to connect all of the necessary components to the loop antenna and computer, and as you complete the steps, ensure that students are checking off		

		tasks in their data collection sheet's checklist. When you are about to begin recording data, make sure that all students can see a clock. Click "Start" on the flowgraph, and make sure students write down the time you began your data recording. As shown in the instruction manual, you should see a bright line in the middle of the waterfall plot centered at 125 MHz. The plot will be centered on 125 MHz instead of 0 MHz because, as we mentioned briefly in Lesson 8, the upconverter shifts the frequencies observed by the loop antenna up by 125 MHz so that the computer can process them properly. So in our plot, 125 MHz corresponds to zero, so our 24 kHz submarine communication signal should appear as a faint line at around 125.024 MHz. 4. Now for the fun part. If the GNURadio Waterfall Plot does not look like it should, or does not start at all, follow the instructions in the "Troubleshooting" section of the instruction manual to try and isolate the problem (make sure students are involved in this step!) And remember, if all else fails, contact someone at Open Source Radio Telescopes (or me, Ellie! My contact info is given in the note at the beginning of this lesson plan), and you should get an answer in no more than a few days' time.		
Closure	Time 5 mins	1. If your antenna setup is working, congratulations! Leave the flowgraph running in the background (do not close the waterfall plot or hit "Stop"), and make sure the computer won't turn itself off or fall asleep on its own, because you will need to leave this flowgraph to run for 1-5 days (according to what is possible for you); keep in mind that it is better to let the antenna run longer in order to get a good amount of data.		

		2. If, on the other hand, the antenna is still not acting properly, set it aside and do some more troubleshooting the next day in class. This is an important part of the learning process for students, and while it may be frustrating, it teaches perseverance, creativity, and problem-solving. However, as emphasized before, if you cannot figure out the problem, contact someone at OSRT or me and we would be happy to provide suggestions from our own experiences with projects like this. 3. Wrap up by telling students that in our next lesson, we will switch gears from technology to science, and will begin learning some important facts about astronomy that will come in handy when it is time to analyze our loop antenna's data.		
Contingency	Time	If you would like to go deeper and give your students some experience writing code, visit https://scratch.mit.edu/. This website give you the ability to write code with your students using drag-and-drop code blocks so that you can create simple games and programs.		

LOOP ANTENNA LESSON PLAN 11		
Content Area: Physical Science	Lesson Topic: Lifecycles of the Stars	Length (timing) of Lesson: ~65 mins

INSTRUCTIONAL OUTCOMES

WV Standard(s):

S.6-8.L.4
S.9.ESS.3
S.9-10.L.4
S.11-12.L.4

Learning Objective(s):

Students will learn about how stars are born, live, and die, and how stars' deaths form elements that are important for new stars, and eventually life, to form.

Formative Assessment:

Students' involvement in class discussion about the topic (asking insightful questions, giving answers or making comments that suggest an understanding of the material), the quality of their stellar evolution paintings, and their participation in the Hertzsprung-Russell diagram activity will provide a measure of their mastery of this subject.

PREPARATION

Materials/Resources:

- Slides showing different stages of stars' lifecycle (incl. in Loop Antenna Lesson Plan Attachment C)
- Projector
- Link with info about stellar evolution (for instructor's reference): https://imagine.gsfc.nasa.gov/educators/lessons/xray_spectra/background-lifecycles.html

For stellar evolution paintings activity:
- Black cardstock or construction paper
- Paintbrushes
- Acrylic paints (primary colors plus black and white)

- Palettes
- Water cups (to wash brushes)

For Hertzsprung-Russell diagram activity:

- 3'x3' sheet of black (or white) butcher paper
- Yellow, blue, red, yellow, and white construction paper
- Instructions for Hertzsprung-Russell diagram activity: http://www.mrsgeology.com/wp-content/uploads/2015/08/HR-Diagram-What-Types-of-Stars-are-in-our-Universe.pdf
- Hertzsprung-Russell activity materials (print on cardstock): http://www.mrsgeology.com/wp-content/uploads/2015/08/HR-Diagram-Star-Circles.pdf
- Double-sided tape
- Scissors
- White crayon or colored pencil

Preparations:
For the Hertzsprung-Russell diagram activity, you may want to cut out the star circles you printed out on cardstock as indicated above. Additionally, you may want to draw labeled coordinate axes on the butcher paper as shown in the Instructions linked above. Finally, for the purposes of the activity, it may also be helpful to separate out the colored circles you have cut out into a few groups, each containing an equal number of stars with mixed colors and sizes. Hang the butcher paper with the labeled axes up somewhere in your classroom prior to beginning.

INSTRUCTIONAL PROCEDURES

*Highlight **BLUE** for materials/**GREEN** for technology
*Highlight **PINK** for instructional strategies
*Highlight **YELLOW** for discipline-specific academic language/vocabulary

		Procedural Steps	Questions	Differentiated Instruction
Activating Strategy/ Introduction	Time 40 mins	1. Remind students that up to now, we have been learning about how we can use technology to learn about the Universe around us, and that the antenna we built to observe the invisible universe is now collecting data. Tell them that while our telescope is observing, we are now going to learn more about the Universe so we can better understand the data it produces. As you go through this	1. Do stars last forever? Why or why not? *Suggested answer: No. They run out of fuel.* 2. Where are stars born? *Suggested answers: clouds of gas and dust, nebulae, etc.*	It is up to the instructor to assess the classroom and determine how to adapt the lesson to best reach all of her/his students.

		lesson, show students the slides that were included with this lesson plan. 2. Tell your class that the first things we are going to learn about are stars! Discuss questions 1-2 with students, then tell them that just like people and animals, stars have lifespans, too – they are born, they grow up, they grow old, they die, and the cycle repeats. Tell them that a star's life starts out in a cloud of gas and dust called a nebula, which is a kind of stellar nursery. Now tell students that stars form when gas and dust in the nebula starts clumping together and eventually gets so dense that it starts to shine. Discuss question 3 with students. Then explain that when stars start to shine, this is because the star has begun fusion. Explain that fusion just means that the star is combining hydrogen atoms (which have a single proton) in its core into helium atoms (which have two protons) and that this process releases lots of energy, causing the star to shine. 3. Tell students that once stars have begun the fusion process and have started to shine, it enters the main part of its lifecycle, called the "main sequence." Explain that this is the longest stage of a star's lifespan, and that our Sun is a main-sequence star. 4. Now, discuss with students what happens at the end of a star's lifespan – go over questions 4-5 with students, then explain to them that after a star has burned through its hydrogen fuel, its core collapses and the outer layers swell and the star becomes a red giant. At this point the star begins to fuse helium atoms into other elements (as you discussed), such as carbon. After this stage, the star's progression depends on its mass. For low-mass stars, after the helium has fused into carbon, the core collapses again	3. What causes gas and dust in a nebula to clump together? *Suggested answer: the force of gravity causes clumps of dust and gas to attract and coalesce into a star.* 4. What do you think causes a star to die? *Suggested answers: they run out of fuel to burn – i.e., they have fused all of their hydrogen atoms into helium.* 5. What do you think might happen when a star begins to run out of hydrogen atoms to fuse? *Suggested answer: it will fuse helium atoms together instead).* 6. What do you think happens to the outer shell of a star after it has gone supernova? *Suggested answer: it becomes a nebula.*	

		and the outer shell is blown off and forms a nebula, and the core of the star becomes a small, cold star called a white dwarf. If the star is massive, on the other hand, after it has fused the helium in its core into carbon its gravity is strong enough to force the star to fuse carbon atoms and heavier atoms all the way up to iron. Once the core consists mostly of iron, the star undergoes a gravitational collapse, and then violently blows off its outer layers in a supernova explosion. If a star is between 1.4 and 3 times the mass of our Sun, it will now become a neutron star (also called a pulsar) which is an extremely dense stellar remnant that is smaller than a city and rotates at a very precise rate that we can measure using radio telescopes. If the star is slightly over 3 times the mass of our Sun, on the other hand, the star becomes a black hole – an object that is extremely tiny and so massive that it attracts and consumes anything that goes near it, including light. 5. Now that students have learned about the lifecycle of a star, discuss question 6. Explain that the process of stellar evolution is an endless cycle of death and rebirth – when old stars die and shed their outer layers, which contain the elements they fused in their cores, this material forms a new nebula – a place where baby stars and planets are born. Explain that the Sun was born in such a nebula, and that the elements that the Earth is made of – and that you are made of – were forged in the hearts of stars. So, as famous astronomer Carl Sagan once said, “We are made of star stuff.” 6. To reinforce these ideas and illustrate the beauty of the lifecycle of a star, have students create artwork to		

		represent one or more of the stages of a star's lifecycle. Pass out black construction paper (or cardstock), paints, paintbrushes, palettes, and water cups, and encourage students to choose one or more stages of a star's lifecycle to illustrate (i.e. nebula, newborn star, main sequence star, red giant, white dwarf, supernova, neutron star, and/or black hole). 7. Optional: After students have completed their paintings and they have dried (which will probably be on another day), hang them up in your classroom if you like and create a stellar evolution art gallery.		
Core Instruction	Time 20 mins	1. After you have completed the art activity with your students, introduce them to one more concept – the Hertzsprung-Russell (H-R) Diagram. Show them the slide with the H-R diagram on it and discuss question 1 with students. 2. Explain that the H-R diagram gives us a way to visually represent the progression of a star's lifecycle. Tell them that the diagonal line they noticed extending from the upper-left to the lower-right is comprised of main sequence stars; any star on this main branch of the graph is in the main part of its lifecycle. The clump of stars in the lower left corner are mainly white dwarfs, which are at the end of their lifecycle as we discussed earlier. The clump of stars in the top right of the diagram are giant stars, also at the end of their lifespan. Also explain that the axes of the graph are temperature (x-axis) and luminosity (y-axis), which is another way of saying "brightness." 3. Now have students do another activity. Divide students up into a few groups (the same number of groups as you	1. What do you notice about the H-R diagram? *Suggested answers: open-ended, some possibilities include the diagonal line of stars extending from the top-left to the lower-right, the clumps of stars in the lower-left and the upper-right, and how the colors of the stars change from left to right.*	

		divided the colored circles into in your preparations), then give each group of students a group of the labelled colored circles (which represent stars). Have groups take turns attaching their stars to the black butcher paper graph you prepared – make sure they know that to place their stars on the right place, they must check the temperature and luminosity of each of their stars as indicated on the circles, and place them on the corresponding places on the graph using double-stick tape. (Refer to these Instructions for guidance if necessary).		
Closure	Time 5 mins	1. After your students have finished putting their "stars" on the H-R diagram, analyze it with them. Discuss what they can infer about the stars they placed on the graph based on what you discussed earlier, and go over any questions students have. 2. Now finish up by telling students that in our next lesson, we will be discussing the evolution and life cycle of one very special star – our Sun!		

Contingency	Time	If paintings take too long, you can split this lesson into two lessons, you can have students make drawings instead, or you can assign this project as homework.		

<table>
<tr><th colspan="3">LOOP ANTENNA LESSON PLAN 12</th></tr>
<tr><td>Content Area:
Physical Science</td><td>Lesson Topic:
The Sun and Solar Activity</td><td>Length (timing) of Lesson:
~65 mins</td></tr>
<tr><th colspan="3">INSTRUCTIONAL OUTCOMES</th></tr>
<tr><td colspan="3">WV Standard(s):

S.6-8.L.3, S.6-8.L.4, S.6-8.L.12, S.6-8.L.13, S.6-8.L.16, S.6-8.L.19
S.9.ESS.1
S.9-10.L.3, S.9-10.L.4, S.9-10.L.12, S.9-10.L.13, S.9-10.L.16, S.9-10.L.19
S.11-12.L.3, S.11-12.L.4, S.11-12.L.12, S.11-12.L.13, S.11-12.L.16</td></tr>
<tr><td colspan="3">Learning Objective(s):

Students will learn where the Sun is in its lifecycle, about the 11-year sunspot cycle, the structure of the Sun, and what causes “solar weather”.</td></tr>
<tr><td colspan="3">Formative Assessment:

Students’ involvement in class discussion about the topic (asking insightful questions, giving answers or making comments that suggest an understanding of the material), the quality of their solar models, and the quality of their sun observation assessments will provide a measure of their mastery of this subject.</td></tr>
<tr><th colspan="3">PREPARATION</th></tr>
<tr><td colspan="3">Materials Needed:
- Link to Space Weather forecast page: http://www.spaceweather.com/
- Sun Diagram templates – print one for each student (incl. in Loop Antenna Lesson Plan Attachment A)
- Construction paper in warm colors (red, orange, yellow, and black)
- Scissors
- Tape and/or glue
- Markers, colored pencils, and/or crayons
- Video of a solar flare: https://www.youtube.com/watch?v=HFT7ATLQQx8
- Projector
- Binoculars or very small telescope</td></tr>
</table>

- Clipboard
- White paper
- Lab report forms – 1 for each student (incl. in Loop Antenna Lesson Plan Attachment A)
- Reference on the Sun's structure (for instructor's reference): https://www.nasa.gov/mission_pages/sunearth/science/solar-anatomy.html

A Safety Precaution: While this lesson focuses on the Sun and includes experiments to observe it, remember that looking at the Sun with the naked eye, with binoculars, through a telescope, using a camera, or any other way will cause lasting damage to the retina resulting in potential loss of vision. So, make sure to remind your students often to ***never look directly at the Sun!***

INSTRUCTIONAL PROCEDURES

*Highlight **BLUE** for materials/**GREEN** for technology
*Highlight **PINK** for instructional strategies
*Highlight **YELLOW** for discipline-specific academic language/vocabulary

		Procedural Steps	Questions	Differentiated Instruction
Activating Strategy/ Introduction	Time 40 mins	1. Remind students that in our last lesson, we learned about the lifecycles of stars of different masses. Tell them that today, we will be learning in detail about one star we are all very familiar with – the Sun. Discuss question 1 with students, then tell them that the Sun is about 5 billion (5,000,000,000, or 5 thousand million) years old, and it is only about halfway through its lifespan. Tell them that like every other star, the Sun was born in a nebula and that when the Sun dies, like other low-mass stars it will expand into a red giant then collapse into a white dwarf (if you feel that learning about the Sun's death may disturb your students, feel free to leave it out. However, if you do cover this, remind them that this won't happen for several billion more years). Emphasize that the Sun is not unusual as far as stars go, so if we can understand the Sun, we have a better opportunity to understand other stars in our Universe.	1. What stage do you think the Sun is in its lifecycle? Do you remember? *Suggested answer: Main sequence*. 2. What do you notice about the diagram of the Sun's layers? *Suggested answers: open-ended, possibilities include the fact that the outer layers of the Sun (the photosphere and chromosphere) are much thinner than the other layers, etc.* 3. What do you think is the hottest layer of the Sun? The second hottest? The third hottest? And so on. *Suggested answer: In order from hottest to coolest: The core (15 million degrees Kelvin), the radiative zone (2 to*	It is up to the instructor to assess the classroom and determine how to adapt the lesson to best reach all of her/his students.

		2. Tell students that like the Earth, our Sun has many layers. Show them the diagram of the Sun's anatomy from the included link (https://www.nasa.gov/mission_pages/sunearth/science/solar-anatomy.html) – either project it on a screen or print it out and pass it around the room. Explain to students what each layer of the Sun is called and what it does: -The core is the Sun's innermost layer; this is where the fusion we discussed in our last lesson takes place. This process generates lots of energy. -The radiative zone is the layer of the Sun just outside the core; in this region, energy from the Sun's core (in the form of light particles called photons) travel outward toward the Sun's next layer… -In the convective zone, the energy from the core continues to travel outward, only now it is buffered by currents of hot and slightly cooler gas. -The next layer of the Sun is called the Photosphere, and this is the layer of the Sun that we can see in visible light using protected telescopes and cameras (remember to NEVER look directly at the Sun). -Outside the photosphere, the next layer of the Sun is called the chromosphere, and this region contains strong magnetic fields which hold the electrically charged plasma that the Sun is made of in place. (Plasma is the fourth state of matter, and it is made up of lots of charged subatomic particles – like protons, for example – flying around).	*7 million degrees Kelvin), the convective zone (5800 to 2 million degrees Kelvin), the corona (about 1 million K), chromosphere (4300 to 8300 K), photosphere (about 5800K). Where some of these overlap in temperature range, the order can vary).*	

		-Finally, the outermost layer of the Sun is called the solar corona. This layer of the Sun is composed of a thin outer halo of gas, which we can only see during a solar eclipse unless we use X-Ray and Ultraviolet imagers. 3. Discuss questions 2-3 with students; while discussing question 3 make sure to tell them the temperature of each layer once they figure out the right order. Explain that the term Kelvin refers to a way of measuring temperature like Fahrenheit or Celsius, but instead of starting at some arbitrary point as those temperature scales do, it starts at absolute zero, which is the coldest that any object can ever be. Tell them that absolute zero Kelvin (or K) is equal to about -273°C or -468° F. 4. Now that you have discussed the Sun's structure, do an activity with your students to reinforce this new concept. Set out construction paper, tape and/or glue, drawing tools, and scissors, and pass each student a printed-out template to create their own Sun models out of paper. Make sure students follow instructions on the template in assembling their models.		
Core Instruction	Time 20 mins	1. Next, we will learn about how the Sun's structure affects its behavior. Discuss question 1 with students. Now explain to students that sunspots and solar flares are believed to form near or just above the Sun's photosphere. Both sunspots and solar flares occur as a result of activity in the Sun's magnetic field, but scientists are not sure exactly what causes them to form; below is one way scientists have hypothesized that solar flares may be formed: "Imagine the magnetic field on the Sun as loops like rubber bands that wrap around the Sun, with one end attached to	1. Can you name some things that happen at the Sun's surface (near the photosphere)? *Suggested answers: sunspots and solar flares.*	

		the south pole and the other end attached to the north pole. The Sun is rotating, so as the Sun rotates, the magnetic loops wrap tighter and tighter until it is wound up so tight that the fields ('rubber bands') snap! Where the magnetic field snaps is where active regions on the Sun form and where the flare erupts on the solar surface." (from http://solar-center.stanford.edu/FAQ/Qsolflares.html). Explain to students that both sunspots and solar flares get more active every 11 years during a period of time called "solar maximum". This 11-year cycle is called the solar cycle, and it happens because every 11 years the Sun's magnetic poles flip (north becomes south and south becomes north), and this causes an increase in solar activity. To see what the Sun's current activity is like, check out this website with your students: http://www.spaceweather.com/. 2. To give students an idea of what solar flares look like, show them this video (https://www.youtube.com/watch?v=HFT7ATLQQx8) from NASA depicting a 2012 solar flare event. Discuss the video with your students, and point out anything you find interesting about it. 3. To wrap up this investigation of extreme solar activity, now do an experiment. Pass out lab report forms to each student, and gather the clipboard, white paper, and binoculars (or telescope) and head outside (note that this experiment will only work if the Sun is unobscured by clouds). Clip the white paper into the clipboard, then have one of your students hold the board so that it is angled toward the Sun (i.e. there is a lot of sunlight falling on the paper). Now, pick up the binoculars or telescope (note that if you are using binoculars, you may want to cover one of		

		the lenses because only one is necessary to this experiment), then, being very careful NOT to look through the eyepiece, try to angle the binocular or telescope so that the Sun beams through it onto the paper – refer to the instructions on pg. 15 of this document: http://solar-center.stanford.edu/solar-weather/Space-Weather-Forecast.pdf. 4. Once you have projected the Sun onto the clipboard, have your students look at the projected image (NEVER at the real Sun), and quickly sketch what they see on their lab reports in the Measurements section. Make sure to point out any features on the solar disk like sunspots, and encourage them to record those in their sketches.		
Closure	Time 5 mins	1. After completing this experiment and returning to the classroom, have your students fill out the rest of their lab reports and discuss what happened with the experiment – was it successful? What would you have improved about it if you could do it again? And so on. 2. Wrap up by telling students that at our next class, we will be learning about ways that we can experience solar activity on Earth.		

Contingency	Time	If the sun is behind clouds or the weather is foul, do the sun projector experiment another day. If the sun diagram activity and/or completing the lab reports takes too long, assign these items as homework.		

LOOP ANTENNA LESSON PLAN 13		
Content Area: Physical Science	Lesson Topic: The Aurora Borealis	Length (timing) of Lesson: ~55 mins

INSTRUCTIONAL OUTCOMES

WV Standard(s):

S.6-8.L.4, S.6-8.L.18
S.9-10.L.4, S.9-10.L.18
S.11-12.L.4, **S.11-12.L.18**

Learning Objective(s):

Students will learn how the aurora borealis is formed as a result of the Earth's magnetic fields' interaction with particles from the Sun, and how this cosmic wonder affected ancient civilizations.

Formative Assessment:

Students' involvement in class discussion about the topic (asking insightful questions, giving answers or making comments that suggest an understanding of the material) and the quality of their aurora-inspired myths will demonstrate their mastery of the subject.

PREPARATION

Materials Needed:

- Reference about the aurora borealis (for instructor's use): http://earthsky.org/earth/what-causes-the-aurora-borealis-or-northern-lights
- Video about the Aurora Borealis by Prof. Brian Cox: https://www.youtube.com/watch?v=Zlk3RmL7NHE
- Native American Myths about the Aurora Borealis: http://www.native-languages.org/northern-lights.htm
- Projector
- Paper and pencils

INSTRUCTIONAL PROCEDURES

*Highlight **BLUE** for materials/**GREEN** for technology
*Highlight **PINK** for instructional strategies

*Highlight **YELLOW** for discipline-specific academic language/vocabulary				
		Procedural Steps	**Questions**	**Differentiated Instruction**
Activating Strategy/ Introduction	Time 10 mins	1. Tell students that while in our last lesson, we learned about the Sun and solar activity, today we will learn about one way people have been able to directly observe the Sun's influence on the Earth – the Northern Lights. 2. Discuss questions 1-2 with students. Explain that the Northern Lights appear as shafts of colored lights in the night sky, and that they can be seen from high latitudes on Earth. Tell them that there is a similar phenomenon in the southern hemisphere called the Aurora Australis that is visible from low latitudes. 3. Discuss question 3. Now explain to students that the aurora borealis is caused by the interaction of particles from the Sun with the Earth's magnetosphere. The magnetosphere is the magnetic field that surrounds the Earth connecting its North Pole to its South Pole. When solar flares or other violent events called Coronal Mass Ejections (CMEs, which are giant bubbles of gas that are ejected from the Sun) occur, solar particles are hurtled through space toward the Earth. When these solar particles get through the Earth's magnetosphere, by riding on the magnetic field they are accelerated toward the Earth's poles where they collide with particles in the atmosphere. These collisions excite the particles in the atmosphere and cause them to emit light, which we see as the Aurora Borealis (or Aurora Australis). 4. Explain that the Earth's magnetosphere protects the planet from most potentially harmful high-energy particles	1. Have you ever heard of the Northern Lights? Have you ever seen them? *Suggested answers: open-ended.* 2. What is another name for the Northern Lights? *Suggested answer: the Aurora Borealis.* 3. What do you think causes the aurora borealis? *Suggested answers: open-ended.*	It is up to the instructor to assess the classroom and determine how to adapt the lesson to best reach all of her/his students.

		from the Sun by deflecting these particles; in most cases, this shield works so well that the only thing we experience on Earth are beautiful light displays in the sky.		
Core Instruction	Time 40 mins	1. After discussing the cause of the Aurora Borealis, watch the linked video (https://www.youtube.com/watch?v=Zlk3RmL7NHE) of particle physicist Professor Brian Cox discussing and witnessing the Northern Lights. Discuss the video, then go over question 1 with students. 2. Tell students that while we now have a scientific understanding of what causes the Aurora Borealis, for thousands of years ancient people did not know what caused these mysterious lights, so they came up with mythical explanations of why they occurred. Many cultures throughout history developed their own myths explaining the aurora; some believed the aurora were portents of doom, while others thought them to be the spirits of their ancestors, and so on. 3. There is a particularly rich tapestry of stories surrounding the Northern Lights in Native American mythology. Discuss question 2 with students. Now, refer to the link provided (http://www.native-languages.org/northern-lights.htm) and read some of the myths linked from this page, and discuss them with your students. While students may find some of them amusing, encourage them to think about these stories as if they were an ancient person without access to technology or Google – what would they have thought about these lights, and how would they explain them? 4. Which brings us to today's activity! Pass out paper and pencils (or let students use their own) and invite them to	1. What did the Northern Lights look like to you? How do you think it would feel to watch a light display like that in person? Would it give you a better understanding of the Earth's interaction with its outer space environment? *Suggested answers: open-ended.* 2. Why do you think that the aurora borealis feature prominently in Native American mythology? *Suggested answers: open-ended, possibilities include: because the ancient people of America spent a lot of time observing nature and following its patterns.*	

		write their own myths explaining the aurora borealis. The stories can be serious or humorous depending on your and your students' preferences. After students have completed their stories, if you want you can have them read their myths to the rest of the class, and see if there are any common themes among their myths.		
Closure	Time 5 mins	1. After you have finished creating your own Aurora Borealis myths, wrap up by telling students that while in this lesson we discussed harmless (and, in fact, beautiful) ways that the Sun affects Earth, in our next lesson we will learn what happens when the Sun's energy is so strong that it can be dangerous to our technologies and systems on Earth.		

Contingency	Time	If the myth-writing exercise is going on for too long, have students complete them as homework.		

LOOP ANTENNA LESSON PLAN 14		
Content Area: Physical Science	Lesson Topic: The Sun's Effect on Earth and Communications	Length (timing) of Lesson: ~55 mins
INSTRUCTIONAL OUTCOMES		
WV Standard(s): **S.6-8.L.3, S.6-8.L.4, S.6-8.L.12, S.6-8.L.13, S.6-8.L.16, S.6-8.L.19** **S.9-10.L.3, S.9-10.L.4, S.9-10.L.12, S.9-10.L.13, S.9-10.L.16, S.9-10.L.19** **S.HS.PS.17** **S.11-12.L.3, S.11-12.L.4, S.11-12.L.12, S.11-12.L.13, S.11-12.L.16, S.11-12.L.19** **S.HS.P.14**		
Learning Objective(s): Students will learn how solar activity can affect radio communications and power grids on Earth, and how the Sun can be a source of power for Earthlings.		
Formative Assessment: Students' involvement in class discussion about the topic (asking insightful questions, giving answers or making comments that suggest an understanding of the material), their participation in the solar energy experiment, and the quality of their lab reports will demonstrate their mastery of the subject.		
PREPARATION		
Materials Needed: - Small solar car kit(s) - Flashlight - Lab report templates (incl. in Loop Antenna Lesson Plan Attachment A) *Note that if you want to build more than one solar-powered car with your class, you will need to get extra solar car kits.		
INSTRUCTIONAL PROCEDURES		

*Highlight **BLUE** for materials/**GREEN** for technology
*Highlight **PINK** for instructional strategies
*Highlight **YELLOW** for discipline-specific academic language/vocabulary

		Procedural Steps	Questions	Differentiated Instruction
Activating Strategy/ Introduction	Time 15 mins	1. Remind students that while in our last lesson, we learned about a way that solar activity can cause beautiful natural phenomena, today we will be learning about how it can affect our everyday lives, both for good and for bad. 2. Discuss question 1 with students. Now tell them that when the Sun undergoes periods of extreme activity, it poses a threat to our technologies on Earth. Explain that when particles stream toward the Earth from a particularly strong solar flare, radio antennas on Earth (which are used not only for traditional radio transmissions but also for transmitting cell phone signals among many other functions that we use in our everyday lives) pick up these particles and turn them into an electric current (just like our antenna!), and this causes static in the signals; in extreme cases it can even overload and burn out electronic equipment. In addition to impacts on communications and antennas on Earth, in the case of a really large CME (remember that this is a violent solar event which we learned about in our last lesson), our power grids could face potentially catastrophic damage. Solar particles streaming in from a really large CME would induce currents to flow in our power grids that could overload them and cause them to blow out. In the event of a really large solar storm this could destroy the Earth's power grid and leave us without electricity for an extended period of time. Discuss question 2.	1. Can you think of some ways that a lot of solar activity could negatively impact us? *Suggested answers: extreme solar activity can negatively impact radio communications and even (in rare cases) power grids.* 2. If the Earth lost its power in the event of a large solar storm, what do you think would happen? How do you think you would react? What do you think some effects of this might be on society as a whole? *Suggested answers: open-ended.* 3. Do you think a giant solar storm would have affected people as much in 1859 as it would now? What do you think the storm might have affected in those days? *Suggested answers: open-ended. Possibilities for the storm's effects include: it impacted telegraph communications.*	It is up to the instructor to assess the classroom and determine how to adapt the lesson to best reach all of her/his students.

		3. Tell students that as a matter of fact, a really large solar storm like this did hit the Earth in 1859. Discuss question 3, then explain that the storm was called the Carrington Event after the astronomer (Richard Carrington) who observed flares on the Sun preceding the event. During this time the Earth was bombarded with a succession of CMEs, which caused aurora to be visible far from the poles, and overloaded telegraph wires which shocked telegraph operators and caused fires to start. Fortunately, phenomena like the Carrington Event are rare, and most of the effects we see from the Sun are nowhere near this catastrophic. 4. Explain to students that while we understand what kinds of damage extreme solar activity can cause, scientists still don't really know how to predict violent events like solar flares in advance, so we have no warning when a solar storm is about to hit and we have little-to-no time to prepare for such an occurrence. Tell them that this is why it is so important to research the Sun as we are doing with our loop antenna. Monitoring our Sun's activity in a variety of ways, such as with telescopes at multiple wavelengths, as many professional astronomers do, and by monitoring the effect of solar activity on our Earth's ionosphere, like we are doing, can give us valuable new insights into the Sun's behavior which could eventually lead scientists to have a better understanding of how to forecast these hazardous solar weather outbursts. Tell students that data you take with your loop antenna could directly benefit the scientific community – a group called the Stanford Solar Center (part of Stanford University) is collecting data from antennas like ours and using them for high-level solar research, so if you send your data in to them, they can use		

		it in their research to improve scientific understanding of our Sun.		
Core Instruction	Time 35 mins	1. Now that you have gone over the potentially hazardous outcomes of the Sun's activity, tell students that you will now learn about how the Sun can help us. Of course, we wouldn't be here without the Sun – its energy gives us the light and heat we need to survive, and it powers photosynthesis among plants (photosynthesis is a process that allows plants to turn sunlight and carbon dioxide in the air into sugars that they can consume for energy). Humans are learning to use the Sun's energy to power our lives, too – we can use solar panels to get energy from the Sun. 2. Explain to students that solar energy is considered a renewable energy source – a resource which never runs out and comes from natural sources. Discuss questions 1-2 with students, then tell them that while renewable energy sources are not as widely used as non-renewable energy sources right now, they are becoming more and more widespread. Discuss question 3 with students. 3. Now explain to your class that solar panels are composed of many photovoltaic cells (PV cells) linked together. PV cells are made of silicon, and when the Sun's light hits a PV cell, it knocks electrons loose and these electrons travel to conductive plates in the PV cell. The movement of these electrons creates a current and this generates electricity. The more PV cells you link together in a solar panel, the more energy you can produce. 4. Tell students that you will now do an experiment to test out how solar panels work. Pass out lab report templates, then set out the solar car kit(s). Make sure that students	1. What is another example of a renewable energy source? What about an example of a non-renewable source? *Suggested answers: renewable energy sources include wind, water, etc. Non-renewable sources include fossil fuels like oil and coal.* 2. Do you think renewable resources or non-renewable resources are better for the environment? *Suggested answers: renewable resources, because producing and processing them results in less pollution, or harm to Earth's air and water.* 3. Why do you think it has taken so long for renewable energy sources to catch on? *Suggested answers: we had to figure out how to turn wind, water, and the Sun's light into energy we could use; renewable energy sources were more expensive than non-renewable energy, though they are getting increasingly cheaper to use.*	

		keep track of their hypotheses and methods in their lab report. How you do this activity will depend on whether you decide to build one car or several cars; if you are just building one, try to make sure your students observe the construction of it so they can see how it works; on the other hand, if you have several car kits, have each student build a car or separate students into groups and have each group build a car together. Follow the instructions included with the kit build the car(s), then take the car(s) outside and set it (them) in the sunlight for about 10 minutes (make sure to bring the flashlight with you). At this point, experiment with the car to get it to drive – if the sunlight alone isn't enough, shine the flashlight on the solar panel and see if this gives it a boost. Have students write down their observations and conclusions in their lab reports.		
Closure	Time 5 mins	1. After you have completed the solar energy experiment, tell students that next week, we will be completing our observations with the loop antenna and will learn to read the data graphs it produces and see what our observations reveal!		

Contingency	Time	If it is not sunny outside, do the solar activity experiment on another day, or try to do it indoors using a flashlight or lamp as a power source. If you run out of time, assign the lab reports as homework.		

LOOP ANTENNA LESSON PLAN 15		
Content Area: Physical Science	Lesson Topic: How to Interpret Data from the Loop Antenna	Length (timing) of Lesson: 55 mins
INSTRUCTIONAL OUTCOMES		
WV Standard(s): **S.6-8.ETS.3, S.6-8.ETS.4** **S.6-8.L.4** **S.9-10.L.4, S.9-10.L.7, S.9-10.L.16** **S.HS.PS.24** **S.11-12.L.4, S.11-12.L.7, S.11-12.L.16** **S.HS.P.23**		
Learning Objective(s): Students will be able to read time series and spectrum plots produced by the antenna and will interpret the plots to find evidence of sunrise/sunset signatures, interference, and solar flares.		
Formative Assessment: Students' involvement in class discussion about the topic (asking insightful questions, giving answers or making comments that suggest an understanding of the material), their participation in the verbal analysis of the data you've collected, and the quality of their data collection sheets will demonstrate their mastery of the subject.		
PREPARATION		
Materials Needed: - Slides on spectrum plots, time series plots, and data examples (incl. in Loop Antenna Lesson Plan Attachment C) - Projector - Small Loop Antenna Instruction Manual (incl. in Loop Antenna Lesson Plan Attachment D) - The computer you are using to record data from the antenna - Data collection sheets that you started when you began your observations in Lesson 10.		

INSTRUCTIONAL PROCEDURES *Highlight **BLUE** for materials/**GREEN** for technology *Highlight **PINK** for instructional strategies *Highlight **YELLOW** for discipline-specific academic language/vocabulary				
		Procedural Steps	**Questions**	**Differentiated Instruction**
Activating Strategy/ Introduction	Time 20 mins	1. Remind students that in our last lesson, we learned about the reasons it is important to understand our Sun. Tell them that today, we will be analyzing the data we took with our antenna to see what discoveries we have made! 2. So, before we start analyzing our antenna's data, we need to understand what we will be looking at! Explain to students that our loop antenna's data will appear in the form of two graphs, and tell them that each of those graphs tells us something different about the signal we've detected. Tell them that these two graphs are called a spectrum plot (also called a bandpass plot) and a time series plot. Discuss question 1 with students, then explain that an analogy to a spectrum plot would be like making a chart describing the brightness of a particular rainbow – the spectrum plot would tell you how bright each color is. The idea of a spectrum plot in this situation is the same, but instead of looking at visible colors, we are looking at invisible radio colors. Another analogy would be to say that a spectrum plot shows you the intensity of different channels on the radio – e.g. your graph would have the radio channel (like 97.9, etc.) on the x-axis (horizontal axis) and how strong the signal is would be indicated by the height of the graph above the x-axis. Project the slide with the example spectrum plot on it and remind them that the x-axis tells the frequency while the y-axis tells the intensity. Explain to them that the purpose of this kind of plot for our	1. Based on its name, do you have any idea what a spectrum plot might tell you about your signal? (Remember what an optical spectrum is, and what the differences are between the colors?) *Suggested answers: the spectrum plot tells us about the different frequencies of radio waves we are picking up, and how the intensity of the signal changes with frequency.* 2. Can you guess what a "time series plot" shows? Think about the name, and about what we are trying to measure with our antenna! *Suggested answer: a time series plot shows a graph of the intensity (or strength) of one frequency of the signal we are picking up over time.* 3. What are the most noticeable features of this graph? *Suggested answers: the two big dips in the signal.* 4. Do you notice anything about the time that these dips occurred? What could that mean? *Suggested answer:*	It is up to the instructor to assess the classroom and determine how to adapt the lesson to best reach all of her/his students.

		loop antenna observations is to make sure we are picking up the 24-kHz submarine communication signal – it is really a "sanity check" that doesn't tell us much about our observations except that we have, in fact, detected the signal we need to. The other important graph we are going to be learning about today is called a time series plot. Discuss question 2. Explain that, to use one of our analogies from earlier, the time series plot would be like tuning your radio to channel 97.9 then graphing how the intensity of that one radio station changed over time. Except, in this case, the channel isn't Magic 97.9, it's the 24 kHz submarine communication signal. Show them the slide with an example of a time series plot, reminding them that the x-axis represents time while the y-axis (again) represents intensity. Tell them that this plot gives us the most important information about our signal – by analyzing the time series plot and looking for large decreases or increases in the signal, we can deduce whether we've detected any solar activity, human-made interference, or other effects that we will now talk about. 3. To prepare students to analyze their own data, show them the slide with the image from the Stanford Solar Center showing sample data taken with a similar loop antenna on a quiet day (no solar flares). Discuss questions 3-4 with students, and explain that these dips are caused when the Sun strikes the ionosphere at a strange angle because it is setting (or rising), and this often causes the submarine communication signals to bounce off the ionosphere in a way that cancels the submarine communication signals out, therefore making the signal we detect weaker.	*the dips occurred near sunrise and sunset – this may mean that the sun does something interesting at these times of day.* 5. So what do you notice about this graph that wasn't in the last graph? What do you think caused these features to appear? *Suggested answers: the giant spikes, and they were probably caused by solar activity like solar flares.*	

		Now flip to the next slide, showing Stanford data from a day with solar flares. Discuss question 5 with students, then remind them that when a solar flare strikes the Earth's ionosphere, the ionosphere becomes more ionized and reflects our submarine communication signal at a lower angle, making it appear stronger and showing up as a big spike in our graph. Now, to encourage students, show them the slide displaying data taken with a loop antenna very similar to theirs by me (Ellie) when I was a high school student – if another student can do it, so can you! Point out that the spikes in this graph are also due to solar activity, and discuss this data plot with them to see what observations they have about it; i.e., if they notice that this graph is more wiggly than the Stanford graph, explain that this is likely due to interference (radio waves coming from electronic devices) around the area where the student recorded this data. Show students the slide displaying an example of interference to illustrate what it may look like in their data graphs.		
Core Instruction	Time 40 mins	1. Now that your students have an understanding of what they will be looking at when the observations come in, it's time to complete the observing process with our loop antenna. Make sure students have the data collection sheets they started when you began your observations, and also make sure you have the Small Loop Antenna Instruction Manual on hand. Refer to the section: "Taking Data with Your Loop Antenna->Completing Your Observations", and follow the steps outlined there to complete your observing run and display your data using the Python program we discussed earlier. Make sure students can either participate in or watch you perform the steps in the instruction manual, and be sure to prominently		

		display the data plots (perhaps using the projector) once you have them up. 2. Discuss the graphs with your students. (Note that you can zoom in on the plots by dragging a box around the region you want to zoom in on in the Python plots). If possible, you may also want to print out copies of the graphs and pass them around to your students so they can circle any interesting features they notice on paper. In the spectrum plot, there should be a number of interesting features, but the most prominent one will be a large spike in the center that dominates everything else in the graph. Explain that this spike is actually not our 24 kHz signal – it is coming from the upconverter part of our antenna setup, and the fact that this spike is there means that the upconverter and the software are working properly. If you zoom in on the plot near the 125.024 MHz (± 0.005 MHz or so) mark on the x-axis, there should be a very small spike in the graph there – this is your 24 kHz submarine communication signal! (Note that the frequenciy channels of the signal start at about 125 MHz and increase from there; this is just a result of the way the upconverter combines the incoming signal with its own signal to make it so the software can process it). Encourage students to point out any other noticeable features in the graph and make suggestions as to what they might be (many of the other spikes will be due to either interference from sources like electronic devices or lightning, or other radio stations – this could be a good thing to investigate!) Make sure students are taking notes in their data collection sheets about what they observe. 3. Next, move on to your time series plot. Ask students what features they see in this graph – do they see any dips		

		in the signal that could be sunrise or sunset signatures? What about solar flares? Anything that looks like interference? Any other strange features? Again, make sure students take careful notes of their observations in their data collection sheets – this will come in handy in our next lesson. Discuss these at length, and if you come across anything really unusual or cool that you would like to learn more about, remember that you and your students are always welcome to email us on the Open Source Radio Telescopes mailing list to share your results and ask questions!		
Closure	Time 5 mins	1. Finally, wrap up today's session by telling students that now that we've made our observations and analyzed them, we will be doing what all good scientists do – we will be writing up detailed reports and presentations about our experiment so that we can share our results with others and have a lasting record of the work that we did and the discoveries that we made.		

Contingency	Time	It is up the instructor to determine how best to adapt or change this lesson if necessary.		

LOOP ANTENNA LESSON PLAN 16		
Content Area: Physical Science	Lesson Topic: Scientific Papers and Presentations	Length (timing) of Lesson: 75 mins

INSTRUCTIONAL OUTCOMES

WV Standard(s):

S.6-8.L1, S.6-8.L.5, S.6-8.L.6, S.6-8.L.7, S.6-8.L.8, S.6-8.L.9, S.6-8.L.11, S.6-8.L.12, S.6-8.L.13, S.6-8.L.14, S.6-8.L.15, S.6-8.L.16, S.6-8.L.17, S.6-8.L.18, S.6-8.L.19

S.9-10.L.1, S.9-10.L.5, S.9-10.L.6, S.9-10.L.7, S.9-10.L.8, S.9-10.L.9, S.9-10.L.10, S.9-10.L.11, S.9-10.L.12, S.9-10.L.13, S.9-10.L.14, S.9-10.L.15, S.9-10.L.17, S.9-10.L.18, S.9-10.L.19

S.11-12.L.1, S.11-12.L.5, S.11-12.L.6, S.11-12.L.7, S.11-12.L.8, S.11-12.L.9, S.11-12.L.10, S.11-12.L.11, S.11-12.L.12, S.11-12.L.13, S.11-12.L.14, S.11-12.L.15, S.11-12.L.17, S.11-12.L.18, S.11-12.L.19

Learning Objective(s):

Students will be able to represent their scientific findings in the format of scientific papers and presentation slides. They will incorporate their own observations from the loop antenna experiment and compare these results to the findings of others. Students will also learn about the importance of null (or negative) results in science.

Formative Assessment:

Students' involvement in class discussion about the topic (asking insightful questions, giving answers or making comments that suggest an understanding of the material) and the quality of their presentations and final reports will demonstrate their mastery of the subject.

PREPARATION

Materials Needed:

- Computer(s) with access to the Internet
- Research question sheets (incl. in Loop Antenna Attachment A)
- Data collection sheets completed in Lesson 15
- Link to relevant E-Book (for instructor's reference): https://doi.org/10.1117/3.2317707.sup

Note to instructor: It would be optimal to do this activity in your school's computer lab. If your school does not have a computer lab or any computers available to students, another option would be to combine today's lesson with a field trip to the local public library in order to make use of the materials and resources available there.				
INSTRUCTIONAL PROCEDURES *Highlight **BLUE** for materials/**GREEN** for technology *Highlight **PINK** for instructional strategies *Highlight **YELLOW** for discipline-specific academic language/vocabulary				
		Procedural Steps	**Questions**	**Differentiated Instruction**
Activating Strategy/ Introduction	Time 10 mins	1. Start today's lesson by discussing your experimental results from the last lesson with your students, using questions 1-3 and any other questions or prompts you think of to guide the discussion. Encourage them to write down any thoughts, questions, or ideas that come to them about the loop antenna experiment and to keep them close by. 2. Explain to students that part of being a scientist is doing experiments in the lab and making careful records of the data we took in doing these experiments, but there is more to being a scientist than just doing lots of experiments. Discuss questions 4-5 with students. 3. Now tell students that when researchers do experiments and learn something new, one of the most important parts of their job is to share their discoveries with others. Discuss question 6 with students. Explain that in science, a negative result (meaning you didn't find anything new or unexpected) is called a "null result" ("null" is just another word for zero). Re-emphasize that null results are just as important as positive results, as you just discussed.	1. What did you think was the most interesting part of our loop antenna experiment? *Suggested answer: open-ended.* 2. What did you learn from doing this experiment that you didn't know before? *Suggested answer: open-ended.* 3. What didn't go so well about this experiment? What could have been done to improve it? *Suggested answer: open-ended.* 4. After scientists do their experiments and record their data, what do you think they do next? *Suggested answer: They communicate their findings to others.* 5. Why do you think scientists might want to share their discoveries with	It is up to the instructor to assess the classroom and determine how to adapt the lesson to best reach all of her/his students.

		4. Tell students that when professional researchers want to share their scientific results, they write scientific papers and publish them in peer-reviewed journals, which is just a fancy name for a published collection of scientific papers that are reviewed and edited by experts to make sure they are high-quality and original so that no one plagiarizes anyone else's work or tries to publish something that is incomplete or of poor quality. Scientists around the world read the same journals, so if a researcher publishes a paper in a journal (called a "journal article"), then scientists from around the world can read about their work and perhaps will be inspired to pursue similar research or collaborate with the original author on research projects to follow up on a point that the author didn't have the time or resources to do on their own.	others? *Suggested answers: open-ended. Possibilities include: so that other people can build on their work, so they get credit for their discoveries, so that the public knows about the importance of their research, etc.* 6. Do you think it's important for scientists to share their results even when they don't find anything (i.e. they didn't detect any solar flares with their loop antenna)? Why or why not? *Suggested answer: Yes! It is important for scientists to share their findings even if they don't detect anything, because negative results can teach us something too – in the loop antenna example, the fact that we didn't detect solar flares can tell us that perhaps there is no solar activity going on right now, or that we need to do something to improve our loop antenna so that it is capable of detecting solar flare signatures. These outcomes would be just as important to share with your colleagues as a successful one.*	
Core Instruction	Time 60 mins	1. Tell students that today, you are going to start writing your own scientific papers so that future students and scientists can learn from your results. Here you have a few options – you can split students into groups of however many you like (preferably no more than about 5) to work on their research papers, or you can let them write their papers on their own. You can also decide whether to give	1. Why do you think it might be advantageous for scientists to give oral presentations of their findings in addition to publishing written papers? *Suggested answers: open-ended. Possibilities include: at presentations, other scientists can ask them questions*	

		all of your students the same research question sheet or if you would rather give each group (or each student) a different research question sheet to direct their paper composition. Once you have split students into groups (or not) and passed out the research question sheets, move on to the next step. 2. Explain to students that scientific papers generally follow a consistent format, often abbreviated as IMRaD, which stands for: -Introduction: this is the part of your paper where you give a brief overview of your research, and tell readers why it matters by relating it to past research that has been done in this field. - Methods: this is where you describe in detail the experiments you did. -Results and Discussion: in this section, you explain what results you obtained with your experiment and what this could mean – i.e., if your results were that you detected big spikes in your loop antenna data graph, your discussion would try to explain these results by saying something like "the big spikes in our data graph could be due to a detection of solar flares or interference"). In addition to these "IMRaD" steps, there are often a few other components to a scientific paper: -Abstract: The abstract comes at the beginning of the paper, before the introduction. The abstract is a very brief summary of why you did your experiment, how you did it, what your results are, and what those results mean. The abstract is generally not more than a few sentences long.	*immediately, presenters can adapt their presentation to the audience to make it more engaging, etc.*	

		-Conclusion: The conclusion comes after the "Results and Discussion" section, and gives a brief summary of the results of the experiment, but instead of just restating your "Results and Discussion", the conclusion is a great place to say what could be done next, to follow up on your experiment and learn more. -References: the final section of most scientific papers is the References section, and this is where scientists list the books, papers, and other resources they referred to when doing their experiment and writing their paper. This is how scientists give one another credit for their work. So, in summary, here is an outline for how a research paper should look: 0. Abstract (the abstract isn't a numbered section) 1. Introduction 2. Methods 3. Results and Discussion 4. Conclusion 5. References 3. Now, tell students that their job as scientists is to write their own scientific papers about the loop antenna experimental results. Each student (or student group) must write their paper with a focus on the topics outlined on their research questions sheet. Instruct students (or student groups) to work at computers and use a word processor (like Microsoft Word or Google Docs) to write their papers (show them how to do this if necessary), making sure to create sections with the titles listed above in the proper order.		

		4. Tell students to now begin writing their papers by incorporating information from their data collection sheets and from resources they find online. Remind students that not all sources they find on the internet are reliable; encourage them to use NASA websites and to find articles using the Google Scholar search engine, and to use other reliable sites. Tell them to consult you if they are unsure of a site's credibility, and remind them to record the author, title, web address, and publication date of the sources they find in the "References" section. 5. After students have worked on their papers for an amount of time you deem appropriate, assign further work on papers as homework and move on to the next topic. Tell students that another way that scientists communicate their ideas to one another is by giving presentations to their colleagues at large meetings called conferences, where scientists from around the world meet up to talk with each other about the research they are doing. Discuss question 1 with students, then tell them that we are going to write and give our own presentations. 6. Show students how to create presentation slides using PowerPoint or Google Slides. Then encourage each student (or student group) to create a presentation about their research (on the same topics as their papers, just in presentation format instead of paper format). Tell them that the presentations should roughly follow the same format as the papers did, and that they should be roughly 5-10 slides long (plan to spend 1-2 minutes on each slide). If you are doing this in groups, make sure that the presentations are long enough that each student in the group gets a chance to work on at least 1-2 slides each.		

Closure	Time 5 mins	1. After students have completed their presentations (or worked on them for a while), encourage students to practice presenting their slides as homework, and assign any remaining work on papers and presentations as homework as well. Tell them that at the end of this unit, we will be having our own scientific conference in which we will be presenting our research and discussing what we've learned over the course of this project. Tell them that while today we focused on how to write up our results in a technical way, in our next lesson we will focus more on creatively representing what we've learned.		
Contingency	Time	This lesson covers a lot of material, so you may find it more practical to spread it over two lessons – one for scientific papers, one for presentation preparations. Or, if you are short on time, you may choose to just cover paper-writing or just cover presentations.		

LOOP ANTENNA LESSON PLAN 17		
Content Area: Physical Science	Lesson Topic: Conclusion	Length (timing) of Lesson: 65 mins
INSTRUCTIONAL OUTCOMES		
WV Standard(s): **S.6-8.L.12, S.6-8.L.13, S.6-8.L.18** **S.9-10.L.12, S.9-10.L.13, S.9-10.L.18, S.9-10.L.19** **S.11-12.L.12, S.11-12.L.13, S.11-12.L.18, S.11-12.L.19**		
Learning Objective(s): Students will be able to show their understanding of the topics covered in this unit by representing them in creative ways. Students will also learn how they can get involved in more STEM-related opportunities in West Virginia.		
Formative Assessment: Students' involvement in class discussion (asking insightful questions, giving answers or making comments that suggest an understanding of the material) and the quality of their creative representations of the topics covered will demonstrate their mastery of the subject.		
PREPARATION		
Materials Needed: - Construction paper - Drawing supplies (colored pencils, markers, and/or crayons) - Scissors - Tape and/or glue - Acrylic paint - Paint brushes and paint cups - Palettes - Access to computer(s)		

- Access to printer (optional)
- Handouts outlining future opportunities for STEM involvement – print 1 for each student. (incl. in Loop Antenna Lesson Plan Attachment A)

Note that today's lesson is generally open-ended and creative, and the supplies listed above can be modified as you see fit. If you are unsure which of these supplies you will need, you may wish to discuss what types of creative expression your students are interested in before today's lesson to get a better idea of this.

INSTRUCTIONAL PROCEDURES

*****Highlight **BLUE** for materials/**GREEN** for technology
*Highlight **PINK** for instructional strategies
*Highlight **YELLOW** for discipline-specific academic language/vocabulary

		Procedural Steps	Questions	Differentiated Instruction
Activating Strategy/ Introduction	Time 5 mins	1. Remind students that in our last lesson, we learned about ways that scientists communicate their work with others in two structured, technical formats. Tell students that today, we are going to be dedicating our time to working on projects to creatively represent what we've learned over the course of this Loop Antenna unit. 2. Discuss question 1 with students, then tell them that throughout history, science and art have been very much intertwined. Explain that Leonardo da Vinci, the great inventor and scientist, was also a very talented and famous artist, and pioneered new ways of painting. Nicolaus Copernicus, the 15th century astronomer who proposed the theory that the Earth went around the Sun (rather than the other way around) was a painter as well. Inventor Hedy Lamarr was also a very successful actress. Dario Robleto is a modern-day artist who is an Artist in Residence at the SETI Institute (a research facility dedicated to the search for intelligent life beyond Earth), and much of his artwork is based around scientific themes. Discuss question 2 with students.	1. Why do you think it might be important to represent scientific findings in a creative way? *Suggested answers: open-ended. Possibilities include: representing science and technology creatively makes it more appealing, and may interest people in learning more about it, etc.* 2. Why do you think so many scientists and inventors were also great artists? *Suggested answers: open-ended. Possibilities include: science, technology, and art all share a common theme – the need for creative thinking!*	It is up to the instructor to assess the classroom and determine how to adapt the lesson to best reach all of her/his students.

Core Instruction	Time 50 mins	1. Now tell students that today's lesson is going to be entirely self-directed. Encourage them to choose a topic – or several topics – that they found interesting in this unit of study and to represent it artistically in some way. Possibilities include creating: - A painting, drawing, or sketch - A collage - A news article, short story, or poem - A play or skit - Composing a piece of music or song lyrics - Choreographing and performing a dance piece - And anything else your students can dream up! Tell students that they are free to work independently or to form groups, depending on the projects they choose. Set out the materials you've gathered for today's lesson, then encourage students to get creative! Provide guidance and answer questions as they arise.		
Closure	Time 10 mins	1. After your students have worked on their projects for as long as you see fit, discuss possibilities for sharing these creative works, and your research presentations, with each other and with the students' families. Perhaps consider hosting a "mini conference" at your school, in which students can present their research, perform their artistic compositions, and display their favorite artworks from the unit's activities.		

		2. Pass out the handouts outlining future opportunities for STEM involvement to your students, and discuss these opportunities with your students. Consider wrapping up your unit with a field trip to the Green Bank Observatory. Encourage students to contact you or the appropriate person at your school if they have questions and would like to get involved in any additional STEM programs.		
Contingency	Time	If your students need more time to work on their projects, you could either assign this as homework, or you could spread this lesson over two days or more.		