# National MagLab STEM Lesson Plan:

## The Big Reveal - Magnetic Resonance Imaging (High School)

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Research Experiences FOR TEACHERS

**Lesson Objectives:** Student will be able to:

- Characterize and compare the magnetic field of different materials: diamagnetic, paramagnetic, or ferromagnetic.
- Characterize the relationship between electrical and magnetic force interactions
- Explore the design, development, and uses of MRI technology for medical scans
- Examine the potential socio-economic influences on the availability and cost of "Hospital vs Non-Hospital MRI" scanning services

## Next Generation Science Standard:

- MS-PS2-3: Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.
- HS-PS2-5: Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.

**STEM RATIONALE FOR LESSON:**

In this activity, students will apply their understanding of material properties to investigate the phenomenon of magnetism. They will begin by characterizing magnetic fields in two dimensions, carefully observing how magnetic forces behave in various scenarios. Through hands-on experimentation, they will map out magnetic field lines and gain a deeper understanding of the underlying principles that govern magnetic interactions.

Next, students will explore the intricate relationship between electrical forces and magnetic fields, delving into how electricity can influence and even modify the magnetic properties of certain materials. By experimenting with electromagnetism, they will discover how electrical currents can be used to generate magnetic fields, and how these fields can, in turn, be manipulated to achieve specific effects.

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Finally, students will extend their newly acquired knowledge of magnetic fields to practical applications, particularly in the field of medical imaging and scanning technologies. They will explore how magnetic fields are used in devices such as MRI scanners, gaining insight into how these tools harness the power of magnetism to visualize the internal structures of the human body. This extension will provide a real-world context for the scientific concepts they have studied, allowing them to appreciate the importance of magnetism in modern technology.

## Culturally Responsive Connection:

According to the US Food and Drug Administration, "millions of MRIs are performed in the US each year." This statistic highlights the likelihood that a student, or someone they know, has undergone an MRI scan as part of a medical detection, diagnosis, or treatment protocol. MRI scans are frequently used for diagnosing a wide range of conditions, including knee and shoulder injuries, brain tumors, aneurysms, and issues involving the spinal cord and nerves. In recent years, there has been growing interest in using MRI technology to assess concussion-related brain injuries, a relatively new application that shows promise in sports medicine and neurology.

MRI technology has evolved to the point where scans can now be performed in both hospital and non-hospital settings, expanding access for patients. However, compared to other imaging techniques like X-rays and CT scans, MRI scans are significantly more expensive. These higher costs can be attributed to several factors, including the maintenance and upkeep of sophisticated MRI equipment, the procurement of helium to cool the superconducting magnets, and the use of proprietary components to ensure optimal functionality. Due to these elevated costs, insurance companies often favor covering X-rays and CT scans over MRIs, as they are less expensive to perform and process.

This economic reality opens avenues for students to extend their study of magnetic fields and their medical applications by examining the socio-economic implications of MRI accessibility. For instance, students might investigate how socio-economic status affects access to high-quality medical imaging, including post-scan follow-up and care. Creating a map of accessible MRI facilities, accompanied by a cost comparison, could reveal trends related to geographic disparities, insurance coverage, and patient outcomes. This type of analysis would provide valuable insights into the intersection of technology, healthcare, and economics, making the study of MRI technology even more relevant and impactful.

**Time:** Each part can take 30-40 minutes.

## Materials:

Provided by the teacher:

- Compass
- Variety of classroom lab magnets - bar, disk, stainless steel spoons, etc.
- Graphing paper
- Electromagnet kit
- Magnetometer, or Gaussmeter (optional)
- Laser pen light
- Two small transparent drinking glass or measuring cup
- Tape

Provided by the student:

- Common household refrigerator magnet
- Laptop or other digital device for conducting research
- Magnetometer Downloaded App (Magnetscape Lite, Fluxmeter, magnetic detector Lite)
- Poster Board - for final presentation

## Previous Knowledge:

- General properties of magnets - poles, materials, forces - attractive and opposing
- Use and interpretation of rubrics for performance tasks

## Lesson Introduction:

1. **Bell Ringer:** To kick off the lesson, consider presenting a news article or scientific source that introduces students to comparative measures of magnetic fields, particularly in Teslas. One engaging example is the "Sun Churn" article

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from the Fall 2019 issue of *Fields* magazine (https://nationalmaglab.org/magnet-academy/history-of-electricity-magnetism/places/magnetic-field-of-sun/), which discusses the intense magnetic fields generated by the Sun. This real-world context will help students grasp the scale and significance of magnetic fields before applying that knowledge to MRI technology.

2. **Discussion Starter:** Open the discussion by asking, “Who here has had, or knows someone who has had, either an X-ray, CT scan, or MRI? How are these scans different from each other?" Encourage students to reflect on their personal experiences or what they know about these medical imaging technologies. Use this as a springboard to introduce the lesson, framing it as an investigation into the cutting-edge advancements and growing use of MRI scans in modern medicine. Highlight the innovative progress in MRI technology and its increasing importance for accurate diagnosis, particularly in comparison to other imaging techniques like X-rays and CT scans. This sets the stage for an exploration of the science behind MRI scans and their broader implications in healthcare.

## Lesson Instructions:

Part 1: Characterizing Magnetic Fields

1. **Selection of Materials:** Students will begin by selecting two different magnetic items from the classroom’s available inventory. These magnets will serve as the focus of their investigation.
2. **Magnet Placement:** Place the first magnet in the center of a sheet of graphing paper and draw a border around it. This ensures a defined area for mapping the magnetic field.
3. **Identifying the North Pole:** Using a compass, students will determine the North pole of the magnetic material. This serves as the reference for plotting magnetic field lines.
4. **Map Compass:** In the upper corner of the graphing paper, students will draw a simple map compass that corresponds to the North pole of the magnetic material. This visual guide will help orient the directions for their magnetic field measurements.

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5. **Plotting Measurement Locations:** Students will place up to 30 points around the magnet's border on the graphing paper. These points will represent the locations where they will measure the magnetic field.
6. **Measuring Magnetic Field Directions:** Using a second compass, students will measure the direction of the magnetic field at each plotted point. They will center the compass on each point and draw a vector arrow indicating the direction in which the magnetic needle points. This process will be repeated for all 30 points to map the magnetic field around the first magnet.
7. **Repeat for Second Magnet:** Students will then repeat the entire process for the second magnet, ensuring they follow the same steps to accurately compare the two magnetic fields.
8. **Determining Field Strength Distance:** Finally, students will assess the distance at which the field strength becomes noticeably diminished in all four cardinal directions (North, South, East, West) for each magnet. This distance should be documented on the graphing paper, providing a complete visual representation of each magnet's field strength and area of influence.
9. **Extension: Water & Magnets** In this extension activity, students will design and conduct an investigation to explore the following driving question: How does water respond to a magnetic field? To test this, students can examine the interaction between water and a magnetic field using basic refraction properties. Start by setting up two small transparent glasses filled with water. Students will shine a pen laser through each glass to observe and compare the refraction patterns.
10. Next, they will create a magnetic field in one of the glasses by placing two magnets on opposite sides of the glass, ensuring the field passes through the water. Students will observe whether the laser light behaves differently in the presence of the magnetic field, paying close attention to any changes in the refraction angle or the path of the light beam.
11. This investigation will provide an opportunity for students to explore the potential effects of magnetic fields on water's properties, and to consider how this might relate to the behavior of other materials or fluids in the presence of a magnetic force. Through this experiment, students will deepen their understanding of magnetic fields and their influence on matter.

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Part 2: Introduction to Electromagnets

1. **Teacher-Led Demonstration: Designing a Simple Electromagnet:** In this teacher-led demonstration, students will observe the creation and functioning of a simple electromagnet, gaining insights into the relationship between electricity and magnetism. The demonstration will involve wrapping a conductive wire around a metal core, such as a nail, and connecting the wire to a power source. As the current flows through the wire, it generates a magnetic field, effectively turning the metal core into an electromagnet. The teacher will explain the underlying principles of electromagnetism, emphasizing how electrical current produces a magnetic field and how varying the current affects the strength of the magnet.
2. **Student Extension: Field Diagrams for Electromagnets:** As an extension activity, students will be encouraged to explore the effects of different electrical forces on the electromagnet. Using a variable power source, they can observe how increasing or decreasing the voltage impacts the strength and reach of the magnetic field. Students will then create field diagrams for the electromagnet, mapping out the magnetic field lines and showing how they change in response to variations in the applied electrical force. This hands-on extension will deepen students' understanding of how electromagnets function and allow them to visually represent the relationship between electrical current and magnetic field strength, linking theory with practical observation.

Part 3: Research on Magnetic Resonance Imaging (MRI)

**Students investigate the following questions using multiple sources:**

1. What is MRI?
2. How does MRI work?
3. What is MRI used for?
4. Are there risks?
5. What are the latest advances in MRI technology?
6. Safety comparison: magnetic fields vs radiation (MRI, CT scan, and X-ray)
7. Where are the MRI facilities in your community, or city?
8. How much does an MRI scan averagely cost in your state?

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Part 4: Assessment - Bringing it All Together

Working individually or with a partner, students will prepare a detailed presentation to showcase their findings across the following key areas (see suggested scoring rubric for evaluation criteria):

1. Students will present an in-depth analysis of the magnetic fields generated by the two selected materials. This will include a comparison based on the size, composition, and strength of the magnetic fields. Students should incorporate visual aids such as graphs or field maps to demonstrate how each material's properties affect its magnetic field. The comparison will highlight any significant differences in field strength and range, providing a comprehensive understanding of how various materials interact with magnetic forces.
2. In this section, students will explain the fundamental relationship between electrical currents and magnetic fields. They will outline how an electrical force can generate a magnetic field, as demonstrated in electromagnets, and discuss key concepts such as electromagnetism and the Lorentz force. Visual diagrams or animations can be used to illustrate how electrical and magnetic forces interact, helping to clarify these complex principles for their audience.
3. Students will explore the design and evolution of MRI (Magnetic Resonance Imaging) technology, focusing on its innovative use in medical diagnostics. The presentation should include an overview of how MRI machines function, detailing the role of magnetic fields and radio waves in producing detailed images of the body's internal structures. Students should also cover various applications of MRI, such as scanning for brain injuries, tumors, and musculoskeletal conditions, highlighting its importance in modern healthcare.
4. The final part of the presentation will focus on the socio-economic factors that influence the availability and affordability of MRI scanning services. Students will compare the cost and accessibility of MRI scans in hospital settings versus non-hospital facilities, discussing how insurance coverage, geographic location, and overall healthcare costs can impact patient access to these vital diagnostic tools. They may also analyze trends in healthcare inequalities and explore how socio-economic status can affect the quality of post-scan follow-up care. Maps, graphs, or case studies may be used to visualize these disparities and prompt a discussion on the broader implications for healthcare systems.

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By engaging with these diverse topics, students will develop a well-rounded understanding of the scientific, technological, and socio-economic dimensions of magnetic fields and MRI technology. Their presentations should provide a clear narrative, linking theoretical concepts to real-world applications, and stimulating thoughtful discussions on the importance of accessible medical imaging.

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# Appendix:

Additional Resources and References

1. K. Roberts, C. Raftery, “Sun Churn” , Fields, Fall 2019, a publication of the National MagLab (https://nationalmaglab.org/magnet-academy/history-of-electricity-magnetism/places/magnetic-field-of-sun/)
2. Food and Drug Administration - Benefits and Risks of MRI - https://www.fda.gov/radiation-emitting-products/mri-magnetic-resonance-imaging/benefits-and-risks
3. National Institute of Biomedical Imaging and Bioengineering - Magnetic Resonance Imaging (MRI) - www.nibib.nih.gov
4. Johns Hopkins Medical - MRI Physics - Magnetic Resonance and Spin Echo Sequences https://www.youtube.com/watch?v=jLnuPKhKXVM
5. Philips - Learn More About Helium-Free MR Operations - https://www.usa.philips.com/healthcare/resources/landing/the-next-mr-wave/sealed-mr-technology
6. Questions and Answers in MRI - https://mriquestions.com/index.html

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# MagLab Lesson Rubric and Self-Evaluation

| | Advanced (4) | Proficient (3) | Emerging (1) | Total Points |
|---|---|---|---|---|
| **Due Date** | Presentation report submitted and in class ready when name is called. | | Presentation report not submitted, or not present when name is called. | |
| **Background Research on MRI Technology** | Provides detailed overview of the design, development, and uses of MRI technology for medical scans, including technological advances in MRI research over the most recent decade, with a 2D or 3D model. | Provides detailed overview of the design, development, and uses of MRI technology for medical scans, including technological advances in MRI research over the most recent decade. | Provides a general overview of the design, development, and uses of MRI technology for medical scans. | |
| **Characterization of Magnetic Fields** | Provides a detailed characterization and comparison of the magnetic field for the two selected materials relative to size, composition, and field strength, with labels and dimensions shown on the graphing paper. | Provides a general characterization and comparison of the magnetic field for the two selected materials relative to size and composition, with labels and dimensions shown on the graphing paper. | Provides a general characterization and comparison of the magnetic field for the two selected materials relative to size and composition. | |
| **Relationship between electrical and magnetic force interactions** | Discusses the relationship between electrical and magnetic force interactions by including a characterization of the magnetic field relative to changes in the electrical force. | Provides a general overview of the relationship between electrical and magnetic force interactions. | Provides a summary statement of the relationship between electrical and magnetic force interactions. | |
| **Potential socio-economic influences on availability and cost of MRI services** | Presents findings using a detailed map, table of costs, and conclusions on the potential socio-economic influences, whether positive or negative, relative to the availability and cost of "Hospital vs Non-Hospital MRI" scanning services for this community. | Presents findings using a map, table of costs, and conclusions on the potential socio-economic influences relative to the availability and cost of "Hospital vs Non-Hospital MRI" scanning services for this community. | Provides a general statement on the potential socio-economic influences relative to the availability and cost of "Hospital vs Non-Hospital MRI" scanning services for this community. | |
| **Resources and References** | Cites resources and references. | | Resources and references not included. | |
| **TOTAL SCORE** | | | | |