STEM Lesson Plan:

Exploring the Hertzsprung-Russell(HR) Diagram with 3D Printing (High School)

Note on 3D Printing:
This lesson was written as is with the use of a 3D printer for making models of the stars on the HR Diagram. However, this piece can be replaced with an arts & crafts section where students

Lesson Overview:
- This two-day lesson engages high school students in understanding the Hertzsprung-Russell (HR) diagram through the use of 3D printing and introduces them to the applications of Nuclear Magnetic Resonance (NMR) or mass spectrometry technology in studying stellar compositions. This lesson integrates Earth and Space Science standards, emphasizes STEM education, and fosters culturally responsive teaching by connecting scientific discoveries to contributions from diverse cultures.

Next Generation Science Standards:
- HS-ESS1-3: Communicatescientific ideas about the way stars, over their lifecycle, produce elements.
- HS-Ess1-2: Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and the composition of matter in the universe.
- HS-PS4-1: Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.

Time: Two Class Periods

STEM Rationale for Lesson:
This lesson incorporates 3D printing and NMR technology to enhance students' understanding of the HR diagram, which classifies stars based on their luminosity and temperature. Using 3D printing allows students to create tangible models, fostering spatial thinking and a deeper grasp of stellar classification. Exploring NMR technology highlights the role of spectroscopy in astronomy, bridging the gap between classroom learning and real-world scientific research conducted at the National High Magnetic Field Laboratory (MagLab).
- Engagement with Cutting-edge Technology
- Visual and Tangible Learning
- Enhanced Conceptual Understanding

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STEM Lesson Plan:

- Real-world Applications
- Cross-disciplinary Learning
- Interactive Learning Experience
- Accessibility of Complex Data

MagLab Connection:

- At the MagLab, scientists use NMR technology to measure interactions of atomic nuclei with RF radiation and magnetic fields. Mass spectroscopy is used to analyze chemical composition.

Student Learning Objectives:

SWBAT

- interpret the Hertzsprung-Russell diagram to classify stars based on their luminosity and temperature.
- design and 3D-print models representing different types of stars.
- analyze the cultural significance of astronomy in various ancient civilizations, including Indigenous and African cultures.
- explain how NMR technology and spectroscopy are used to study stars.

Materials:

- Computers with 3D modeling software (Tinker CAD)
- 3D printer with filament
- Access to online HR diagram simulators
- Research materials on the cultural significance of astronomy
- Projector for presentations

Lesson Activity Steps:

Day One: Understanding the HR Diagram and Star Classification

1. **Bell Ringer (5 Minutes)**
   Begin with a thought-provoking question: *"What do you think astronomers can learn about stars by studying their light?"* Encourage students to jot down their ideas individually, then share with a partner or small group. Facilitate a brief discussion to surface key concepts like brightness, color, temperature, and composition.
2. **Introduction to the HR Diagram (10 Minutes)**
   Present the Hertzsprung-Russell (HR) diagram using visuals and real-world examples. Explain how it plots stars based on their luminosity and temperature, and how it helps astronomers classify stars into groups like main sequence,

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giants, and white dwarfs. Use guiding questions: *"Why do you think temperature and brightness are important?"* and *"What patterns do you notice in the diagram?"*

3. **Activity 1: Explore the HR Diagram (20 Minutes)**
   Divide students into small groups and provide access to online HR diagram simulators (e.g., from NASA or university sites). Each group will explore how stars are distributed on the diagram and explore the classification of stars (e.g., main sequence, giants, dwarfs, supergiants).Groups will answer questions such as:
   - What patterns do you notice in the HR diagram?
   - How does temperature relate to the color of stars?
   - Where are the hottest and most luminous stars located on the diagram?
   - What types of stars are most common?
   - How does a star's position relate to its life cycle?

   Groups will record observations and prepare to share one insight with the class.

4. **Activity 2: Design 3D Star Models (15 Minutes)**
   Students will choose three types of stars (e.g., red dwarf, blue giant, white dwarf) and sketch designs for 3D models that represent their size, color, and temperature. Encourage creativity and scientific accuracy. Provide materials or digital tools for design. Students will label their models and explain how each one fits into the HR diagram. Assign students to complete their designs as homework, ensuring they are ready for 3D printing on Day 2.
5. **Exit Ticket (5 Minutes)**
   Students write a brief reflection responding to: *"How does the HR diagram help astronomers understand the life cycle of stars?"* Collect responses to assess understanding and identify misconceptions.

Day Two: Spectroscopy, Star Composition, and Cultural Astronomy

1. **Bell Ringer (5 Minutes)**
   Prompt students with: *"How do you think scientists can determine the chemical composition of stars?"* Encourage students to think about light, color, and tools scientists might use. Facilitate a short discussion to introduce the concept of spectroscopy and liking it to NMR.
2. **Activity 1: Peer Review and 3D Printing Star Models (15 Minutes)**
   Students will exchange their star model designs with peers for feedback on scientific accuracy and clarity. After revisions, students will begin the process of

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3D printing their models using classroom printers or submit files for printing. While waiting for prints, students can

   1. explore sample 3D-printed star models and discuss how their designs represent different star types.
   2. Discuss how visual models can aid understanding and communication in science.

3. **Activity 2: NMR and Spectroscopy Explained (15 Minutes)**
   Introduce Nuclear Magnetic Resonance (NMR) and Spectroscopy as tools used to analyze the light emitted by stars. Use diagrams and short videos to show how light spectra reveal elements like hydrogen and helium. Show an interactive simulation or demonstration of how NMR works and its application in studying celestial bodies.
4. **Activity 3: Connect to Cultural Astronomy (10 Minutes)**
   Students will research how ancient cultures—such as the Maya, Egyptians, or Indigenous North American tribes—used astronomy to guide agriculture, navigation, or spiritual practices. In small groups, students will choose one astronomer or cultural figure to briefly present to the class. Encourage connections between ancient observations and modern tools like the HR diagram and spectroscopy.
5. **Closure & Reflection (5 Minutes)**
   Students discuss how 3D printing and modern technology like NMR continue to expand our understanding of the universe. Have students respond to: *"What was the most surprising thing you learned about stars or ancient astronomy?"* as a brief written response. Share a few responses aloud to close the lesson with curiosity and connection.

Assessment

Formative Assessment: Throughout the lesson, ongoing formative assessments will be used to gauge student understanding, engagement, and skill development:

- Monitoring Student Engagement: Teachers will circulate during group and individual activities to observe participation, collaboration, and on-task behavior. Informal check-ins and questioning will help identify students who may need additional support or clarification.
- 3D Model Design Drafts: Students' initial star model sketches will be reviewed for scientific accuracy, creativity, and alignment with the HR diagram. Feedback will be provided to guide revisions before 3D printing.
- NMR and Spectroscopy Discussion: During the spectroscopy lesson, students will participate in guided discussions and complete a worksheet analyzing

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spectral lines. Their responses will be used to assess comprehension of how light reveals a star's chemical composition.

- Checks for Understanding: Throughout both days, the teacher will use questioning strategies (e.g., cold calling, think-pair-share, exit tickets) to assess conceptual understanding of star classification, the HR diagram, and spectroscopy. Misconceptions will be addressed in real time.

Summative Assessment: Summative assessments will evaluate students' ability to synthesize and apply their learning in creative and reflective ways:

- 3D-Printed Star Models: Final models will be assessed using a rubric that considers:
  - Scientific Accuracy: Correct representation of star types based on size, color, and temperature.
  - Creativity and Design: Thoughtful and innovative use of materials or digital tools.
  - Explanatory Labels: Clear, concise explanations of each model's classification and placement on the HR diagram.
- Written Reflections: Students will submit two written reflections:
  - Day One: How the HR diagram helps astronomers understand the life cycle of stars.
  - Day Two: Insights gained from spectroscopy and cultural astronomy.

These reflections will be assessed for depth of thought, clarity of explanation, and ability to connect scientific concepts to broader contexts.

Extension Activity

For students who finish early or seek additional challenges, assign a research project on how NMR technology is used beyond astronomy, such as in medicine or environmental science. Encourage students to present their findings to the class.

Reflection on Cultural Responsiveness

This lesson emphasizes inclusivity by recognizing the contributions of diverse cultures to the field of astronomy. By drawing connections between ancient knowledge systems and modern scientific practices, students can see the value of different perspectives in the pursuit of knowledge. This approach fosters an appreciation of both historical and contemporary scientific achievements, making learning more meaningful for students of all backgrounds.

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