Environmental Science Institute
THE UNIVERSITY OF TEXAS AT AUSTIN

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Get Chilly: Life in Frozen Seas REVISITED:
Finding Energy for Life in Cold, Dark Environments

Lesson plan for grades 9-12
Length of lesson: 1 Class Period, 75 minutes
Authored and Adapted by: Jesús Aguilar-Landaverde; Environmental Science Institute; July 14, 2012
Included images from: "Hydrothermal Vents", Amanda Bruener, Ocean & Coastal Interdisciplinary Science (OACIS), 2010

SOURCES AND RESOURCES:

- Fundamentals for Life and Extremophiles
  - *California Academy of Sciences*—Extreme Life
    http://www.calacademy.org/exhibits/xtremelife/ingredients.php
  - HowStuffWorks: How Extremophiles Work
    http://science.howstuffworks.com/environmental/life/cellular-microscopic/extremophile.htm
  - *PBS: NOVA—"*Life's Little Essential"
    http://www.pbs.org/wgbh/nova/evolution/liquid-of-life.html
  - *Popular Mechanics*—"The Ingredients for Life (Revised)"
    http://www.popularmechanics.com/science/space/deep/ingredients-for-life-nasa-arsenic-extremeophiles
  - *Natural Science Foundation—"*Xtreme Microbes: Radiation Eaters"
    http://www.nsf.gov/news/special_reports/microbes/textonly/eaters.jsp
- Hydrothermal Vents and Extremophiles
  - Indiana University: Vent Communities
    http://www.indiana.edu/~g105lab/images/gaia_chapter_13/vent_communities.htm
  - Marshall Hydrothermal—An Introductory Description of Hydrothermal Vents
    http://marshallhydrothermal.com/complete.htm
  - *Nature*—Integrating Ecology and Biogeochemistry: Hydrothermal Vents as a Case Study
    http://www.nature.com/nrmicro/journal/v4/n6/box/nrmicro1414_BX1.html
- Current Research on Earth/Europa
  - Astrobiology Magazine: "Through Thick or Thin: Exploring Europa's Outer Layer of Ice"
    http://www.astrobio.net/exclusive/16/through-thick-or-thin-exploring-europas-outer-layer-of-ice
  - Global Warming Blog: *"Jason Amundson et al.: Jakobshavn Glacier—Time Lapse Footage Reveals Greenland Ice Sheet in Crisis"*
    http://warmingsystem.blogspot.com/2008/10/jason-amundson-et-al-jakobshavn-glacier.html
  - Honolulu Star-Bulletin: "Building blocks of life found on Europa"; October 10, 1997
    http://archives.starbulletin.com/97/10/10/news/story4.html
  - JPL Video: "Europa – Cool Destination for Life?"

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http://www.jpl.nasa.gov/video/index.cfm?id=649

- NASA Images: "Thick or Thin Ice Shell on Europa?"
  http://www.nasaimages.org/luna/servlet/detail/nasaNAS~20~20~120924~227627:Thick-or-Thin-Ice-Shell-on-Europa
- Letters to Nature: *Geological evidence for solid-state convection in Europa's ice shell; R.T. Pappalardo et al.* (Abstract)
  http://www.nature.com/nature/journal/v391/n6665/abs/391365a0.html
- LPI/USRA: "New Measurements of Impact Crater Topography Show that Europa has a Thick Shell"
  http://www.lpi.usra.edu/resources/europa/thickice/
- **Nature: *Active formation of 'chaos terrain' over shallow subsurface water on Europa*; B.E. Schmidt et al.**
  http://www.nature.com/nature/journal/v479/n7374/full/nature10608.html
- NASA Earth Observatory: Breakup of Larsen Ice Shelf, Antarctica (2002)
  http://earthobservatory.nasa.gov/IOTD/view.php?id=2288
- NORDVULK/University of Iceland: *Subglacial lakes and jökulhlaups in Iceland; H. Björnsson*
  http://www.norvol.hi.is/pdf/HB2003GlobPlanCh.pdf
- University of Alaska: Jakobshavn Calving (Greenland) Video
  http://www.youtube.com/watch?v=c7_pkWVjRXU
- University of North Florida: "Researchers: Jupiter moon has 'ingredients' for life"
  http://www.unf.edu/~lkmao/astro-news/life-jupiter.html
- The University of Texas at Austin: "Scientists Discover New Site of Potential Instability in West Antarctic Ice Sheet", May 10, 2012
  http://www.utexas.edu/news/2012/05/10/ice_sheet/
- Wikipedia – Conamara Chaos
  http://en.wikipedia.org/wiki/Conamara_Chaos

- Future Research on Europa
  - Stone Aerospace: About ENDURANCE
    http://www.stoneaerospace.com/products-pages/products-ENDURANCE.php
  - Technovelgy: "Antarctic ENDURANCE Robot Helps NASA Explore Europa"
    http://www.technovelgy.com/ct/Science-Fiction-News.asp?NewsNum=1452
  - JPL: Europa Jupiter System Mission (EJSM)
    http://opfm.jpl.nasa.gov/europajupitersystemmissionejsm/
  - ESA: EJSM-Laplace
    http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=42291

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POTENTIAL CONCEPTS TEKS ADDRESSED THROUGH THIS LESSON:

§112.32. Aquatic Science, Beginning with School Year 2010-2011 (One Credit), Grade: 10, 11, or 12
c.(9).(C). identify biological, chemical, geological, and physical components of an aquatic life zone as they relate to the organisms in it.

§112.33. Astronomy, Beginning with School Year 2010-2011 (One Credit), Grade: 11 or 12
c.(9).(A) compare and contrast the factors essential to life on Earth such as temperature, water, mass, and gases to conditions on other planets;

§112.35. Chemistry, Beginning with School Year 2010-2011 (One Credit), Grade: 10, 11, or 12
c.(10).(A) describe the unique role of water in chemical and biological systems;

§112.37. Environmental Systems, Beginning with School Year 2010-2011 (One Credit), Grade: 11 or 12
c.(6).(E) investigate and identify energy interactions in an ecosystem.

§112.38. Integrated Physics and Chemistry, Beginning with School Year 2010-2011 (One Credit), Grade: 9 or 10
c.(5).(E) investigate and demonstrate the movement of thermal energy through solids, liquids, and gases by convection, conduction, and radiation such as in weather, living, and mechanical systems;

PERFORMANCE OBJECTIVES (in order of increasing difficulty to permit tailoring to various age groups):

Students will be able to:

- Retrieve and summarize modern research on the structure and surface of Europa.
- Check his/her own model hypothesis with ongoing research.
- Compare and contrast factors essential to life on Earth and elsewhere.
- Report and explain individual his/her methodology for forming a hypothesis.
- Integrate scientific information surrounding hydrothermal vents to form a hypothesis.

MATERIALS:

Students (per group)

- One sheet of stock paper (writing/illustration must be visible)
- Writing utensils
- Notebook paper
- Internet access

Instructor

- Overhead or projector
- Black/whiteboard

CONCEPTS:

According to modern science, the essential ingredients for life are **energy, liquid water,** and **raw chemical materials.**

Energy transfers and interactions are vital for ecosystems.

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For most of life on Earth, sunlight is the primary source of energy that drives growth, maintenance, and reproduction. However, there exist extreme environments on earth like around **hydrothermal vents** where life can flourish with geochemical energy can be the dominant source of energy in water that is otherwise very cold and devoid of light. **Conditions are extreme** in these environments (atmosphere, pressure, temperature, light).

That **residual geothermal heat** from the formation of the Earth can drive geological, biochemical, physical, and ecological processes through **plate tectonics.**

Europa, one of Jupiter's satellites, may have a deep ocean beneath its icy surface.

Tidal interactions with Jupiter may be causing volcanic activity on the ocean floor of Europa.

It is possible that **Europa may harbor life** if the geochemical and geothermal energy from its interaction interacts with and cycles the organic materials observed on the surface of the moon.

Current research on both Earth and Europa indicate that these interactions might be possible based on studies of ice shelves, icebergs, and glaciers.

BACKGROUND:

Dr. Britney Schmidt of The University of Texas Institute for Geophysics is a leading researcher of the structures on the surface of the moon, Europa. She compares life to a circuit—or more generally, a cyclic flow of energy. Although not all life may require sunlight for this circuit to function, geochemical processes in extreme environments around hydrothermal vents mimic, in her words, what life is doing. That is, the reduction-oxidation reactions that occur due to the super fluid water at the bottom of the ocean are also circuits, moving electrons from place to place. This transfer of energy sets up conditions for certain microbes and other organisms to thrive in extreme environments. Dr. Schmidt's collaborative research indicates that such a circuit might exist beneath the icy surface of Europa possible of sustaining or harboring yet undiscovered life.

This lesson is built around this idea—that life is dependent on a transfer of energy. In this lesson, the student will begin with a discussion of the most basic ingredients necessary for life as demonstrated by modern science. Dr. Schmidt's analogy to the deep ocean floor is also included in the lesson as a stepping-stone for the students to be introduced to the research on Europa. The students will work together to synthesize different scientific observations from these exotic ecosystems to develop an understanding for the basic geological processes that drive this flow of energy. The students will then be introduced to the current scientific understanding of Europa.

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The presence of a weak magnetic field on Europa is evidence of an ocean much more voluminous than all of Earth's oceans below the surface of Europa. Also, the tidal interactions with the massive planet of Jupiter are believed to be driving volcanic activity and heating up the sea floor on Europa. The rising volcanic plumes of warm liquid water would carry with them reduced materials as a black smoker on Earth. Raw organic materials have also been observed on the surface of Europa from either accretion or comet impacts. The key question of Dr. Schmidt's presentation and her research is whether these two types of materials are interacting. In other words, she asks if the circuit—a circuit not unlike one of Earth's—is a closed circuit. This is question is at the frontier of modern research of Europa and the search for extra-terrestrial life in the Solar System.

The students will formulate their own hypotheses on how energy transport may/may not be possible on Europa and will check their hypotheses by researching some of the modern theories of the melting of Europa's ice shell. Included in the resources above is a link to Dr. Schmidt's own work (bolded); it contains her group's investigation of the formation of what she calls 'chaos terrain' on the subsurface of Europa.

PREPARATION:
Have the projector ready prior to class with the two included images handy. Also, have the appropriate amount of cards and final evaluation sheets for your classroom groups.

ENGAGE:
To begin the lesson, project the following image for the class to see.

It is very likely that students will recognize this image, for it is a direct reference to the popular television series, *The Office*. Also, these types of image macros are colloquially known as a type of "meme"—a shortening of the word mimeme (Gk. μίμημα, "something imitated")—in the internet community after the same word

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coined by geneticist Richard Dawkins in 1976. There are dozens of image macros such as these in the internet subconscious; especially since the beginning of this decade, there has been an increase in their popularity.
It is for this precise reason that the author of this lesson plan has chosen to begin this scientific lesson with a popular culture reference.

Most high school students who use any form of social networking sites or other media have almost certainly encountered these macros. Moreover, this particular image was the epoch of a meme in the year 2011. One cultural name for this meme is "Schrute Facts," referencing the last name of the pictured TV character; and it is among the most popular image macro-based memes online. These memes play upon phrasal templates, repetition, and cliché. In the case of "Schrute Facts," text is overlaid over the image of this character, which is portrayed as a braggart intellectual, to highlight logical or scientific inconsistencies in an idea or object. This almost always follows the format of writing the subject in question at the top of the image in the form of a question. At the bottom of the macro, the line usually reads, "False," followed by a witty scientific clarification. Again, this is to imitate the know-it-all demeanor of the character, Dwight, and to create humor wherever the author of the image macro decides to post it. The author of this lesson predicts that more than a few students may laugh at first seeing this image.

So, thus, may the science lesson begin. The first intention for that students to look beyond the cultural references ["love is all you need" is a direct reference to the famous Beatles song, "All you need is love" (1967)] and validate the correction at the bottom of the image.

Some guiding questions might be,

- What do you think about this?
- Scientifically speaking, is Mr. Dwight/Mr. Schrute correct?
- Are water and rations really all we as humans need?
- What exactly *do* we **need** to live (or survive)?
- Let's be general. What does *all* life need to thrive?*
    - Water: why is it important?
- What life as we know it need to *form?**
    - What are we made of mostly?
    - What is the most common element in our chemical make-up?
    - What are the "blueprints" for life to form? Where are they? What are they made of (chemically)?
- Is there anything else besides water and food?
- What exactly is food? Why do we need to eat?
    - What about the rest of life forms? Do they all eat?
    - What do they do instead?
    - How do plants stay alive? What about microbes?

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*Call on students and generate a list of their responses to these questions on the board or other projected space.

The second goal of this exercise is to establish what is scientifically necessary for life to exist through group discussion. After enough responses have been recorded, go over every item listed and ask the students why each is essential to life. Things such as water; sunlight; oxygen; shelter; food; and temperature may be among the list of responses. What is important here is to guide the students into realizing that not all life requires sunlight, oxygen, or even "favorable" temperatures to survive without dictating. Rather, the author proposes presenting an extremophile like those in the included resources above to each of the students' arguments for the necessity of things like temperature, oxygen, or salinity of water. The sample questions above are intended to highlight the fact that raw organic materials, liquid water, and energy are extremely important for life to exist.

Discussion should lead the students to re-evaluate their own thoughts about essentials for life; but, again, there should not be heavy lecturing in this opening. The students will have an opportunity to explore a specific extreme environment in the next section.

EXPLORE:

To keep the students engaged, the author has chosen now to appeal to the world of literature. Specifically, the description of the Eighth Circle of Hell, Bolgia 5 in Dante Aligheri's *The Divine Comedy.* The author chose this work for its powerful imagery and popularity to lead into an exploration of hydrothermal vents.

In the Eighth Circle is where the sinners guilty of various forms of fraud are punished. It is divided into ten ditches of stone (bolgie), and bolgia number five contains corrupt politicians throughout the ages. It is written that here the sinners are submerged in a lake of boiling pitch. With high hopes, the author hopes that students will not only be more interested in the lesson with a reference to literature but also research and read the work for themselves.

Now, the science. Boiling pitch is a tar-like substance derived from petroleum and often used as a thermal weapon in the Middle Ages. As a rough estimate, the boiling point of tar is 250 degrees Celsius (482 Fahrenheit). In the case of hydrothermal vents, the emerging heated water can escalate to over 400 degrees Celsius. This is how the teacher should segue into the activity. By describing first the unbearable conditions in the *Inferno* and then contrasting that with the higher temperatures, higher pressures (300 atm is a fair estimate), high acidity, and darkness at hydrothermal vents—without mentioning the words, "hydrothermal vents." The intention is to create an image of an utterly uninhabitable scenario.

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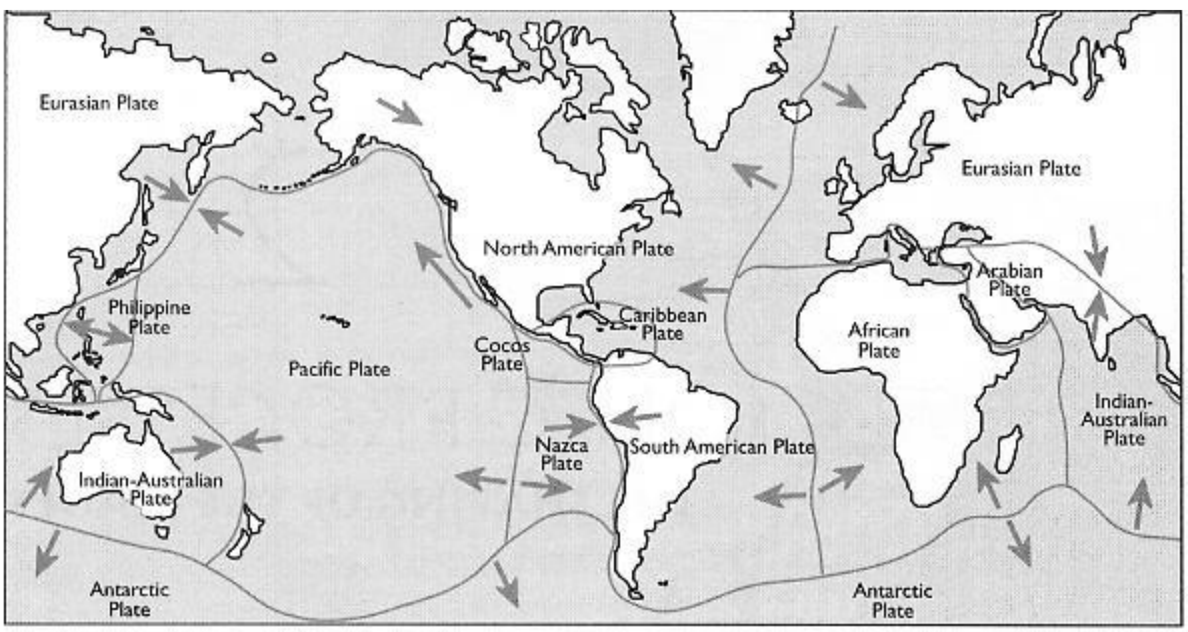
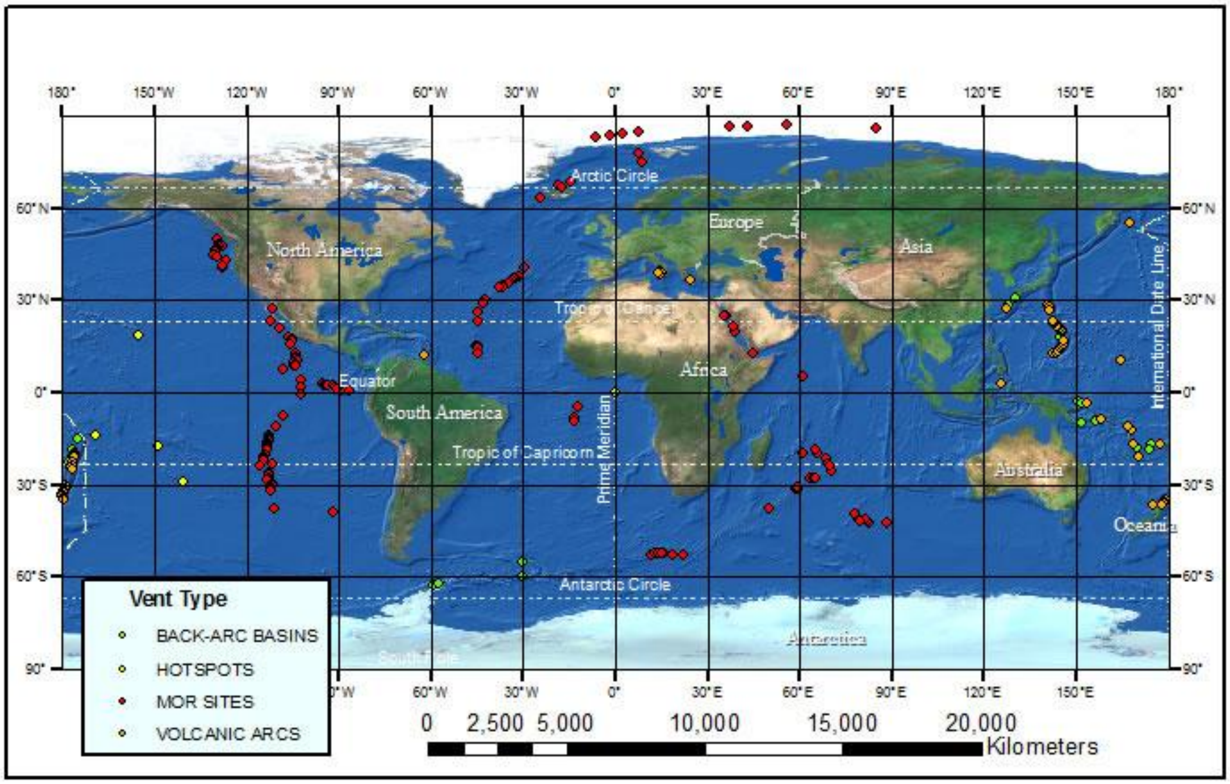
Then, the instructor should prompt the students, "What if I told you that entire communities live in such conditions, and they exist within ecosystems that are dark, and cold?" Or, if students already know about the existence of these vents, the question could be, "Then, *how* do these ecosystems manage to survive?" (This is one of the main ideas of this section) The students will now work among themselves to try to tackle this problem with guidance.

1. Present students with just an image of hydrothermal vent. Remind them of the extreme conditions surrounding them.
2. Students should work in small groups (maximum of four) or in pairs.
3. Because of the open nature of the exercise, the instructor should walk around and help struggling groups. The instructor should be careful not to give away answers, but helpful hints might be to refer to the previous discussions, especially that of extremophiles.
4. As a hint, the instructor is free to use the included maps (Bruener, 2010) that highlight along which plate boundaries vents are located



http://www.greenibis.com/edu/geo/images/tectonic-plates.jpg



Bruener, 2010

5. Given a time limit (fifteen minutes is recommended), the students should work together to formulate their own hypothesis on how hydrothermal vents remain sustainable. They should focus on finding and explaining the fundamentals needed for life as discussed at the beginning of class, if indeed they are present in this ecosystem. The presence of water and the existence of life forms (and thus organic material) are obvious. The real key to this exercise is for the students to try and identify how energy is moved around. And, most importantly, where most of the energy is coming from. That is, what is literally driving this ecosystem?

a. The geochemistry at work really depends on the movement of ions from superheated sea water that has seeped through cracks in the ocean floor and risen through plumes from hydrothermal vents. Compounds like hydrogen sulfide are ejected from these vents and are used by some extremophilic chemolithotrophs for energy.

b. The presence of magma beneath the sea floor supplies the thermal energy to create these superheated plumes.

c. Another crucial fact is that seawater is constantly *cycled* as it falls through the seafloor and expelled by vents. This is what "completes" the circuit.

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6. Each member should have a role in participation; there should be an assigned writer and an illustrator in each group.

EXPLAIN :
After the allotted time is over, regain order of the classroom. Have each group come to the front of the class and present their hypotheses and illustrations on the projector (or overhead). Each member should have a role in participation; there should be an assigned writer and an illustrator.

- Ask questions like, "Can you explain to us your drawing?"
- "How is this like the systems we discussed before?"
- "How did you come to this conclusion?"
- "Does this system remind you of anything else? Have you seen this before?"
- "Can you [or anyone] think of something like this in our everyday lives?"
    - This could be a door to discussing most of the rest of life on Earth and where most of our energy ultimately comes from (the sun)
- "Where is the energy coming from?"
- "What form of energy is present at this step in your diagram?"
- "[To rest of class]: what do you all think about this?"
- Did anyone else come up with something similar? Totally different?

ELABORATE:
At last, the case for Europa: the center of this lesson. In this section, the students expand on all that has been discussed in class thus far about life and its ability to endure some of the most unlikely environments.

1. At the heading of this lesson are numerous sources on the moon Europa. Now that the students have explored hydrothermal vents, the instructor should present the case for Europa. Its water content; its distance from the sun; its weak magnetic field; the tidal heating; and the detection of organic compounds are all good facts to introduce. The following image is supplied especially for visual learners. Feel free to include other images of the moon in your introduction, but try to leave out images depicting the ice shell of Europa. This will be a topic of the final assignment.

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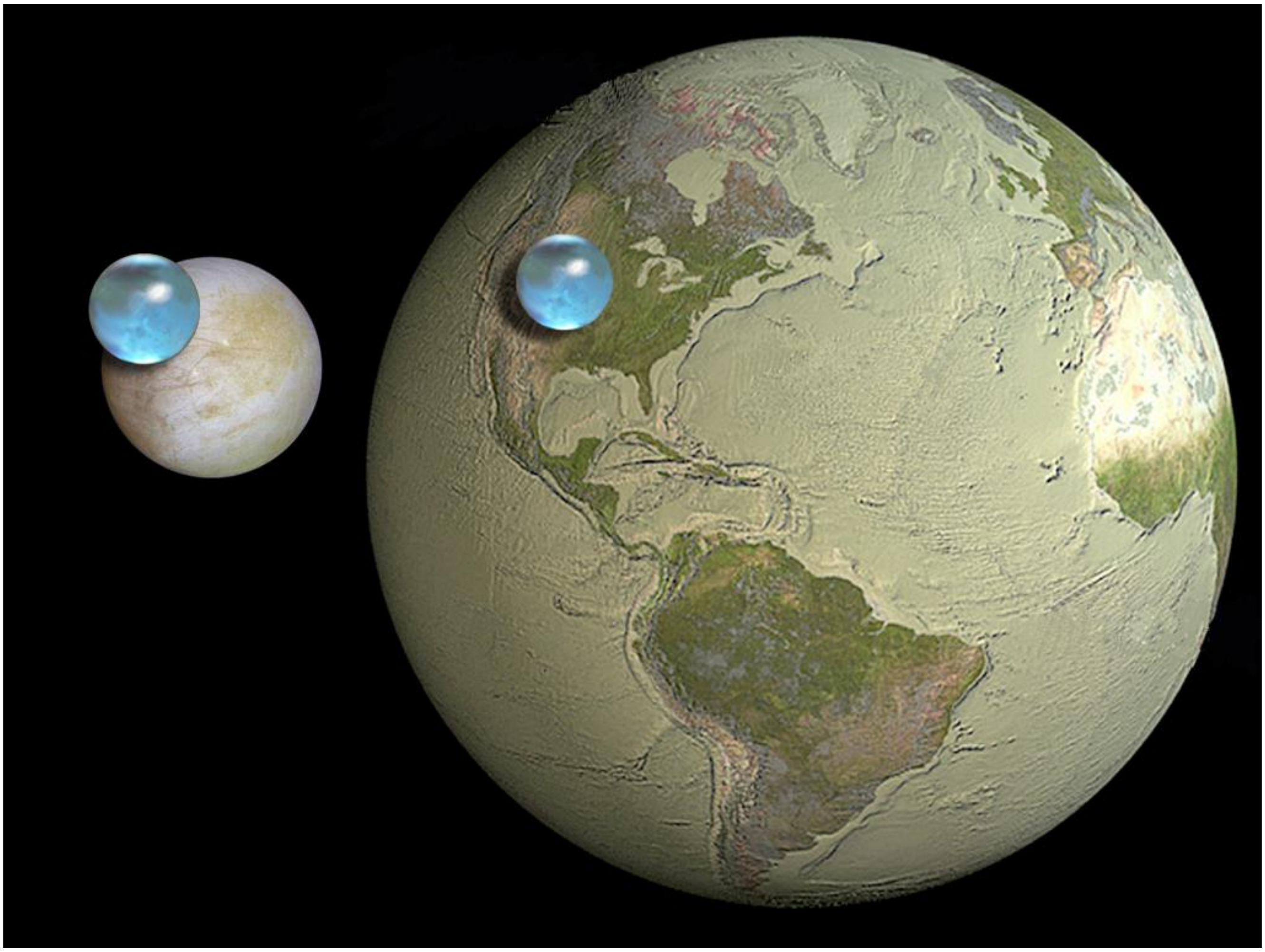

2. Turn it over to the students: "Knowing what you now know about the energetic processes around extreme environments on Earth like hydrothermal vents, develop your own physical model (no more technical than previous exercise) on how such energy cycles (like those on Earth and the seafloor) could happen on Europa. Or, create a model that demonstrates why these cycles could *not* be possible." Create an illustration/explanation.
3. It is at the instructor's discretion on how much time should be allotted for this step.

<u>EVALUATE</u>:

This final synthesis is to check for the students' understanding of the necessary factors for life and of the transport of energy vital for life to thrive. It will also expose the students to very real, very current research on both Earth and Europa. The student will independently research how scientists like Dr. Schmidt hypothesize the surface layers of ice on Europa interact with theorized, rising plumes of warm ocean water. In her own words, this offers a way to, "connect the two terminals [of a circuit necessary for life]." The student will write

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about at least two hypotheses, and they are also asked to compare and contrast these with the model they created in class.

This is contained in a separate document (LINK) for the students to complete and hand in. It is at the discretion of the instructor how students should cooperate for this assignment. The instructions ask for resources from the teacher, so at the heading of this lesson are numerous links for the instructor to choose from.