The Origin of Life

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This curriculum unit is recommended for:
Grade 9/10 Biology

Keywords: evolution, origin of life, biochemistry, data analysis

Teaching Standards: See Appendix 1

Synopsis: North Carolina essential standards for biology state in objective 3.4.1 the following: "students must be able to summarize the hypothesized early atmosphere and experiments that suggest how the first cells may have evolved and how early conditions affected the type of organism that developed (first anaerobic and prokaryotic, then photosynthetic, then eukaryotic, then multicellular)." In this unit I provide background information for the abiotic appearance of organic molecules on Earth. I then discuss the chemical properties of these compounds as well as the results of experiments supporting the formation of the components of life in an abiotic environment. In addition, experimental results regarding how these abiotic molecules could exhibit some of the characteristic of life, for example competition and reproduction is also included. Life as an emergent property is brought up at the beginning of the unit as an introduction, then again at the end as a means to tie together the information provided about the origin of life. I have included activities that demonstrate various properties of organic molecules as well as practice in data analysis for topics such as surface area and nucleic acid replication.

I plan to teach this unit during the coming year in to 60 students in an honors biology I course.

Rationale and Background:

This unit is appropriate for students in a first year biology course.

I teach at William A. Hough High School, a suburban high school that is located in Cornelius, North Carolina. It is in the Charlotte Mecklenburg School District. The number of students attending the school is approximately 2600. We offer standard level, honors level, Career and Technical Education, and Advanced Placement courses that serve a variety of students. The school day is run on a block schedule where most classes meet for 90 minutes each day per semester.

North Carolina biology essential standards objective 3.4.1 states that students must be able to "summarize the hypothesized early atmosphere and experiments that suggest how the first 'cells' may have evolved and how early conditions affected the type of organism that developed (first anaerobic and prokaryotic, then photosynthetic, then eukaryotic, then multicellular)."

In addition to meeting the essential standards for biology, all CMS teachers are encouraged to be trained in Reading Apprenticeship. Reading Apprenticeship gives teachers strategies to increase literacy. This program encourages teachers to provide rich and varied sources of text to students. One example of this would be articles from scientific journals. Students can increase their analytical and comprehension skills as they analyze data from scientific experiments. Not only will students increase their level of literacy, they will also learn valuable scientific concepts while doing so. This curriculum unit includes activities that involve analysis of data as well as links to primary source articles.

As teachers in a typical biology classroom in CMS, we follow a pacing guide that has students study the following topics: basic biochemistry; followed by abiogenesis vs. biogenesis. We often use the work of Francesco Redi and Louis Pasteur as our example of controlled experiments with the additional lesson of disproving abiogenesis. The big idea of these lessons is to show how their data supports biogenesis. Students become convinced that life has to come from other life.
When students are in middle school they study the cell and in the high school curriculum they learn about the cell theory. We consider these lessons successful if, among other things, the students memorize the following: all cells come from preexisting cells. As the semester moves on we cover natural selection. If we follow the pacing guide, the next topics are the work of Miller and Urey and the endosymbiotic theory. This material is covered in the textbook that was adopted by CMS but does not explain the origin of life. The text and lessons that spring from it tell that an anaerobic cell may be first life form but not *how* that type of cell may have come about. There is no connection between the chemical properties of the organic molecules that the students learn about in the

beginning of the semester and the "appearance" of the first cell, nor is there any connection made between the earliest forms of life and the types of cells/organisms that the students see as subject to natural selection. And there is no mention of the obvious contradiction between the concept of abiogenesis and the origin of life. When I asked my colleague about this "contradiction" she said "students ask me that all of the time, I don't have an answer". We teach the students that Redi and Pasteur disproved abiogenesis, then we jump to the Cell Theory, then to evolution of complex systems. Life had to have come from abiotic factors. The purpose of this curriculum unit is to provide scientific evidence for the origin of life as background information for teachers, provide scientific data for students to analyze and provide activities that help students understand some of the major concepts involved in our understanding of the origin of life.

In a first year biology course, we teach how various organisms accomplish the life functions as described in the North Carolina Essential Standards for Biology: "transport and excretion, respiration, nutrition, reproduction, growth and development. The students learn that the simplest cell can carry out these life functions. As the semester progresses they learn these functions in complex, multicellular organisms. If we are to consider the origin of life, then these complex functions need to be distilled down to more basic characteristics. The earliest cells may not have carried out all of these functions at the same time, yet they all share these characteristics: passing information from one generation to the next; occupying three-dimensional space; and changing over time.[1] Understanding that life cannot exist without these 3 fundamental properties will be essential for teachers as they follow the path from the abiotic to the biotic. When does a particular entity become living? In the context of this curriculum unit, it is when it exhibits the aforementioned fundamental properties.

The origin of all living things can be explained through the disciplines of chemistry, physics and astronomy. These subjects do not delve in the living, but must be considered if one is to understand the origin of life, and therefore the discipline of biology. It is a good idea to expose students to the interdisciplinary nature of science. It brings home the point that scientific work does not occur in a vacuum, but rather that the most important discoveries are the result of painstaking preparation before a hypothesis is even generated. The work of the chemist, physicist and astronomer helps us understand how life began, and how it continues. As Dr. Albert Eschenmoser, professor at the Scripps Research Institute and professor emeritus at the Swiss Federal Institute of Technology so eloquently stated: "Going from "nothing but chemical" to "living". The question for science is not did it occur, but how rather, how did it occur?" [2] He continued with: "The crux of the question of the origin of life lies in the fact that it refers to chemical processes that happened more than 3 billion years ago. The origin of life cannot be discovered, as other things in science, it can only be "re-invented."[2] In this unit you will review the emergent property of life as it originated from a sea of biological molecules. You will read about results of recent research that focus on the abiotic origin of life from these molecules. In addition, you will be prepared to lead students in activities that increase their scientific literacy and problem solving skills.

The Science Behind the Unit

What is an Emergent property?

Life itself can be considered an emergent property. An emergent property being one that only exists when two or more components interact. To use a non-biological example, if someone gave you the mechanical components of a stapler then told you to staple some papers together, you would not be able to do it. You would not have a functioning stapler unless you combined the components in a very specific way. This same principle can be applied to many biological systems, not the least of which is the functioning cell. You would not consider the organelles to be separate living structures, yet when they are organized in a particular way, the basic building block of all living things has "emerged". As the components of life are described in this unit, you will be able to lead the way for students to consider the possibility of them assembling into the earliest forms of life.

The Chemical Compounds of Life:

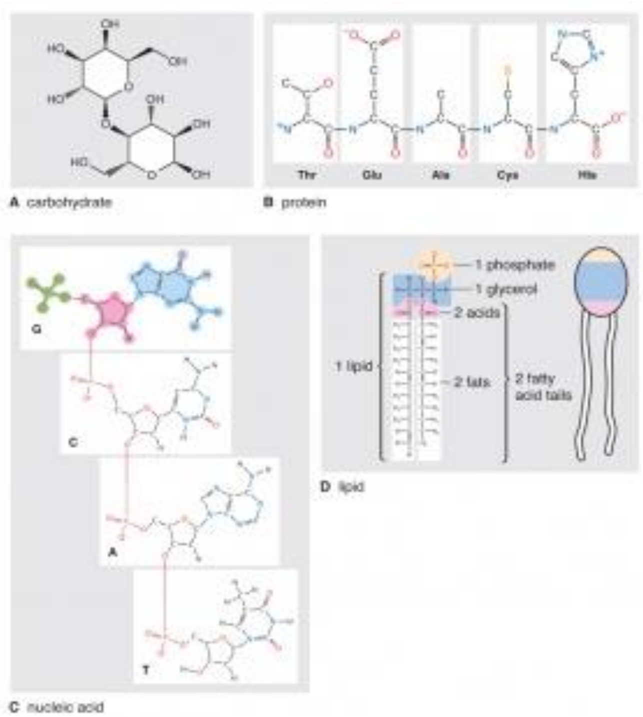

Fig. 1. A. Carbohydrate, B. Amino Acids, C. Nucleic Acids, D. Lipids. With permission from Campbell, Paradise and Heyer.

The four major organic compounds, the building blocks of life, carbohydrates, lipids, proteins and nucleic acids, fig 1.[1] Our curriculum stresses the function of each of these and we reference them throughout the semester. Students in a Biology 1 course learn the differences and functions of each of these, but because they have very little knowledge of basic chemistry, they may not appreciate that these essential biological molecules were originally formed in abiotic conditions. Chemical compounds form because the compounds are more stable than their component atoms or molecules. In other words chemical reactions occur because the products are more stable than the reactants. The organic molecules shown in the figure below did not appear on the planet so that they could combine in various ways to form the components of cells, they are the result of chemical reactions. These compounds result from reactions that lead to stable products. Their formation follows the rules of atomic theory. In this curriculum unit I will present information which shows how these organic compounds showed up on the early Earth through abiotic means. Once present, these compounds could join together to form a primitive cell that exhibits the basic properties of life: change, replication and existence as a three dimensional object.

Please refer to figure 1. Diagram A shows a carbohydrate, these molecules serve as energy sources and as building blocks for many structural components of living things. Diagram B shows five examples of the 20 different amino acids that comprise the variety of protein molecules that are an integral part of every organism. Diagram C shows four nucleotides. These DNA nucleotides are composed of three parts: the sugar deoxyribose, a phosphate group and one of four possible nitrogenous bases, adenine, guanine, cytosine or thymine. The diagram also shows that these nucleotides joined together with a phosphodiester bond. RNA, a second, important nucleic acid, is also composed of similar nucleotides with the substitution of the sugar with ribose as well as the replacement of the nitrogenous base thymine with one called uracil. Polymers of these nucleotides form molecules that are responsible for storing and transmitting information during the life of every organism. DNA is also is key for passing that information to the next generation of organisms. Diagram D shows the lipid, specifically the phospholipid. Note the colored phosphate and glycerol “head” as well as the “tails” which are composed of two fatty acid chains. This molecule is an essential component of all membranous structures, most importantly the cell membrane. In this unit you will read about the research that has led to us our understanding of the origin of these molecules as well as how these molecules could have come together to form the first living cells.

Take a look at the different types of organic molecules. This may be a good time to review basic atomic structure, covalent bonding, common elements among these compounds, examples that students may know and functions of these compounds in living systems.

The Origin of Amino Acids: The work of Miller and Urey was ground breaking in that they demonstrated that organic molecules could be produced abiotically.[3] In the 1950s these scientists wanted to find out if organic compounds could be synthesized in a laboratory apparatus that simulated conditions of the early earth. You can point out to your students that in order to form a hypothesis, scientists read and study the work of others. Miller and Urey used their knowledge of geology and built a reaction chamber that contained water and gases that, as evidence suggests, were present on the earth billions of years ago. They removed the air from the chamber and replaced it with Methane (CH_4), Hydrogen gas (H_2) and Ammonia gas (NH_3). Since it is also known that lightning was prevalent, they used an electric charge to provide energy for the reactions in the chamber. As the reaction occurred the color of the reaction chamber changed indicating that chemical reactions were occurring (figure 2) When the contents of the vessel were analyzed they found that several different types of amino acids were produced. The amino acids first determined were aspartic acid, glycine and alanine. These amino acids are the same building blocks that are found in many proteins today. In addition to these amino acids, a fatty acid, butyric acid was also found in the chamber. If you refer to figure 1, you will notice that fatty acids compose the tail section of the phospholipid. Miller and Urey's experiment was one of the first to show that organic molecules, specifically amino acids and fatty acids, could be synthesized in an abiotic environment that was similar to the early Earth.

In 2008 a paper was published in Science that further supported these results.[4] When scientists examined the original work of Miller and Urey, they learned that there was a collection of water vapor in the vessel. Knowing that erupting volcanoes can spew a mixture of materials along with water vapor, and that this, along with lightning was a common occurrence on the early Earth. They reanalyzed the contents of the vessel and learned that there were more types of amino acids in the apparatus. These scientists coupled a great idea with advanced technology. This work provides increased evidence that many amino acids were formed during chemical reactions on the early Earth. You can stress to your students that this shows how an improvement in technology improves the way that scientists collect data. The fact that Miller and Urey's experiment was replicated, and new information was learned, is key to understanding the process of science.

An additional source of amino acids was discovered from the analysis of the Murchison Meteorite.[5] This meteorite landed in Australia in 1969. Interstellar bodies are subject to forces which cause them to break up. When these bodies brake up into pieces they carry with them the molecules of their parent body and, as it bullets its way through the dust and debris of our solar system, all kinds of other materials from space. These fragments land on earth (which is what a meteorite is) and provide the Earth with the building blocks of life. The analysis of this meteorite revealed many types of amino acids. In addition to this, organic compounds found in the meteorite were similar to the ones synthesized by Miller and Urey.

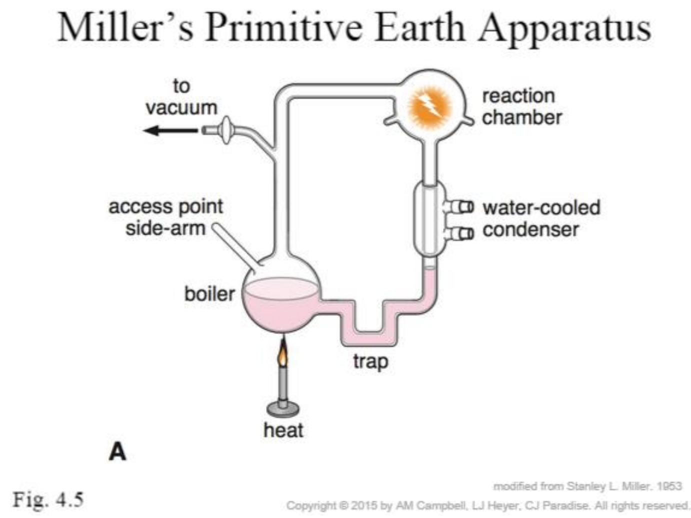

Figure 2. Miller and Urey apparatus. Campbell, Heyer, Paradise, with permission.

The Origin of Lipids: One of the most important compounds, when considering the origin of life, is the group known as the lipids. It is known that the plasma membrane and all membrane bound organelles are composed of a phospholipid bilayer. The amphiphilic property of the phospholipid is what makes it the ideal molecule for membrane formation. An amphiphilic molecule has one end which is hydrophilic (water loving) while the other is hydrophobic (water fearing). In the case of the phospholipid, the head is hydrophilic and the tail is hydrophobic. Where did these special lipids come from? We can look at the Murchison meteorite for answers. Analysis of the interior of the meteorite showed evidence of lipids. This means that the synthesis of lipids occurred abiotically in another part of our solar system and were delivered to Earth by meteorites. Scientists from NASA were able to recreate this synthesis by simulating the conditions found in space.[5] They set up an experiment with vessels that contained an ice mixture of water, methanol, ammonia and carbon monoxide. After these vessels were exposed to UV light (which is very abundant in space), the contents of the vessels were analyzed and amphiphilic molecules as well as fluorescent molecules were found. In summary, phospholipids can be synthesized in an abiotic environment.

Consider the amphiphilic nature of the phospholipid as well as the watery environment of the early Earth. How can two molecules that "resist" each other find stability in the same environment? If you think about the hydrophobic tail of the molecule and compare it to a simple lipid or fat, you know that fats and water don't mix. Similar to the layers in salad dressing, these two compounds are not chemically compatible. The solution to this dilemma is the formation of a bilayer. The hydrophilic heads point toward the watery environment while the hydrophobic tails of each layer face each other. When these phospholipids are put in an aqueous environment they will spontaneously form a vesicle. You can point out the fact that when children blow soap bubbles with a soap solution and a wand, a spherical bubble forms. This sphere is the result of the chemical properties of the soap. In order to have anything resembling a primitive cell, there must be some kind of vessel, or vesicle, where there is a defined interior. Figure 3 shows a diagram of a vesicle .The round hydrophilic heads are facing the aqueous environment as well as the watery lumen (interior) of the vesicle. The hydrophobic tails are facing toward each other away from the water.

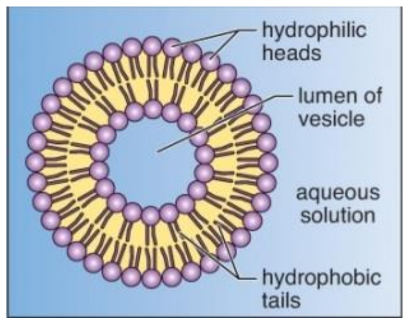

Figure 3. lipid vesicle.Campbell, Paradise and Heyer, with permission[1]

This type of arrangement makes sense, but is there evidence that these really form? And can they form abiotically, without the presence of cells? The answer to this question is “yes”. These same NASA scientists provide evidence in their paper for the “self’ assembling of amphiphilic “molecules”. Their research not only supports the abiotic formation of these amphiphilic lipids but also the formation of vesicles similar to the one pictured above. You can see their published paper which includes photographs of these vesicles by clicking the link in which I have included in the readings section. We have now accounted for two of the necessary molecules necessary for the life: amino Acids and Lipids, B synthesized without the presence of any living thing.

The Origin of Nucleic Acids. One of the criteria of life is that it must contain some type of molecule that is capable of storing and transmitting information. We know that DNA (deoxyribonucleic acid) and RNA (ribonucleic acid), are these types of molecules. Is there evidence that either of these may have come about abiotically? We already know that abiotic replication of these can be accomplished in a lab with a thermo cycler, but what about the origin of these molecules? Precursors of nucleotides have been identified on meteorite samples. This fact suggests that they are the products of abiotic reactions. Was DNA or RNA the first nucleic acid? One possible answer to this questions is known as the RNA-world hypothesis. This hypothesis explains that the earliest nucleic acid must have been RNA. In 1985 two biochemists named Michael D. Been and Thomas R. Cech set up an experiment hoping to generate enough data to support their claim.[6] Since one of the defining features of a nucleic acid is its ability to replicate, they wanted to find out if they could add nucleotides to a growing RNA chain without using an enzyme composed of protein nor any cellular components. Their research question: could RNA alone catalyze a growing RNA chain? This idea was based on the fact that the ribosome is a self-organizing non-membranous organelle composed of RNA. An experiment was designed to see if RNA would polymerize itself. A good analogy for this process would be: if given a necklace with only 5 beads, can the necklace make itself longer if more beads were provided?

To begin, samples of short pieces of RNA with 5 Cytosines called pC5 were added to 4 test tubes. This was the starter RNA. In test tubes 1-4 one of four different RNA dinucleotides GpC, GpU, GpA, or GpG was added. The p represents the phosphodiester linkage between two individual nucleotides. C is cytosine, U is uracil, A is adenine and G is guanine. Simply put, 4 different RNA nucleotides were added to each test tube, C, U, A, and G. They checked the test tubes after 10, 30 and 60 minutes and counted the number of nucleotides added to the starter RNA.

The data from their experiments are shown in figure 4.

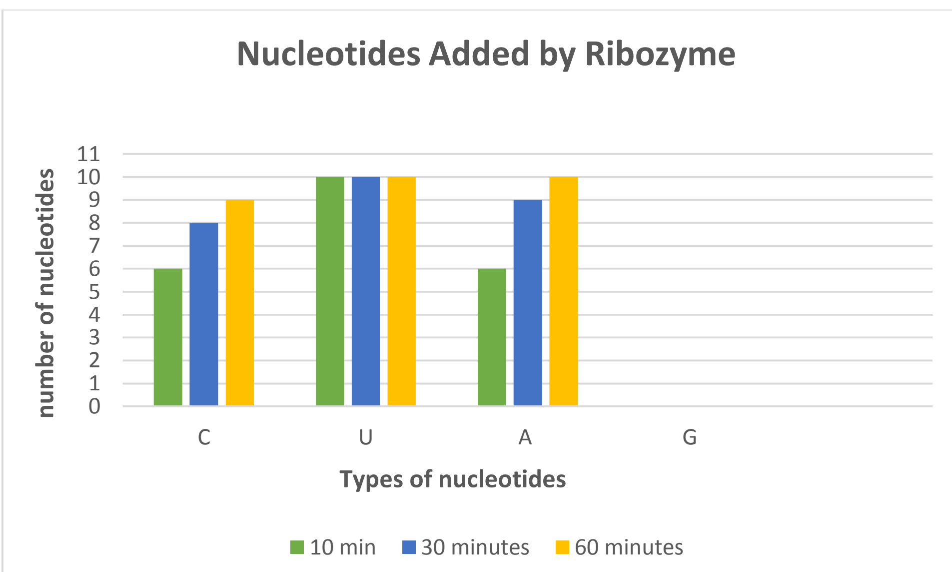

Figure 4

According to the data above, the scientists discovered RNA can polymerize itself. They learned that a molecule of RNA acted as an enzyme. It could add bases onto the starter chain of pC_5. They named this enzyme a ribozyme. This name distinguishes it from protein based enzymes since it is composed of RNA. Let's look at some of the details of the work of this ribozyme. The ribozyme was unable to add the G nucleotide to the pC5. It was able to add C, U and A. The U nucleotide was added to the starter chain the fastest since after 10 minutes, 10 nucleotides were added. The hypothesis is supported by these data, a necklace can get longer if provided with more beads! This adds to the growing evidence that abiotic molecules can perform tasks on their own without the help of cellular components or other enzymes.

As so often happens in biology, additional evidence for biochemical processes, or evolutionary patterns is discovered in organisms that exist right alongside of us. In this case it is the discovery of a functioning ribozyme in an organism known as Tetrahymena.[7] Tetrahymena is eukaryotic and single celled. This organism has RNA which can chop itself up, then using only RNA, tie the loose ends back together. Cutting and splicing RNA is part of RNA processing during protein synthesis. In our cells this is accomplished by a combination of RNA and enzymes composed of protein. In Tetrahymena, it is accomplished with RNA alone. The existence of ribozymes in Tetrahymena and the fact that scientists can synthesize RNA in the laboratory gives powerful evidence to support the RNA hypothesis. In addition to the discovery of the ribozyme, scientists were able to use directed evolution (artificial selection) to choose the most efficient ribozymes. A group of ribozymes with varied catalytic ability were obtained, and the fastest ones were selected for. After several rounds of directed evolution, a group of ribozymes that were faster than the originals were isolated. In this way scientists showed how molecules may have been the subjects of natural selection.

RNA very well may have been the first molecule that could store information. Storage of information is a vital characteristic of life and, as we know, RNA is a molecule capable of doing just that.

Putting the pieces together:

How did these organic molecules organize themselves into the necessary structures for life? In the last section of the background information section, you will read about some of the experiments that support the origin of some of the structures and processes associated with life.

Self-organizing Vesicles

We've already seen that phospholipids will form vesicles due to their amphiphilic properties. What evidence is there that this could have happened in an abiotic environment? Is there any evidence to show these molecules could even have "found each other" in the vast volumes of water in the prebiotic earth? Three researchers, Martin Hanczyc, Shelly Fujikawa and Jack Szostak wanted to see if this could happen.[8] They set up an experiment with a mixture of phospholipids, water and clay. Clay was included in the experiment because they wanted to simulate the environment that was most like that of the early Earth. Clay is one of the most common materials in the Earth's crust.[9] They were able to observe the spontaneous formation of vesicles inside of their reaction vessel. The scientists noted that as the number of vesicles increased, clay was not consumed in the process. The clay provided the surface for the phospholipids to meet and form vesicles. Their data showed that with increased clay concentrations, there was in increase in vesicle formation. The clay served as a catalyst for the formation of the vesicle. The formation of vesicles on clay can be compared to how bubbles form on a saltine when a piece is added to some soda. An activity that explores surface area and bubble formation is included in this unit. Phospholipid molecules come together to form a structure which has 3 dimensions, and a defined interior (or lumen). This experiment adds to the evidence that the structures needed for the earliest cells can come together as a result of the interaction of abiotic materials.

In addition to vesicle formation, the scientists noted that bits of clay could be trapped inside the vesicles. In a sense, the vesicles were trapping the catalyst. If these vesicles could trap clay, could they trap RNA too? The answer to this question is yes. When the scientists provided RNA to their experiments, RNA was spontaneously engulfed as the vesicles formed. The presence of RNA actually encouraged vesicles to form around it. This is evidence that membrane bound vesicles containing a nucleic acid can form spontaneously in an abiotic environment.

Processes of life: growth and reproduction

The abiotic production of vesicles containing a nucleic acid cargo has been accomplished in a laboratory. Is there evidence that these vesicles are capable of any of the processes of life? We know that cells are able to grow and divide. Can these characteristics be observed in an abiotic environment in the laboratory?

Experiments were conducted to determine if abiotic vesicles could grow and reproduce in a laboratory. The scientists obtained a sample of vesicles. A good starting point to see if vesicles can increase in size would be to have a sample of vesicles that are all the same size. To accomplish this the vesicles were pushed through a small filter. The size of these vesicles was then measured and recorded. The next step would be to provide the materials necessary for growth. Phospholipids in the form of micelles (solid balls of lipid) were added to the vesicles. Samples of the vesicles were analyzed over a 4 hour period and the results indicated a linear growth curve. Over time, vesicles grew as more phospholipids were provided.[1]

To test whether or not these vesicles could reproduce, the scientists then took these newly formed large vesicles and put them through the filter. Each large vesicle divided into 2 smaller ones. They observed a "parental" vesicle forming two smaller daughter vesicles. This can be compared to cell division in which enzymes and complex cellular machinery work together in the reproductive process. In this case only physical stress and chemical properties are involved in reproduction of these vesicles. Abiotic vesicles, subjected to conditions that may have been present on early Earth exhibit characteristics of life. An interesting note about these experiments is that when scientists looked at the sizes of the parent vesicles and the daughter vesicles over a five cycle period, the size pattern was similar to the life cycle of organisms that reproduce asexually.

Process of life: Competition

Competition for limited resources is the driving force for evolution. Could there have been competition between these vesicles? Do they compete for phospholipids?

Two types of vesicles were put together inside a container. One type was considered "stressed". The stressed vesicles were given a high concentration of sucrose as cargo and as result water diffused into the vesicle causing osmotic pressure, or stress. The second type was not given the sucrose solution and was considered unstressed. The volumes of both types of vesicles were measured at the beginning of the experiment and then over a course of several hours. The conclusions were interesting. The volume of the stressed vesicles increased while the volume of the unstressed vesicles decreased. The conclusion that the researchers made was that the vesicles were in competition for the phospholipids and the stressed vesicles essentially stole phospholipids from the non-stressed vesicles. To further support these data, the scientists used a more relevant molecule to create the stressed vesicles. They added t-RNA molecules (to simulate RNA cargo). These t-RNA stressed vesicles also incorporated phospholipids from non-stressed vesicles into their membranes and increased in size.

Process of life: Reproduction

As we've taught our students, one of the reasons that cells divide is that they become too large. When a cell increases in size the volume may increase four fold while the surface area may only double. This condition is one of the triggers for cell division.

Scientists wanted to test whether cells with a cargo of t-RNA would divide when forced through a filter. Forcing vesicles though a filter simulates vesicles in a drying environment. Here a physical change is used to approximate the abiotic environment. They observed that when these vesicles divide some of the RNA would spill out into the environment and trigger the formation of even more vesicles. These abiotic vesicles are reproducing and forming new vesicles with a variety of RNA cargo. There is an activity at the end of this unit where students calculate volume and surface area of cells of different sizes. The mathematics table can be filled out by the students since all of the equations are provided. Using math to support concepts in biology is a powerful tool and one that students should be familiar with. In addition to comparing volume and surface area between cells of different sizes, you can point out to the students that there is not enough “membrane” to engulf the large volume of t-RNA when a large vesicle divides. Therefore, some of the t-RNA would have to spill out into the environment.

A logical question that you could pose to students would be: If primitive vesicles contained a self-replicating molecule such as RNA, and are capable of growth and division, is it possible given billions of years, this type of mechanism could have developed into a primitive cell?

Processes of life: Storage and harvest of energy

Every living thing uses energy for life processes. One type of energy that can be harnessed for biological processes is the potential energy of a proton gradient. In eukaryotic cells, Hydrogen ions (H^+) are pumped across the mitochondria membrane to create a gradient. As H^+ ions flow back along the gradient, they flow through a protein, ATP synthase, which then harnesses this energy to build ATP molecules. The production of this gradient, which is merely pumping protons, is used to generate one of the most important molecules for life, ATP, the currency of cellular energy.

Is it possible for an abiotic system to create a proton gradient? Scientists wanted to see if they could create a system in which abiotic vesicles could form a proton gradient. In other words, create a vesicle with a higher concentration of H+ inside the lumen when compared to the outside. An effective way of measuring whether or not a proton gradient was created was to measure the pH changes on the interior and exterior of the vesicle. In order for the uptake of the H+ ions to occur, the scientists used vesicles capable of growing. These vesicles were placed in a solution with a low external pH and were “fed” new lipids that had a slight negative charge on their head groups. The new lipids were incorporated into the bilayer of the vesicles. Some of the H+ ions in the solution would bind to these negatively charged heads, resulting in a charge difference between the inside and outside of the vesicles. In order to balance these charges, the lipids with the H+ would flip so that they would be facing the lumen of the vesicle. When this occurred the H+ would then be released into the lumen. Scientists measured the pH differences before and after the incorporation of the negatively charged lipids and recorded a significant drop in the pH of the solution inside of the vesicle. This drop in pH indicates the establishment of a hydrogen ion gradient by an abiotic vesicle. In the resource section of this unit I have provided a link to the paper for this work. You can show students the diagram of the lipids as well as the original data that shows the pH changes. I have also included questions that you can use for student analysis of some of the graphs.

A challenge for students:

The ideas and data in this unit are meant to help students make sense of the gap we have in the state curriculum. There is a wealth of data that supports the abiotic origin of life. You can encourage your students to use each section as a springboard for them to investigate other published works on this topic. With new information and an understanding of life as an emergent property, you can help your students understand that natural forces acted to bring about the earliest life forms on this planet.

Suggested Student Activities:

1. An Oreo cookie as a lipid bilayer model. The properties of the phospholipid bilayer can be easily understood with this fun activity. The chocolate cookie part of the Oreo represents the hydrophilic heads of the phospholipid, the frosting in between the layers represents the fatty, hydrophobic tails. Directions: Have an image of the plasma membrane on the board as a reference. Distribute one Oreo per student with the instructions that they are not to eat the cookie. When all students have an Oreo, tell them to put the whole cookie into their mouths, leaving it there without chewing it. Allow the students 5 minutes with the un-chewed cookie. Instruct them to notice what is happening to the cookie as it sits in their mouths. After 5 minutes allow them to chew and eat the cookie. Points to make: The chocolate part of the cookie dissolves since it is in contact with saliva, which is mostly water. The chocolate part of the cookie represents the hydrophilic heads of the phospholipid. It may help if you have an image of the plasma membrane on the board as a reference. Also call their attention to the fact that the filling of the cookie remains essentially unchanged. The filling of the cookie represents the hydrophobic tails of the phospholipid and would not interact with the water in the saliva. Some students may ask why the hydrophilic heads of the phospholipid do not dissolve in the watery environment or cytoplasm of the cell. Remind them that the heads and tails of the phospholipid are parts of the same molecule.

2. Surface area, Saltines and 7-Up. Materials needed: 3 sheets of construction paper. 1 small bottle of 7-UP, Saltine crackers. Explain surface area with construction paper. Explain how reactions can only happen on the surface of a material. Materials needed: 3 sheets of construction paper, any color. Tape. Tape two sheets of construction paper together. Fold up 2 sheets like a fan and place on top of 1 sheet of unfolded construction paper. Show how both the unfolded and folded take up the same amount of space which is 8 x 11 in. Then unfold the fan and show how it is really two times the area in the same amount of space. Part 2- Saltines and 7-up. Distribute small beakers of soda and one Saltine cracker per group. Break cracker in half. Using one half, break the half into 4 pieces. Add one of the .25 pieces of Saltine to the soda. Observe bubbles forming on cracker. Count the bubbles if possible to get a rough estimate of numbers of bubbles on the cracker. Remove the cracker before it gets too soggy. Take .25 piece of cracker and break it into smaller pieces and add it to the beaker. Observe bubbles and count to get a rough estimate on each piece. Students should compare the number of bubbles on the .25 size vs. the number on the smallest pieces. The smallest piece will have more bubbles.

Have students write the results of their observation and relate it to the information you have given them about the clay and vesicle formation.

3. Comparing volume and surface ratios between small and large vesicles. Students can use the equations provided to show how surface area of vesicles (and cells) does not keep up with an increase in volume when the vesicles increase in size. This concept is taught when we cover cell division since it is one of the triggers of that process. Giving biology students practice with mathematical equations gives them an opportunity to use data to come to this conclusion

$A = 4\pi r^2$. (surface area of a sphere)

$Volume = \frac{4}{3}\pi r^3$ (Volume of a sphere)

The radius of the small and large vesicle is provided for you.

vesicle type	radius (nm)	surface area (nm^2)	volume (nm^3)	ratio (area/volume)
small vesicle	42			
large vesicle	65			
percent change				

Have students compare the surface area to volume ratio of a large vesicle and a small one. In this context, the fact that all of the volume of the large vesicle cannot be accounted for when it divides into smaller vesicles supports the idea that RNA must leak out and provide the means for additional vesicle formation. (worksheet provided in unit)

4. Analysis of ribozyme data. Here is a data table constructed from the ribozyme experiment. You can provide graph paper and students construct their own graphs. When they have finished, you can compare them to the one in the background information.

Size of RNA Strand for Each Nucleotide

Nucleotide	10 min	30 min	60 min
C	6	8	9
U	10	10	10
A	6	9	10
G	0	0	0

Questions for discussion:

1. Discuss the possible set up of the experiment/experimental design.
2. The data for the control is not included here. What would be in the control tube?
3. What do you suppose the data for the control would look like?
4 .What is the independent variable?
5. What is the dependent variable?
6. Which nucleotide appears to be incorporated best into the growing pC5 chain?
7. What nucleotide did not become part of the pC5 chain?
8. What conclusions can you make after 1 hour of time?

5. Reading a primary source article. The following link is the paper titled: Membrane Growth Can Generate a Transmembrane pH Gradient in Fatty Acid Vesicles.
http://www.ncbi.nlm.nih.gov/pmc/articles/PMC419540/pdf/1017965.pdf
This article is appropriate for the application of many Reading Apprenticeship strategies.

Understanding Volume to Surface Ratio. **Name:**

Complete the table below.

The surface area of a sphere is:

$$A = 4\pi r^2.$$

The volume of a sphere is:

$$Volume = \frac{4}{3}\pi r^3$$

The radius of the small and large vesicle is provided for you.

vesicle type	radius (nm)	surface area (nm^2)	volume (nm^3)	ratio (area/volume)
small vesicle	42			
large vesicle	65			
percent change				

Analysis questions:

1 .Compare the surface area to volume ratios of a small vesicle with a large one.

2. Which type is more efficient for movement of materials into and out of the cell? Explain your answer.

3. Compare the volume of one large vesicle to two small ones. What would happen to some of the material inside the large vesicle when it divides?

Appendix 1: Implementing Teaching Standards

Reading Standards for Literacy in Science and Technical Subjects Grades 11-12:

Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, identifying important issues that remain unresolved.

Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

Students will address these two standards as they review the data that is provided in the links to the primary text. They will also use evidence from the text to support their conclusions.

District/ NC state standards.
Essential Standards. Biology

Bio.3.4 Explain the theory of evolution by natural selection as a mechanism for how species change over time.

Bio.3.4.1 • Summarize the hypothesized early atmosphere and experiments that suggest how the first "cells" may have evolved and how early conditions affected the type of organism that developed (first anaerobic and prokaryotic, then photosynthetic, then eukaryotic, then multicellular).

Students will apply the 5 tenets of evolution as they make their way through the unit. The students will piece together the evolution of the first "cells" as the teacher presents each section and as they complete the activities included in the unit.

Materials for Classroom Use:

1. For the first activity: one Oreo cookie per student.
2. For the second activity: construction paper, tape, 1 liter of 7-Up and one sleeve of Saltine crackers.
3. Calculators
4. Rulers and graph paper

Reading List for students

1. Integrating Concepts in Biology. Campbell, Heyer, Paradise
   Online text book for a first year college biology course and AP biology. This has excellent examples of data that can be used for analysis.

2. Membrane growth can generate a transmembrane pH gradient in fatty acid vesicles. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC419540/pdf/1017965.pdf
   This primary source article has a good abstract. There is a great diagram here that shows how the lipids of the membrane attach to and move protons. There are also good graphs for analysis.

3. A Kinetic Study of the Growth of Fatty Acid Vesicleshttp://www.ncbi.nlm.nih.gov/pmc/articles/PMC1304506/pdf/988.pdf
   This is a primary source which has a good abstract and several graphs and data tables for analysis.

Bibliography for Teachers

Campbell, Heyer, and Paradise, Integrated Concepts in Biology. Accessed October 24, 2015. This is the college text written by our seminar leaders. It is a great text with many examples of data for students to analyze and discuss.

Chen, I. A., and J. W. Szostak. "Membrane Growth Can Generate a Transmembrane PH Gradient in Fatty Acid Vesicles." *Proceedings of the National Academy of Sciences*, 2004, 7965-970. This article has a great diagram of the plasma membrane which shows how the lipids move hydrogen ions across the membrane. It also has a great graph of pH changes across the membrane.

Chen, I. A. "The Emergence of Competition Between Model Protocells." *Science*, 2004, 1474-476. Good data that shows competition between abiotic protocells.

Cornell University. "Clay may have been birthplace of life on Earth, new study suggests." ScienceDaily. ScienceDaily, 5 November 2013. <www.sciencedaily.com/releases/2013/11/131105132027.htm>. An article that explains the connection between clay, organic molecules and origin of cells.

Dworkin, J. P., D. W. Deamer, S. A. Sandford, and L. J. Allamandola. "Self-assembling Amphiphilic Molecules: Synthesis in Simulated Interstellar/precometary Ices." *Proceedings of the National Academy of Sciences*, 2001, 815-19. A good article that describes how amphiphilic molecules can be synthesized without cellular components i.e.) as they may have been in space.

Ekland, Eric H., and David P. Bartel. "The Secondary Structure and Sequence Optimization of an RNA Ligase Ribozyme." *Nucl Acids Res Nucleic Acids Research*: 3231-238. Original source of RNA polymerization with Ribozymes. Shows gel electrophoresis data from experiment.

Hanczyc, M. M. "Experimental Models Of Primitive Cellular Compartments: Encapsulation, Growth, And Division." *Science*: 618-22. This article shows how vesicles can encapsulate cargo.

Johnson, A. P., H. J. Cleaves, J. P. Dworkin, D. P. Glavin, A. Lazcano, and J. L. Bada. "The Miller Volcanic Spark Discharge Experiment." *Science*, 2008, 404. This article confirms Miller and Urey’s original work as well as adds more data after analysis of water vapor components.

"Meteorite That Fell in 1969 Still Revealing Secrets of the Early Solar System." Scientific American Global RSS. Accessed September 9, 2015. http://www.scientificamerican.com/article/murchison-meteorite/. An article that describes the discovery of amino acids on the Murchison meteorite.

Miller, Stanley L. "Production of Some Organic Compounds under Possible Primitive Earth Conditions." *Journal of the American Chemical Society*: 2351-361. The original work of Miller and Urey.

"TSRI - News & View, Fundamental Questions: An Interview with Albert Eschenmoser." TSRI - News & View, Fundamental Questions: An Interview with Albert Eschenmoser. Accessed October 25, 2015. A transcript of a speech from Dr. Eschenmoser in which he presents the idea that life had abiotic origins.

Walde, Peter, Ayako Goto, Pierre-Alain Monnard, Michaela Wessicken, and Pier Luigi Luisi. "Oparin's Reactions Revisited: Enzymic Synthesis of Poly (adenylic Acid) in Micelles and Self-Reproducing Vesicles." *J. Am. Chem. Soc. Journal of the American Chemical Society*: 7541-547. This shows abiotic reproduction.

Chicago formatting by BibMe.org.

Notes

1. Campbell, Heyer, and Paradise Integrated Concepts in Biology. Section 4.2

2. http://www.scripps.edu/newsandviews/e_20080421/eschenmoser.html

3. Campbell, Heyer, and Paradise Integrated Concepts in Biology. Section 4.2

4. "Meteorite That Fell in 1969 Still Revealing Secrets of the Early Solar System." Scientific American Global RSS. Accessed September 9, 2015. http://www.scientificamerican.com/article/murchison-meteorite/

5. Campbell, Heyer, and Paradise Integrated Concepts in Biology. Section 4.2

6. Been MD, Cech TR. RNA as an RNA polymerase: net elongation of an RNA primer catalyzed by the *Tetrahymena* ribozyme. *Science* 239(4846):1412-1416, 1988 ICB

7. Campbell, Heyer, and Paradise Integrated Concepts in Biology. Section 4.2

8. Cornell University. "Clay may have been birthplace of life on Earth, new study suggests." ScienceDaily. ScienceDaily, 5 November 2013. <www.sciencedaily.com/releases/2013/11/131105132027.htm>.

9. Chen, I. A., and J. W. Szostak. "Membrane Growth Can Generate a Transmembrane PH Gradient in Fatty Acid Vesicles." *Proceedings of the National Academy of Sciences*, 2004, 7965-970.