Goals:
Students will learn:
1. A hierarchical organization of life.
2. How the different concepts they have learned interact and produce the structures and functions they see.

Objectives:
Students will be able to:
1. Define hierarchy and hierarchy theory and draw a diagram that demonstrates both of these concepts.
2. Identify and organize biotic levels from biomes to subatomic particles.
3. Explain how the levels of organization of multicellular organisms compare to unicellular organisms.
4. Apply hierarchical organization to a new system.
5. Explain how different levels in a hierarchy interact to produce specific patterns and processes at different temporal and spatial scales.

Background:
Hierarchical Organization: Unicellular organisms can easily obtain, break down, and use food to sustain themselves because they consist of only one cell. They remain tiny due to problems with diffusion of matter in large surface area to volume ratios (volume increases at a much quicker rate than surface area; therefore, the amount of food and other essential elements necessary to sustain the volume cannot be met). Multicellular organisms have different structural levels organized hierarchically with specialized functions to ensure all cells obtain needed nutrients (tissues, organs, and organ systems). Except for tissues, organs and organ systems, unicellular organisms have the same hierarchical structure and levels presented in this lesson.

Hierarchy refers to a system of organization in which one level is made up of several parts and is itself a component of the next level. Hierarchy theory includes the interactions between and within the levels. That is, higher levels constrain and provide context for lower levels, lower levels provide the “details” to explain the structure and functions seen at higher levels, and the different components of each level interact. Unique structures and functions occur at each level due to different temporal and spatial scales. Scale refers to the spatial or temporal dimension of an object or process. Higher levels normally occur across larger spatial and temporal scales while lower levels usually have smaller temporal and spatial scales. For example, climate has a regional spatial scale and a temporal scale that spans centuries. On the other hand, temperature fluctuations can be described by spatial scales spanning a less than a few feet and on a daily temporal scale. Furthermore, there are qualities that occur only as a result of the interaction of the different components within a level and are not exhibited by any of the components alone. These are called emergent properties. Net primary productivity (plant biomass production) is an emergent property occurring at the ecosystem level of organization. Plant growth (net productivity) is constrained by the climate of the ecosystem and explained by the community of organisms that live in the ecosystem. Understanding this assists researchers in developing predictions in their studies. Essentially, this theory and method of organization allows us to
simplify complex interactions for better understanding. Moreover, there are many different hierarchies in biology. The one presented here is an amalgamation of three hierarchies (atomic, organismal, and supraorganismal).

Subatomic particles make up the lowest level in this lesson. The four most familiar subatomic particles are electrons, quarks, protons, and neutrons. Subatomic particles form atoms that have unique physical and chemical properties and atoms bond to form molecules that also have unique physical and chemical properties. Molecules form organelles that have specific functions and organelles are the components of cells. In multicellular organisms, cells are specialized for specific functions (e.g. nerve cells). Those specialized cells group together as tissues that also perform specialized functions (e.g. nerve tissue). Different tissue types that work together to carry out a specific function form organs (e.g. the brain) and different organs work together to perform specialized functions (e.g. nervous system). Each multicellular organism is made up of multiple systems that allow it to obtain, transform, transport, release, and eliminate matter and energy that it needs to live, grow, and reproduce (unicellular organisms do this within one cell). Organisms of the same species interacting in time and space form populations (e.g. population of kangaroo rats). Populations of species that interact in time and space form communities (kangaroo rats, vegetation, rattlesnakes, soil microbes, etc.). Communities interacting among themselves and with the abiotic environment in time and space form an ecosystem (e.g. Death Valley in the Mojave Desert). Ecosystems differentiated from other ecosystems by distinct, but similar, structures of the dominant vegetation and usually the climate are biomes (e.g. all hot deserts are a part of the desert biome). It is not known if there are levels below subatomic particles. There are levels above biomes (e.g. biosphere, galaxy, etc.), but they are not included here. In summary, each level in the biotic hierarchy is defined by distinct structures and functions that occur at various spatial and temporal scales.

Traditionally, researchers usually study one particular level (e.g. population ecology, cellular biology, landscape ecology); however, the levels interact. Therefore, researchers are becoming more interdisciplinary to more fully understand what they are studying. For instance, the act of a snake attacking and eating a mouse involves multiple levels. The movement involves the coordination and interaction among the molecular, cellular, tissue, organ, and organ system levels of the snake organism and eating the mouse affects the mouse, snake, and other organism populations (via interactions) in the biological community that lives in that particular ecosystem.

Terms: Following are the definitions of the levels of organization introduced above.

- **Subatomic particles (matter particles)**: the elemental constituents of matter
- **Atom**: the smallest unit of an element that retains the unique set of physical and chemical properties of that element
- **Molecule**: a particle composed of at least two bonded atoms that has a unique set of physical and chemical properties
- **Organelle**: structures in cells that carry out distinct functions
- **Cell**: the smallest level at which all functions of life can be carried out by organisms
- **Tissue**: a distinct area of an organ formed from a mass of similar cells and cell products
- **Organ**: a structure composed of two or more tissue types that work together to carry out a particular function
- **Organ system**: a group of interconnected organs that have a specific collective function
Organism: a living entity that can act or function independently
Population: all organisms of the same species (plant, animal, or micro-organism) that coexist and interact (in time and space)
Community: all populations of different species (plants, animals, and micro-organisms) that coexist and interact (in time and space)
Ecosystem: communities interacting with its abiotic environment
Biome: ecosystems of the world characterized by similar dominant flora, fauna, and climate

Lesson: Since the purpose of this lesson is to introduce hierarchy theory and to develop one overall concept of biotic organization, it is assumed that all, or at least most, of the organizational levels used (subatomic particles to biomes) have already been introduced and discussed in previous lessons. Also, the lesson is written assuming the entire deck will be used. If the lower level cards are removed, replace subatomic particles with whatever level is the lowest level being used. Finally, it is essential that guiding questions are used during the discussions to promote critical thinking on the part of the students rather than just giving them all the answers. This is a major part of what makes this an inquiry lesson.

Materials:
- Markers, colored pencils, or crayons
- Paper for each student
- Materials for making one biology card deck per group of 3-4 students
  - 6 sheets of card stock (for 52 2” x 3” size cards)
  - Laminator (optional—to increase the longevity of cards)
  - Copier
  - Paper cutter

PROCEDURE:
Preparation: Cards

1. The Biotic Hierarchy cards are based on the decks that were created and used in my classroom. The key is below and see the Cards handout for the cards to use. The cards in the handout only have the words. If time permits, pictures should be added to reinforce the examples since students may not know what saguaro, etc. look like. Following is an example.

2. Make enough copies of the Hierarchy card deck on cardstock so there is one per group of 4 students. An optional addition is to print a (colored) mosaic design on the back of the cardstock to
make it more difficult to see through the cards when they are held up. To prolong the life of the cards, have them laminated before cutting them out.

3. Using the template from the Cards handout, make at least three copies of the Question cards on cardstock. Laminate them as well if desired.

Key:

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<th>Equivalent to:</th>
<th>Suits (♠ ♣ ♥ ♦)</th>
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<td><strong>Level</strong></td>
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<td>Ace</td>
<td>Subatomic particle*</td>
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<tr>
<td>2</td>
<td>Atom</td>
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<td>3</td>
<td>Molecule</td>
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<td>4</td>
<td>Organelle</td>
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<td>5</td>
<td>Cell</td>
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<td>6</td>
<td>Tissue</td>
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<td>8</td>
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<td>9</td>
<td>Organism</td>
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<td>10</td>
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<td>Jack</td>
<td>Community</td>
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<tr>
<td>Queen</td>
<td>Ecosystem</td>
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<tr>
<td>King</td>
<td>Biome</td>
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Lesson
Part One
1. Ask students to answer the following question: What are four or more possible responses to the question “Where do you live?” Give the students some time to think on their own, then time to share with their group (3-4 students/group). Afterwards, have the groups share their answers with the class for discussion. Write their answers on the board for everyone to see.

2. Augment the students’ list with some of the following words if they are missing.

   Milky Way galaxy          Milky Way galaxy
   Planet Earth              Planet Earth
   Northern hemisphere       Northern hemisphere
   North American continent  North American continent
   Sonora Desert             Sonora Desert
   Country (e.g. United States of America) Country (e.g. United States of America)

   State (e.g. Arizona) State (e.g. Arizona)
   County (e.g. Maricopa) County (e.g. Maricopa)
   City (e.g. Phoenix) City (e.g. Phoenix)
   Zip Code Zip Code
   Street Street
   Home Home
3. Circle the answers that represent country, state, county, city, and home. Give the students time with their group to answer the question "How would you organize these answers?" Afterwards, have the groups share their answers by writing them on the board or large pieces of paper and discuss how the different groups decided to organize the terms (e.g. How are they similar and different? Were any patterns seen and used? What was the reasoning used by each group?). During the discussion, use the students' answers to develop an agreed upon organization.

4. Have the students work as a group to draw a diagram that represents their organization and then discuss them as a class. At least one group should come up with a diagram that shows multiple levels building on each other (hierarchical structure). Use this discussion to segue into introducing hierarchy and hierarchy theory. Tailor the depth of the information to the level of the students. With the guidance of the students, modify their diagrams to reflect hierarchy and hierarchy theory or ask the students to modify their own diagrams. Below is an example of one possible diagram. The most important aspects of the diagrams that must be present are that each level should be composed of parts, be a component of another level, and show interactions between the levels.

![Diagram of hierarchical organization]

Part Two

5. Write the following 13 science concepts on the board: atoms, biomes, cells, communities, ecosystems, molecules, organs, organelles, organisms, organ systems, populations, subatomic particles, and tissues. Remind the students that these terms have been introduced to them previously in separate lessons and now they are going to connect them together in one organized concept.

6. Tell the students to organize the concepts into a hierarchical list—similar to the one they just created. Present and discuss their lists as a class (e.g. Did they all get the same answers? How do they differ and on what did they agree? Why did they organize them in the order they did? What was their reasoning? What pattern did they see?). This part is important because it is where they think critically about how they connect these concepts. It will also allow you to see what they understand.

7. Use their diagrams and the class discussion to lead into talking about how hierarchy and hierarchy theory applies to biotic systems and present the biotic organization used in this lesson. Since the concepts have been addressed in previous lessons, the focus of this discussion should be on how they relate to each other. As an additional visual, show the students the following website: "Powers of 10" program <<http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/>''. It has a video that begins with our universe and scales down to subatomic particles.
Part Three

8. Pass out one deck of Biotic Hierarchy cards to each group of students. Inform them that each deck contains four groups of 13 cards for a total of 52—just like a regular deck of cards. Each group is designated by a different color, analogous to the suits: blue, purple, yellow, and green. Have the students organize the four groups in hierarchical order.

9. Explain that the cards will be used to practice applying their knowledge of the biotic hierarchy by playing biology card games. Go Fish or Crazy Eights (use the organism card as the wild card) should be played first to familiarize the students with the cards. Rummy is a game that emphasizes sequential (hierarchical) order and can be played next. Other games that emphasize sequential order may also be played (e.g. War, Speed, and Hearts). To add incentive for paying attention and playing well, a tournament can be played. For instance, if there are eight initial groups, there will be eight winners in the first round of Rummy. Those eight students can split into two groups of four and play again. The two winners from round two then play a final game (e.g. Speed or Rummy) for round three to determine the champion. The initial review period with the cards should last approximately 2 days to give the students time to get used to the cards and games. A tournament may take a day or two more.

10. After the students have become accustomed to the cards, discuss hierarchy again and use the cards as specific examples. One way to facilitate this is to give the Hierarchy Interactions student handout as an assignment.

11. For an activity the entire class can play together and that emphasizes conceptual understanding, use the Question cards with the Biotic Hierarchy cards in a modified version of Jeopardy®. For example, split the class into groups of 3-4 students. Choose the first person from each group to compete (the person to answer will rotate in the group to ensure participation by all students). Draw one card from each deck and read them aloud. To earn one point, the first student to stand up must answer the question correctly with regard to the card pulled from the Hierarchy deck. If the student does not answer correctly, then the second fastest group gets the opportunity to answer the question, and so on. Though the students are not experts in the examples used in the cards, their answers should reflect critical thinking about possible interactions. The winning group is the one with the most points. The Hierarchy Interactions student handout will help them play this game.

Evaluation:
An exam can be used to evaluate Objectives 1 - 5. Participation in class discussion and activities can be used to evaluate Objectives 1 - 5. The cards (via games recorded on paper and/or the tournaments) can be used to evaluate Objectives 3 and 5. The handout can be used to evaluate Objectives 2 and 5.

Extensions:
Use any of the subjects to introduce a new topic in the unit. For example, human anatomy and physiology; plant production; (human and non-human) health; effects of climate change; effectiveness of management plans for conservation, restoration, recreation areas, agriculture, and more; social interactions; behavior; city development; etc.