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Using Plants to Explore the Nature & Structural Complexity of Life

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Using Plants to Explore the Nature & Structural Complexity of Life

NABT BioClub RECOMMENDATION

AVA R. HOWARD

Abstract

Use of real specimens brings the study of biology to life. This activity brings easily acquired plant specimens into the classroom to tackle common alternative conceptions regarding life, size, complexity, the nature of science, and plants as multicellular organisms. The activity occurs after a discussion of the characteristics of life and engages students in application of course content and utilization of scientific thinking. It is appropriate for any class in which the nature of life and its structural complexities are addressed and in which teachers want to help students gain familiarity with plants as multicellular organisms.

Key Words: *Plants; characteristics of life; structural complexity; alternative conceptions; application.*

A scientific concept of life – including its nature and its structural complexity – is a topic often covered in K–12 classrooms and in the first week of introductory college biology courses. This is an opportunity to engage students right away in the nature of science (Lederman, 1999), including challenging misconceptions, broadening student experiences, and providing opportunity for knowledge application and critical thinking. Previous approaches to improve our teaching of this topic have used interactive exercises to develop a list of criteria for life (MacKenzie, 2006; Prud'homme-Généreux, 2013). This activity differs by focusing on the application of such a list, using live specimens, tackling misconceptions about plants, and integrating content on the hierarchical, structural complexity of life.

> *"Life" is a concept that most students enter a classroom thinking they already understand.*

"Life" is a concept that most students enter a classroom thinking they already understand. But, with little appreciation for the diversity of life on Earth, most students assume that "to live" means to be like themselves (i.e., a large homeothermic animal; Driver et al., 1994). With a highly anthropogenic perspective, and lacking experience in differentiating scientific from nonscientific ways of knowing (Impey et al., 2011), students find it challenging to utilize a list of characteristics (Table 1) to guide scientific decision-making. Although a familiar mammalian example may be an easily accessible teaching tool, it does not challenge students' misconception that "life" means to be like us. Nor does an easily intuited example encourage students to actively use the criteria for decision-making. Strengthening core competencies (AAAS, 2011) in our students requires that we follow the teaching of a concept with a challenge, such as this activity, that asks them to use the new concepts to *do* science.

The hierarchical organization of living systems is often taught together with the criteria for life, and many textbooks include a figure illustrating this principle. In the majority of cases, they use a familiar, animal-based example (Krogh, 2007; Presson & Jenner, 2008; Audesirk et al., 2011; but see Mader, 2007; Campbell et al., 2008). Students struggle with understanding this hierarchy, and many approach it as a memorization task rather than as a logical sequence. This may be because students possess only a rudimentary conception of scale and have difficulty sorting items by relative size (Tretter et al., 2006). Understanding biological organization requires layering an understanding of complexity (e.g., a community is more complex in its diversity than a population) over a conception of size.

It is clear that students learn best when actively engaged, when alternative conceptions are addressed rather than ignored, and when multiple senses (tactile, visual, etc.) are engaged as part of constructing new knowledge (Brooks & Brooks, 1999; Uno, 1999). This activity helps students construct a more nuanced conception of scientific knowledge and process by applying and combining concepts of size, complexity, and life criteria. This is done with easily acquired yet less familiar plant samples, including seeds, leaves, and planted seedlings. This activity also helps instructors set the classroom tone by using active-learning and nature-of-science strategies and by exciting students with living samples.

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Table 1. Criteria for being a "living organism" according to several introductory biology textbooks.

Criteria	References
Assimilates and uses energy	Audesirk et al., 2011; Campbell et al., 2008; Freeman, 2011; Hillis et al., 2012; Krogh, 2007; Mader, 2007; Presson & Jenner, 2008
Responds to, or interacts with, its external environment	Audesirk et al., 2011; Campbell et al., 2008; Krogh, 2007; Mader, 2007; Presson & Jenner, 2008
Controls its internal environment and keeps it fairly stable (homeostasis)	Audesirk et al., 2011; Campbell et al., 2008; Hillis et al., 2012; Krogh, 2007; Mader, 2007; Presson & Jenner, 2008
Contains heritable coded information for functioning (genetic information)	Audesirk et al., 2011; Campbell et al., 2008; Freeman, 2011; Hillis et al., 2012; Krogh, 2007; Mader, 2007; Presson & Jenner, 2008
Can reproduce (independently)	Audesirk et al., 2011; Freeman, 2011; Hillis et al., 2012; Krogh, 2007; Mader, 2007
Composed of one or more membrane-bound cells	Audesirk et al., 2011; Campbell et al., 2008; Freeman, 2011; Hillis et al., 2012; Krogh, 2007; Mader, 2007; Presson & Jenner, 2008
Evolves; evolved from other living things	Audesirk et al., 2011; Campbell et al., 2008; Freeman, 2011; Hillis et al., 2012; Krogh, 2007; Mader, 2007
Is highly organized and complex	Audesirk et al., 2011; Krogh, 2007; Mader, 2007; Presson & Jenner, 2008
Grows	Audesirk et al., 2011; Presson & Jenner, 2008
Consists of a common set of biological molecules	Hillis et al., 2012
Converts matter; alters molecules	Audesirk et al., 2011; Hillis et al., 2012

○ Questions This Activity Helps Students Answer

- Is this a living organism?
- What level of structural complexity does this represent?
- How big is a cell? Organ? Multicellular organism? Community?
- What is the plant "body"?
- Is an organism alive when it is dormant?
- Is this scientific evidence?

○ Background & Theory

I use angiosperms (flowering plants) because they are the group of plants that students encounter most often. Angiosperms fulfill all the criteria of life listed in Table 1, and their bodies demonstrate hierarchical organization. The multicellular body of an angiosperm can be divided into three basic systems: the root system, the shoot system, and the vascular system. The vascular system connects the root and shoot systems and allows transport of resources throughout the plant body. Systems are composed of organs. In plants, the basic three organs are roots, stems, and leaves. Flowers are specialized and highly modified whorls of leaves. Plants also contain different cell types, and cells that function together form a tissue. For example, sugar transport occurs in the phloem tissue (part of the vascular system), which is composed of a variety of specialized parenchyma-type cells. "Organ systems" are not widely applied to plants, and for the purpose of this exercise I do not distinguish between "organ systems" and "organs."

One fascinating aspect of plant biology is the seed stage. During this stage, the embryonic plant and its surrounding tissues dehydrate to approximately 5–10% water content, and metabolic processes slow (Scott, 2008). In this dormant state, seeds can stay alive for long periods under harsh conditions, which makes it an ideal phase for dispersal. Usually, certain environmental clues are needed to trigger germination and the end of the seed stage (response to stimuli). Inclusion of a seed in this activity challenges students to discern between dead and dormant. I have found that during an abstract discussion of the characteristics of life, students will readily agree that life comes from life via reproduction. However, when given a dormant seed, they will tell me that the seed is not a living organism but that it has the possibility to grow into a plant that is a living organism (Fisher et al., 2002; Allen, 2010). The seed challenges students to use course content to modify alternative conceptions.

○ Methods

Materials

The following supplies are needed:

- Seeds large enough to handle (I use pea seeds)
- Single freshly cut leaves from a branch or branches
- Containers of seedlings of different species growing intermixed in soil
- Dishes labeled A, B, and C
- Worksheets (Figure 2)
- Pens or pencils

The seedlings will need to be started one to two weeks prior to class. The specific mix of species sprouted does not matter but should be chosen for fast germination and to produce visually distinct seedlings. I have used mixes of sunflowers, dill, corn, and barley. Prior to class, one seedling container, one seed, and one leaf should be placed on dishes labeled A, B, and C, respectively (Figure 1). I prepare a tray of these materials for each group of three or four students. Alternatively, one set can be prepared and used as a demonstration.

Or, if time is limited, the teacher may choose to assign one specimen to each student group.

Other materials may be included as alternatives or in addition to those used here. Materials included in the sample tray should include a variety of organizational levels both above and below the level of a single whole organism. Anything below the level of an individual (e.g., a maple leaf, which is an organ) will not meet all the requirements of a living organism, and this provides diversity for the answers to the first question on the worksheet.

Classroom Preparation

Before beginning this exercise, instructors should introduce the concepts of structural complexity and criteria for being a living organism (Table 1). Typically I do this with a classroom discussion. I ask students "What is biology?" and then probe deeper into their answers with the question "What does it mean to have life?" I often use a smartphone (does it have life?) to stimulate ideas. Other objects or activities can be used to generate a similar discussion (MacKenzie, 2006; Prud'homme-Généreux, 2013). As a class we share ideas, and I write a list on the board. We then evaluate and modify the list to ensure that each item meets the criteria for scientific evidence. Once this is done, I discuss the structural complexity of living organisms and hierarchical organization. We begin with atoms and work up to the biosphere. I introduce the theory that all life is made up of one or more cells.

Figure 1. Plant specimens given to students for examination: (A) pea seed, (B) seedling mix, and (C) single freshly cut leaf.

Execution

Next, I ask students to consider the specimens in their tray and determine whether each of their specimens can be considered "a living organism" according to the criteria on the board, and secondly at what organizational level the specimen should be placed. Students are encouraged to discuss their ideas with their neighbor, and then record their own decision on their worksheet (Figure 2) along with a brief explanation of their scientific evidence or reasoning. This usually takes students 10 to 15 minutes.

Debriefing

After students have sufficiently completed the worksheet, I debrief the class by discussing the answers. I take each specimen in turn and prompt students to share their observations of their specimens. I show how these observations, combined with our life criteria and organizational hierarchy, can be used to evaluate and articulate the nature of each specimen. I also point out common alternative conceptions that students may have (Table 2) and explain how our observational evidence fails to support those ideas. For example, in a recent college-level introductory biology class for non–science majors, one quarter of the students classified the pea seed as being a single cell, and over half of them classified it as being "not a living organism." In this same class, over a third of students classified a cut leaf as a "living organism." A freshly cut leaf is composed of cells, contains DNA, and is capable of assimilating energy; therefore, it can be considered at the moment to be "alive." However, a single leaf usually cannot reproduce, cannot maintain homeostasis, cannot independently maintain

Name: ______________________________ Class time: ______________

Please answer the following questions when instructed to do so.

1. Do you think it contains one or more living organisms? Why?
2. At what level of organization should each item be placed? Why?

Object	1. Are there one or more living organism(s)? (Yes or No)	1. Reasoning	2. Organizational Level	2. Reasoning
A				
B				
C				

Figure 2. Worksheet provided to students.

Table 2. Angiosperm specimens, their classification, and common alternative student conceptions recorded by non–science majors in an introductory biology class.

Specimen	Living Organism(s)?	Organizational Level	Common Alternative Conceptions
Leaf	No – does not meet all criteria	Organ	Commonly said to be a "living organism." Often classified as a single tissue, a multicellular organism, or at a higher structural level.
Seed	Yes – meets all criteria	Multicellular organism	Commonly classified at a lower structural level, most commonly as a single cell. Also often said to not be a "living organism" and not capable of responding to stimuli. Often elicits concepts of spontaneous generation – "the seed is not a living organism but can grow into a living organism."
Seedling mix	Yes – meets all criteria	Community (or ecosystem, if the abiotic soil-and-water component is considered)	Commonly said to be a population or a single multicellular organism.

life, and does not meet all of our definitions of a "living organism." The pea seed, however, does meet all the criteria and is, in fact, an entire multicellular organism. This can be reinforced with a soaked seed (any seed can be used, but bean seeds work well) that, when split open, shows the embryonic plant between the nutritive cotyledons.

○ Assessment

I assess students in two ways. Prior to the class debriefing, I collect their worksheets, from which I can assess their effort and intellectual engagement by focusing on the "reasoning" columns. I also assess their content mastery by displaying images of similar and new specimens and asking students to identify both the level of structural complexity and whether the image contains at least one living organism. For the latter assessment, students indicate their answer using a classroom response system (clickers; Figure 3). Later, exam questions that use familiar or novel specimens can be used to evaluate content understanding or application skills. For homework, students can be asked to find objects at differing levels of structural complexity and briefly report on what scientific observations can be made to support conclusions about structural complexity and life status.

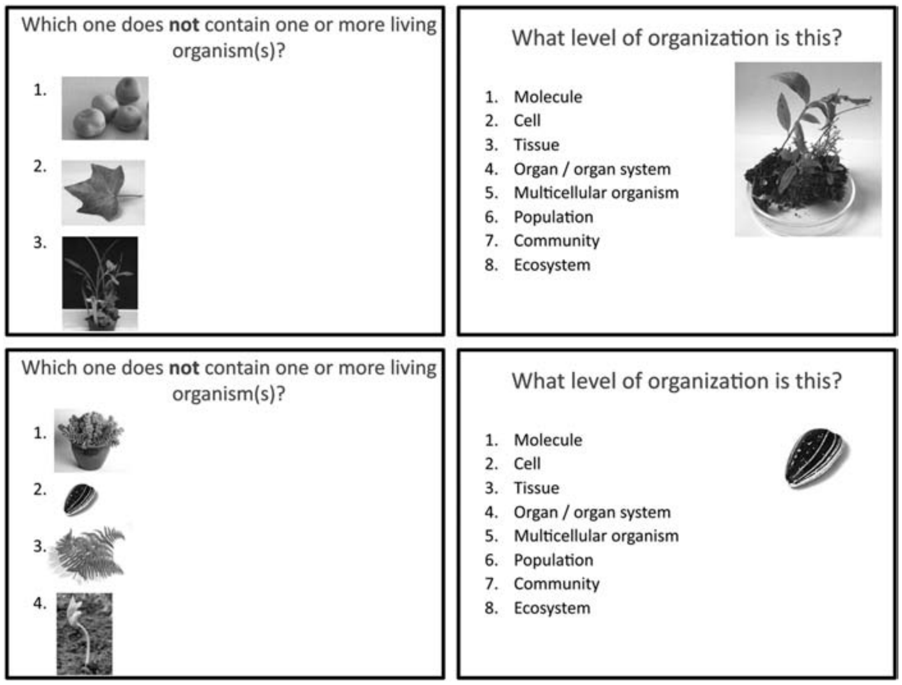

Figure 3. Sample of classroom response system (clicker) questions.

○ Conclusion

Students in my introductory, non–science majors biology class respond well to this activity. They appear to enjoy the challenge and have commented positively about inclusion of tangible real-life examples. The activity reinforces content on "what is life" and "hierarchical structural complexity" and builds skills with nature-of-science, evidence-based assessment. This activity also helps students become familiar with plants and challenges common alternative conceptions.

○ Acknowledgments

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