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Lesson

Using the Cell Engineer/Detective Approach to Explore Cell Structure and Function

Christine Sestero[1]*, Heather Tinsley[1], Zheng-Hua Ye[2], Xiaoyu Zhang[2], Rita Graze[3] and Matthew Kearley[3]

[1] Department of Biology, Chemistry and Mathematics, University of Montevallo, Montevallo, AL

[2] Department of Plant Biology, University of Georgia, Athens, GA

[3] Department of Biological Sciences, Auburn University, Auburn, AL

Abstract

As instructors of introductory biology courses for majors and non-majors, we have struggled with teaching the concept of cell structure and function in an engaging way. However, this is a foundational concept that most biology instructors would agree is vital for all students to know. The overall objective of this teachable unit is to help non-major introductory biology students learn the names and functions of the basic components of eukaryotic cells and, at the same time, understand the connection between cellular structure and function using active learning approaches. The key component of this teachable unit is a group exercise termed Cell Engineer/Detective. In this exercise, students work in groups to design a cell that is well suited for a function that is provided to them by the instructor (Cell Engineer). The groups then exchange their cells with classmates and try to guess the function of their classmates' cells (Cell Detective). This exercise helps students visualize how the organelles of a cell work together to perform a specific function, allows instructors to clarify misconceptions regarding cell structure, guides students away from that quintessential but unrealistic model cell found in most biology textbooks, and reinforces the central biological connection between form and function.

Learning Goal(s)

Students will understand how organelles and cell structure relate to the overall function of the cell.

Learning Objective(s)

Students will be able to:

- Identify the major cell organelles
- List the major functions of the organelles
- Predict how changes in organelle/cell structure could alter cellular function
- Explain how overall cellular function is dependent upon organelles/cell structure
- Relate cell structure to everyday contexts

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Materials and Supplemental Materials: Table 1. Cell Engineer-Teaching Timeline, Figure 1. Cell Engineer-Student exam performance, Supplemental File S1. Cell Engineer-Sample model cells created by students, Supplemental File S2. Cell Engineer-Cell structure and function pre-class preparation reading outline, Supplemental File S3. Cell Engineer-Six example cell engineering cell type assignments , Supplemental File S4. Cell Engineer-Activity instructions for students, Supplemental File S5. Cell Engineer-PowerPoint presentation, Supplemental File S6. Cell Engineer- Examples of cell structure and function exam questions that provided the performance data shown in Figure 1

***Correspondence to:** University of Montevallo, Department of Biology, Chemistry and Mathematics, Station 6480, Montevallo, AL, 35115
E-mail: csestero@montevallo.edu

INTRODUCTION

Lessons about cell structure and function are perhaps one of the most ubiquitous topics in undergraduate biology courses. Particularly in general biology and non-majors courses, great importance is placed on comparing the structures and functions of different types of cells. Focus is often placed on cells that are very different from each other (prokaryotic vs. eukaryotic, animal vs. plant, etc.). Often neglected are the unique natures of different types of cells within the same multicellular organism. Consequently, students often finish these lessons without a strong understanding of this phenomenon.

One potential complication that can be encountered in cell structure and function lessons is that many students

have been introduced to the material at various levels before entering the undergraduate classroom. As a result, students may assume they "know" the material because at some point they memorized a list of organelles and their functions, or filled in a blank cell with pictures of the organelles. Yet when they are asked to describe how the presence or number of a specific organelle varies among cells with different functions, they are stumped: the connection between function and structure/organelle content is often a novel concept. It is not uncommon for students in our courses to easily identify the function of each organelle, yet believe that only one copy of each type is found per cell and that, with very few exceptions, all cells are uniform in their organelle content. This static view of a cell detracts from the relationship between a cell's composition and its function, an extremely important concept for introductory biology students to firmly grasp.

Our desire in designing this lesson was to get away from the "memorize this list of definitions" method of teaching cell structure and focus on the dynamic nature of cells as a way to illustrate the connection between structure and function. We designed our lesson for introductory and non-major biology students in an active learning format that utilizes group activities and collaboration to see the connection between structure and function. The key component of this teachable unit is a group exercise termed Cell Engineer/Detective.

SCIENTIFIC TEACHING THEMES

Active learning

- Activities outside of class: Read about typical cell and organelle characteristics using the textbook and a handout from the instructor.
- Activities in class: Large group discussion of organelle function (list on blackboard); small group cell diagram construction and Cell Engineer/Detective activity.

Assessment

- Pre-assessment: Small group cell diagramming activity, with the option to revise and finalize following group discussion. Alternatively, the instructor may collect pre- and post-group discussion diagrams and assign a grade based on revision quality.
- Summative assessment: Cell Engineering diagram, with the option to revise and finalize following group discussion. Alternatively, the instructor may collect pre- and post-group discussion diagrams and assign a grade based on revision quality. Examples of such diagrams may be found in Supplementary File S1.

Inclusive teaching

- Discussing cellular diversity and the "different, but equally complex" approach to describing differences among cells opens discussion to the important contributions of diversity to biology.
- Discussions on organelle origins can open up discussions related to evolutionary relationships and potential relationship to religious themes.
- The topic of cells (content, organization, division, etc.) is a comparatively easy one for students to relate their own lives and find interesting. For instance, discussions on cell function can provide examples such as hormone production, immune protection, and reproduction that relate to populations diverse in ages, gender, etc.

LESSON PLAN

This lesson is designed for one 50-minute class period, with additional pre-lesson preparation conducted by students outside of class and assessed prior to the lesson (see Table 1 for lesson timeline description on page 3).

The time assigned for conducting each activity component has been optimized for teaching the lesson to an introductory biology course with approximately 50 students, but may be adjusted accordingly to accommodate larger or smaller class sizes. A major component of this lesson is the Cell Engineer/Detective activity, in which groups of students use their knowledge of cell structure and components to "engineer" and draw an imaginary cell suited for a specific, assigned function. These drawings are exchanged with other student groups that use their own knowledge of cell structure and function in a "detective" mode to identify the theoretical function of the cell based on the types and numbers of organelles that it contains.

Teacher Preparation

It may be useful to review the take home reading guide and hand out that is provided to students as part of their pre-lesson preparation (Supplemental File S2) Text Document S1). Teachers should also review the six example cell engineering cell type assignments that are included with this lesson (Supplemental File S3) Text Document S2). These cell types include eukaryotic examples of plant and animal cells, but may be modified as needed to include prokaryotic cells, etc. The instructor may also supply blank pieces of paper and assorted colors of writing instruments for the Cell Engineer activity.

Student Preparation

A few days prior to the activity, students will be given a take home reading guide and handout that will guide their preparation for the activity (Supplemental File S2 Text Document S1). Students will use these materials to guide their review of the basic functions essential for all cells and the organelles found in typical animal and plant cells. Students should be informed that information they gather with this reading guide will be integrated into the start of a pre-assessment activity that will be collected for a grade to ensure they are prepared.

The reading guide includes a list of organelles that students should research to learn about function and structure. This guide is helpful for directing student reading of textbook information on cell structure and is general enough to be used for any text that includes this information. Students who have learned about these organelles before should be encouraged to learn something "new" about each structure and the impact its functions has on the cell.

The reading guide also includes questions designed to help students with the process of connecting organelle content with eukaryotic cellular function and identity. In addition, students are asked to consider the types of internal and external factors that influence the functions of a cell. This prompt serves as an introduction to the dynamic nature of cells.

Resources for Teaching the Unit

- Take home reading guide and handout. (Supplemental File S2) Text Document S1)
- Six example cell engineering cell type assignments. (Supplemental file S3) Text Document S2)
- Activity instructions for students (Supplemental File S4) Text

Table 1: Cell Engineer/Detective-Teaching Timeline

Time (min)	Learning Outcome(s)	Activity/Assessment	Explanation, notes, suggestions, tips
Pre-class	1. Identify the major cell organelles 2. List the major functions of the organelles 3. Know the major differences between plant and animal cells	Using the textbook and a handout from the instructor, students will read about the typical cell in animals and plants as well as the organelles and their basic roles within the cell.	A sample handout is provided as part of the unit.
Learning Activity #1: Preparatory material presentation (5 min)	1. Identify the major cell organelles 2. List the major functions of the organelles	Ask the class as a whole to list some activities that cells must perform (i.e. move, obtain energy, expel wastes); list these on the board. Then ask students to name the organelle(s) primarily responsible for that activity. If any functions/organelles are left out, bring them up.	
Learning Activity #1 (10 min)	1. Identify the major cell organelles 2. List the major functions of the organelles	Working in groups, students will be assessed on their pre-class reading by constructing a model plant and/or animal cell. The class as a whole will discuss this.	The cell diagrams from this activity are turned in and graded.
Learning Activity #2 (15 min)	1. Cell Engineer: Students build an imaginary cell suited for a specific function 2. Cell Detective: Students exchange cell drawings and attempt to guess function 3. Discussion/share out Cell Detective guesses	Each student group will receive a functional description of a cell. They will draw a diagram depicting how they think the cell will look in order to optimize that function. After constructing their cell, each group will exchange their cell with another group and try to guess the function of the other group's cell based on the structure.	
Follow up mini-lecture (15 min)	Address any misconceptions that might arise during Activity 2 Relate imaginary cell structures to real cell types in tissues of plants and animals	This will include clicker questions to get the students thinking about this relationship between cell structure and organelles to function using real-life examples	
Post-activity summing up or transition (5 min)		Have students ponder the question "Do differences in organelles alone account for the different functions of cells?" to prepare for next unit.	

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Document S3)
- Mini lecture PowerPoint including image URLs (Supplemental File S5) Presentation S1)
- The in-class lesson consists of two learning activities: a review of the student's research on organelles and application of their knowledge in a cell engineering/ identification exercise.

Learning Activity #1: Preparatory Material Presentation (5 min)

Begin the class by spending a short amount of time reviewing organelles. Ask the class to list some activities that cells must perform (i.e. move, obtain energy, expel wastes) and write these on the board. Then, ask students to name the organelle(s) primarily responsible for each activity that is listed. If any functions/organelles are left out, bring them up. Resist the urge to use this time to list, label, or identify all organelles and their functions; students should begin the class with a general knowledge of this that will be strengthened by the learning activities.

Learning Activity #1 (10 min)

Divide students into groups of four. We have successfully used "counting off" to form groups randomly, though the instructor may use any alternative method desired. Ask each group to use a blank piece of paper to diagram a typical cell, label the organelles, and summarize their functions. Following this, discuss the diagrams as a class. It may be useful to use the "model" plant and animal cell images in the reading assessment as the basis for this discussion, as most students will likely use these as the guidelines for their diagrams. Ask groups to share details of their diagram and definitions with the class. As a class, discuss any disparities or inconsistencies among the diagrams. Do these differences represent "wrong" answers? If so, why? If not, why not?

Collect the cell diagrams from each student and assign a grade as part of the pre-assessment for this lesson. Students that were well prepared should perform well on the activity.

Learning Activity #2: Cell Engineer and Cell Detective (15 min)

Following the first learning activity, students should feel confident enough in their knowledge of cell structure and the abilities of their group members to begin the next learning activity. Students can remain in the original groups formed during the first learning activity for the second learning activity. The first part of this learning activity asks each student group to "engineer" a cell based on a description that is provided to them. From the description of the cell's function(s), students should be able to build an imaginary cell that is well suited for performing a particular job (ex: involved in transporting key small molecules via veins in an animal). The cell they design can be represented in a simple drawing on butcher paper with colored markers. Students will spend ten minutes engineering their cells and, during the process, consider the types of organelles their cell will need to rely on for its function. How will the function influence the relative number of an organelle in their cell? Are there any organelles the cell will not require for that function? What other characteristics of the cell (surface area, etc.) may influence the cell's function? Encourage students to consider all of these issues in the engineering process. A summary of student instructions for the activity is provided in Supplemental File S4.

Each group should be given a unique cell description that they should not share with other groups or the class at this point. (See Supplemental File S3) Text Document S2 for some suggested cell descriptions.) Their final cell diagram should be carefully labeled to identify its structural components, but the cell's function should not be identified. The second part of the activity requires each group to work as "Cell Detectives" to propose the function(s) of the cell drawn by another group, based on the labeled image that the group prepared. Pairs of groups will swap their drawings and each group will spend about five minutes guessing the primary function of the other group's cell. Each group should work separately and there should be no discussion or collaboration between the groups during this part of the activity. Both groups are asked to discuss the guesses as well as their designs. Following these individual group discussions, the instructor may organize a class discussion to analyze each group's detective work. The Cell Detective group can announce their guess and tell the class what evidence from the labeled image supports their guess. At this point, the Cell Engineer group that constructed the image can provide feedback and clarification if it is needed. If a group struggles to identify a cell's function, or suggests something other than the intended function, encourage discussion that identifies any missing pieces or suggestions that would help. Groups should feel free to modify and revise their drawings based on group discussion.

Revised and finalized versions of the engineered cells will be submitted as part of the summative assessment for this activity.

Follow Up Lecture (15 min)

Once students have had the opportunity to design and identify cells outside of the realm of "general" animal and plant cell diagrams, they will be better prepared to discuss and appreciate the dynamic nature of cells and their changing characteristics. This preparation will set the instructor up to present a "mini lecture" very different from the typical descriptions of a cell and its functions. The included PowerPoint presentation is an example of a mini lecture that provides real life examples of how cell structure aids function to clarify misconceptions revealed during the learning activities (Supplemental File S5). Imaginary cell structures that students used as Cell Engineers to define their model cell's function can be related to real cell types in plant and animal tissues and complement the information in the take-home reading guide and handout. The mini lecture should be envisioned as an active discussion, with students using the knowledge they gained from these activities to lend to their assessment of a cell's function, based on its components. The accompanying PowerPoint includes Clicker questions to facilitate this type of format, but questions may also be discussed as a class in lieu of Clicker use. Use these discussions as a launching pad for clearing up any misunderstandings of organelle functions that students may have encountered with the learning activity.

Post-Activity Summary and Transition (5 min)

Following the mini lecture, students should be left with some thought-provoking questions to further their understanding of internal and external factors that influence cellular functions. This understanding will feed into future lectures that build on the typical cell model. Encourage students to think about some functions of cells that are not so easily described based on their structure or organelle content. What other properties might contribute to cell differences, besides things that are defined

in a single cell? The answer to this question opens the door to explaining cells in the context of multicellular organisms and the specialization of tissues and organs.

TEACHING DISCUSSION

The lesson described here was utilized by one of the authors in her Introductory Biology classes in a manner that enabled her to compare test performance of students in course sections that did or did not incorporate the activity. Performance on a 32-point section of a 100-point lecture exam that covered the Cell Structure and Function unit was compared between two groups comprised of course sections that did not (Fall 2012) or did (Fall 2013) perform the Cell Engineer/Detective activity. The exam section included multiple choice, matching, and short answer questions (see Supplemental File S6 Text Document S4 for question examples). This exam was administered 12 days following the in-class activity and its summative assessment in the sections that performed this activity. As demonstrated in Figure 1, a significant increase in test performance was observed in course sections that utilized the activity. The instructor hypothesizes that this increase is caused by the activity, as material content and testing strategies between the compared course sections did not differ. This increase in performance reflects the general trend observed in biology classrooms when activities that engage students are implemented in place of lecture to teach fundamental concepts (1, 2).

In addition to improved test performance, the instructors that utilized this lesson report a good reception from their students regarding the activity. Most students appreciated the opportunity to pursue an alternate strategy for covering in-class material. Even students who were learning the material for the first time or had not covered it for several years reported liking the Cell Engineer/Detective approach to understanding cell structure and function.

In summary, this exercise helps students visualize how the organelles of a cell work together to perform a specific function, allows instructors to clarify misconceptions regarding cell structure, guides students away from that quintessential but unrealistic model cell found in most biology textbooks, and reinforces the central biological connection between form and function.

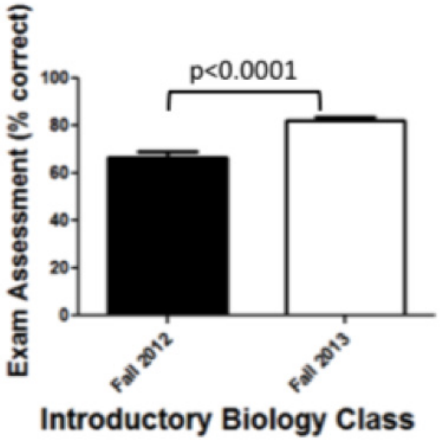

Figure 1. Summary of Introductory Biology lecture exam student performance for sections of the course for which the Cell Structure and Function unit was taught without (Fall 2012) and with (Fall 2013) the Cell Engineer/Detective activity. Data represents overall student performance on a section of a 100-point lecture exam. Material from the Cell Structure and Function unit covered 32 points the exam in the form of multiple choice, matching, and short answer questions (examples of questions asked on the exam may be found in Text Document S4). A significant increase in exam performance was observed when the activity was utilized ($p>0.0001$).

SUPPLEMENTAL MATERIALS

- Table 1. Cell Engineer-Teaching Timeline
- Figure 1. Cell Engineer-Student exam performance
- Supplemental File S1. Cell Engineer-Sample model cells created by students
- Supplemental File S2. Cell Engineer-Cell structure and function pre-class preparation reading outline
- Supplemental File S3. Cell Engineer-Six example cell engineering cell type assignments
- Supplemental File S4. Cell Engineer-Activity instructions for students
- Supplemental File S5. Cell Engineer-PowerPoint presentation
- Supplemental File S6. Cell Engineer- Examples of cell structure and function exam questions that provided the performance data shown in Figure 1

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