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Lesson

Bad Cell Reception? Using a cell part activity to help students appreciate cell biology, with an improved data plan and no loss in coverage

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Abstract

With a veritable myriad of cell parts to cover, it is easy for educators to become locked into marathon presentations that become taxing for both the instructor and the students. While we hope and expect that students master this material, the disconnect between this material and its practical value often encourages students to tune out. How can we cover this topic with the depth and breadth it deserves while simultaneously engaging the students? How can students learn the subtleties of the cell when each part is a world unto itself? Here I explain how educators can accomplish these goals using the "Cells: A World A Part" activity. In this activity, the class is divided into several teams that are each assigned a particular cell part. Guiding questions help students assess their current knowledge about their cell part so they can build on that knowledge using a constructivist approach. Students explore recent scientific literature, ask thought provoking questions, and propose experiments to address some of the enduring mysteries about their assigned cell part. As they work, students develop teamwork and time management skills; they also come to appreciate cell biology as they learn its real-world implications and discover how these cell parts relate to human disease. The climax of this activity is an exciting presentation session that enables students to showcase their scientific communication skills as they share their newfound knowledge with their classmates.

Learning Goal(s)

- Students will appreciate how cell parts relate to their lives and future careers in research or medicine
- Students will think metacognatively to identify what they know about a particular topic
- Students will improve their teamwork and time-management skills as they answer the provided questions and create a poster session presentation

Learning Objective(s)

Students will be able to:

- Identify cell parts and explain their function
- Explain how defects in a cell part can result in human disease
- Generate thought-provoking questions that expand upon existing knowledge
- Create a hypothesis and plan an experiment to answer a cell part question
- Find and reference relevant cell biology journal articles

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Materials and Supplemental Materials: Table 1. Alignment between learning objectives and assessments, Table 2. Recommended timeline for class activities, Supplementary File S1. Lesson PowerPoint slides, Supplementary File S2. Assignment worksheet, Supplementary File S3. How to find information and Supplementary File S4. Useful web resources

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INTRODUCTION

Teaching cell biology in an introductory biology class can be challenging for a number of reasons. First, student prior knowledge on this subject varies markedly (1). As a result, this material is completely new to some students while others feel it is simply a review of what they have already learned. The latter group is particularly challenging, as it is hard to teach someone things that they think they already know. A second challenge is the vast vocabulary that cell biology demands students learn. Every organelle, fluid, and macromolecule has its own name, and students often struggle to remember them all. The amount of unfamiliar (and sometimes nearly unpronounceable) terms can make learning biology feel like

learning a foreign language (2). A third challenge is the wealth of knowledge in cell biology: so much is known about cell biology that student learning is often reduced to simple fact memorization (1, 3). When instructors focus on covering the content, there is little time left for deep learning, critical thinking, problem solving, and skill development (4). Finally, as students struggle to memorize their way to success, the meaning of what they are learning gets lost. If you ask students why this material matters, many will simply shrug their shoulders, provide a vague answer, or quip "because it's on the test?" Perceived lack of meaning may bore students who would otherwise see biology as an exciting field of study (4–6).

Though it pains me to admit it, these challenges may have been exacerbated by the way that I used to teach this part of the course. Historically, I presented basic cell biology to students during an hour-long lecture session. This lecture carefully reviewed and summarized the textbook's description of each cell part in an exhaustive amount of detail. While it was indisputably informative, it was also rather long and it provided little opportunity for student engagement.

The challenges described above led me to ask myself what I really wanted students to get from this material. What did I really want them to remember five years from now? I jotted down a few ideas and discovered that fact memorization was not even on my list. Instead of "covering the content," I wanted to spend class-time on skill development. I wanted to give students the tools they will need to be successful in their academic career and beyond. I also noticed that the items on my list are widely regarded by employers and educators as areas in which students need to improve (7–9). These include critical thinking, creative thinking, hypothesis generation, experimental design, finding/reading/understanding scientific journal articles, communicating science, and teamwork. In addition to these skills, I wanted to take students' prior knowledge into account, as integrating new knowledge with existing ideas is required for students to get beyond simple memorization (1). Students were clearly not getting this from my marathon lecture sessions. Something had to be done.

"The meaning of 'knowing' has shifted from being able to remember and repeat information to being able to find and use it."

~ Herbert Simon, Nobel Laureate

In response to my teaching goals and to the challenges inherent with teaching cell biology, I developed a new activity entitled "Cells: A World A Part". This student-centered, active learning activity involves almost no lecture. Instead, it gives students time to practice skills they will need throughout their academic and professional careers. One of the key learning objectives of this activity is to expose students to cell biology through the scientific literature. While students often struggle with reading the scientific literature (10–13), studies have shown that incorporating it into the curriculum can enhance critical thinking, quantitative literacy, data analysis, experimental design, and their ability to ask questions about their own research (12, 14, 15). Research article activities have also been used to promote active learning and to get students to think like scientists (13, 15–18).

During the "Cells: A World A Part" activity, students quickly identify everything they know about their assigned cell part and then work as a team to ask and answer their own questions. Identifying what is still unknown about their assigned cell part and devising ways to figure it out is very motivating for students. After all, many of us initially got into this field with the thought that we might be the first human ever to ask a particular question or make a particular discovery. Students become excited when a literature search fails to answer one of their questions because they know that they have asked something that even the most brilliant scientists have not figured out yet. Instead of giving up, students treat this situation like a puzzle that needs to be solved and design experiments to answer their own questions. While perusing the relevant literature students also discover the meaning that was missing in the lecture; they learn not only what scientists are studying, but also why it is important. During the activity students discover that scientists are still actively studying all of the cell parts. They come to see that biology is a living and breathing enterprise, not simply stale words on a page. The connection to real-life science continues to the end of the lesson where students communicate their research to the class in poster presentation.

Intended Audience, Learning Time, and Pre-requisite Knowledge

This activity was developed for BIOL2002, Foundations of Biology, at the University of Minnesota, a land grant and research university. Students in the class are all biological science majors and are primarily in their second semester of college. Each section of the course is comprised of roughly 125 students divided up into 14 teams of nine. The class is typically about 55% female and 65% white. About 5% of the students are international students. Their mean high school GPA is roughly 3.9. This class meets twice per week for 115 minutes in a large active learning classroom active learning classroom (ALC, see http://www.classroom.umn.edu/projects/alc.html for more information).

While I facilitate this activity in an ALC, it could easily be adapted to other course settings. It takes about three hours spread over two class periods. It also requires that the students work an additional one to two hours outside of class. Before beginning this activity, students should have read the relevant text book chapter so that they have a rudimentary understanding of the different cell parts. This activity also requires that students have pre-requisite competence in reading and interpreting papers and pre-requisite knowledge of experimental methods and design. Additionally, students should know the general principles of good teamwork. Finally, students should be familiar with one or more online websites (e.g. PubMed, Science Direct, Web of Knowledge, Google Scholar, etc.) in which they can search for primary literature articles related to their topic.

SCIENTIFIC TEACHING THEMES

Active learning

- Students work collaboratively as part of a team inside and outside of class.
- Students work to ask and answer questions about their assigned cell part.
- Students find and read scientific journal articles and summarize them to their group.
- Students design experiments to answer questions to which the answer is currently unknown.
- Students work both inside and outside of class to create a presentation about their research.
- Students participate in a poster session at the end of the

lesson.

Assessment

Formative

- I ask students questions about their cell part while they work.
- Students present their findings in a poster session at the end of the lesson.
- We discuss what they found (and what they did not find) about their cell part during an activity debrief.
- Students write a minute paper about their muddiest point.
- Students receive peer feedback during and after the poster session.
- 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.

Summative

- Pre-assessment: Students take an online quiz about the reading assignment before the lesson begins.
- On the 2nd day of the activity students take a multiple choice quiz on the material
- Worksheets and slides from student presentations are handed in at the end of the lesson and are scored using a rubric (Supplemental File S2).
- The exam includes questions related to this entire lesson, including questions from student presentations.
- The ability to find and reference relevant journal articles is essential for successful completion this project. This will be scored by examining the information and citations listed in each team's presentation slides.

* Please see Table 1 (on page 4) to see how these assessments match up with the designated learning objectives.

Inclusive teaching

- Diverse student teams are purposely created at the beginning of the semester to ensure that team members have a variety of viewpoints and backgrounds.
- This activity meets students where they are at, regardless of background knowledge. It levels the playing field.
- This activity involves using a variety of skills including independent research, group discussion, and presentation. Students get the opportunity to showcase their talents and to practice in areas where they need improvement.
- Students from all walks of life can see how cell biology relates to their lives and human health in general.
- The group nature of this exercise lends itself well to making accommodations for students with disabilities, should the need arise. Students within each group divide the work amongst themselves; they can volunteer to do tasks that play to their strengths.

LESSON PLAN

Before class

Instructors who are implementing this exercise in their classrooms should review the presentation slides (Supplementary File S1), student worksheets (Supplementary Material 2), and learning outcomes before class begins and modify them as necessary for their particular class. Table 2 (on page 5) should also be reviewed at this time, as it summarizes the lesson plan and provides the suggested duration of each step. Instructors may elect to print out the activity worksheet before class, but I usually have students fill it in electronically on a Google Doc to save paper. Students should complete the assigned readings so they know something about cells, organelles, and macromolecules before the lesson begins. Instructors are encouraged to design an online quiz covering the material to be due before class begins. This requirement will motivate students to do the reading and it will free up valuable class time that would otherwise be spent lecturing on this material (5).

During Class

When you begin class, you may jump right into the activity or you may give an optional mini-lecture first. I have done it both ways and each method has its merits. Mini-lectures allow you to review some of the more challenging concepts from the reading. My mini-lectures include discussions about cell size and scale, microscopy, differences between bacteria and eukarya, nuclear transport, protein targeting, endocytosis, exocytosis, and the cytoskeleton. I do not cover specific structures and functions of organelles and other cell parts, as that is the focus of this activity. Alternatively, skipping the mini-lecture adds more time and depth to the in-class activity.

Introducing the Activity (10 minutes)

Because this activity is unlike other cell biology activities the students have done, I usually begin with an extensive introduction that explains to students why this activity is valuable. For active-learning classrooms, this introduction may be unnecessary. Instructors may instead simply share the learning objectives and then move on with the rest of the activity.

"Greetings class! Welcome to another fabulous day of Foundations of Biology. We have got some really fun and exciting stuff to talk about today. In particular we'll be talking all about cell parts, a topic near and dear to my heart. Our primary goal will be to create a complete catalog of cell parts."

"Here are today's learning objectives. Your mission, should you choose to accept it, is to:

- Identify cell parts and explain their function
- Explain how defects in a cell part can result in human disease
- Generate thought-provoking questions that expand upon existing knowledge
- Create a hypothesis and experimental plan to answer a cell part question
- Find and reference relevant cell biology journal articles."

"Now, there are many ways we could go about achieving these learning objectives. One way to learn this material would be for me to give you a lecture from slides. I have slides. I have a lot of slides (show animation on presentation slides where hands unveil several well-made slides as if they were holding playing cards)! I have detailed slides created for each of the cell parts and I'm proud of these slides, especially since I spent a lot of work to make them. I'm not going to use slides today, however, because of one simple fact: The one who does the work, does the learning. (Pause for dramatic effect.) I created these slides; I did the work; so I also gained most of the learning. Our goal however is to have you learn the

Table 1: Bad Cell Reception-Alignment between learning objectives and assessments

Learning Objective	Assessment								
	Formative					Summative			
	Instructor Questions	Poster Session	Activity Debrief	Muddiest Point Paper	Peer Feedback	Pre-quiz	Post quiz	Exam	Worksheet
Identify cell parts and explain their function	x	x	x	x	x	x	x	x	x
Explain how defects in a cell part can result in human disease	x	x	x	x	x		x	x	x
Generate thought-provoking questions that expand upon existing knowledge		x	x	x	x			x	x
Create a hypothesis and plan an experiment to answer a cell part question		x	x	x	x			x	x
Students will be able to find and reference relevant cell biology journal articles		x	x	x	x				x

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Table 2: Bad Cell Reception-Teaching Timeline

Activity	Student	Instructor	Time
Day 0			
Before Class	Take an online cell parts quiz	Review/modify activity	Variable
Day 1			
Introducing the Activity	1. Listen attentively 2. Take notes	1. State learning objectives 2. Provide background	10 min
Teams Identify Their Cell Part	Identify assigned cell part	Display cell part assignments	1 min
Teams Identify What They Know About Their Cell Part	Write what they know about their assigned cell part then share with their team	1. Ensure equal contributions 2. Help struggling groups	5 min
Teams Ask Questions About Their Cell Part	Write as many questions as they can think of about their cell part on their white board	1. Discourage questions that are simplistic or overly redundant 2. Identify winning teams	5 min
Select 1-3 Favorite Questions	Vote for favorite questions and star them on their white boards	Provide students with access to worksheet	5 min
Teams Answer Their Questions Using the Primary Literature	1. Research scientific literature to find answers to their questions 2. Design experiments to address unanswered questions 3. Prepare presentation	1. Remind the students about good places to look for primary literature articles 2. Share links about how to give a good presentation	90 min
Day 2			
Finish Preparing Presentation	1. Put on finishing touches 2. Presenters practice 3. Recorders divvy up presentations to attend	Ensure that groups have their laptops connected and are ready to display their slides when the presentation starts	15 min
Teams Present Their Findings in a Mock "Poster" Presentation	1. Presenters present slides 2. Recorders take notes on other presentations	1. Time/view presentations 2. Let students know when to move on	30 min
Share and Compare	Compile their team's notes	Let teams know about any errors that were found	10 min
Debrief	1. Ask questions 2. Complete a minute paper	Identify and correct any notable omissions or mistakes	10 min
Quiz	Students take a quiz individually and then retake it as a team	Answer questions	20 min
Day 3			
Assignment Due	Turn in assignment	Grade assignment	Variable

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material and to do so, we'll have to put you to work. Don't worry though; this is going to be fun."

"Right now, you may still be wondering why we are doing things this way. In the spirit of the top ten lists that are commonly presented on late-night talk shows, I present to you our top ten reasons for doing this:"

"10. It'll be on the test!"

"9. You'll get to practice asking questions. This is a very important (and often neglected) skill in science that you'll be using frequently in your career."

"8. You'll get to explore answers to your own questions. Rather than wasting time on what you know, we'll give you the chance to explore the areas you are most curious about."

"7. You'll also get practice finding papers. It is likely that many of you already feel as if you know how to do this but there are a ton of good sources out there and learning where and how to look will increase the relevance, quality, and quantity of the papers you find."

"6. You'll also get to practice reading papers. How many of you have already read a scientific paper, start to finish? (Usually only a subset of the class raises their hand). That's about what I thought. Reading scientific papers can be quite challenging at first. When I started reading them I felt like I highlighted, underlined, and looked up nearly every other word, and I sometimes had the darndest time just trying to determine what the authors were trying to say. This struggle is fairly common and it is normal to feel this way. The bottom line though is that you will have to master reading scientific papers in order to pursue a career in science."

"5. We won't waste time covering what you already know. A lot of this material might be familiar from high school and we plan to move well beyond that today."

"4. You'll get a chance to practice the teamwork and time management skills you've been honing throughout the semester."

"3. You'll be getting good practice for long term project 2 which will also require you to ask questions and find/read a variety of scientific papers. (You can insert a reference to your own class project here)."

"2. Of course, in doing this you will avoid a boring lecture."

"1. And the #1 reason for doing this is: You will discover why cell biology is special and practical. We won't just give you a bunch of facts to memorize; instead, we'll focus on why this matters, especially when we consider how cell parts relate to human disease."

"Alright, let's get started. I've taken the liberty of assigning each group a particular cell part to work with today. Instead of learning about all of the cell parts at once, you will first become experts on your team's assigned cell part. Identify your team's cell part by matching your team number to the cell part number on this slide."

Teams Identify Their Cell Part (1 minute)

Show the slide containing a list of all the cell parts you want your class to research (Supplemental File S1). Your class size and group size will likely be different from mine. I recommend setting it up so that every group gets to work on their own unique part. This requirement is not absolute and it is acceptable to have some groups working on the same cell part if needed. If you do have multiple groups working on the same cell part, it is best to have them seated away from each other so that they cannot listen-in on each other's research. You may also decide to have teams choose their own cell part. This choice has the potential to increase their motivation by giving them more control over what they are doing (6). The disadvantage is that you will end up with many groups researching the same cell part while the more obscure or challenging cell parts are neglected.

Teams Identify What They Know About Their Cell Part (5 minutes)

"Alright, now that you have your cell part in hand we're going to have a little contest. I want your group to pull out a blank sheet of paper and write down everything you know about your cell part. All of this should be from your own heads; do not use your textbook or the internet for this part of the exercise."

One of the great things about this activity is that it uses a classic constructivist approach (19, 20). Students begin by identifying the information that they already know, so you can encourage them to go beyond this baseline. This activity also allows the students to teach each other, as it is likely that not everyone will know the same thing about their team's assigned cell part.

I give students five minutes for this activity, since setting and adhering to strict deadlines keeps students focused and allows them to practice their time management skills (5). I walk around the room while they work, which helps to keep them from breaking the rules by looking up information from outside sources. I will answer any questions that come up and will help any groups who are getting stuck by asking them leading questions (i.e. What else does the cytoskeleton do aside from playing a purely structural role?). I also try to make sure that team members are contributing equally and that single individuals are not dominating their group. Most students write aggressively during this stage because they assume the "contest" I mentioned above is to see who knows the most about their cell part. This is not in fact the case, but is does not hurt to let them think this way about the competition.

Teams Ask Questions about Their Cell Part and Select Their Favorites (10 minutes)

"Okay, now each team should have a clear idea about what they already know about their cell part. Here is where the contest starts. (Upon hearing this students often gasp in surprise.) I want each team to come up with as many questions as possible about their cell part. All questions count, provided that you do not already know the answer. Number those questions and write them on your team's white board. You'll have exactly five minutes for this activity. The winning team will be the one that asked the most questions about their cell part."

Before doing this part of the activity, instructors may decide to have a discussion about what constitutes strong or weak questions. During this discussion students can be prompted to

come up with a list of criteria for evaluating question quality. While this can help students to ask better questions, and also help them to select their favorite questions later, I usually skip this part to save time.

One thing I really like about this question asking part of the activity is that teams who feel they knew the least about their cell part can still win the contest by asking the greatest number of questions about it. The number of questions that teams come up with varies but most teams usually have between 8 and 12 questions and the winning team usually has about 15 to 25 questions. Examples of valid questions include: "How does it form?"; "How are proteins trafficked to it?"; "What happens to it during cell division?"; "How many membranes does it have?" By having teams write their questions on the whiteboard, I can easily see which teams are ahead and can identify teams that are asking overly simplistic or redundant questions (i.e. Is it blue? Is it red? Is it green? etc.).

When the time is up, I point out how pleased I am about the number of questions that were asked. Groups can easily see the relative quantity of questions they had compared to their neighbors by looking at the whiteboards. Before announcing the winner, I share some of the most interesting questions I saw while walking around the room. "Alright, time is up. Let's look to see who has the most questions. Team X has 18; does anyone have more than that? No? Okay, let's hear it for Team X!" I usually give the winner a round of applause. Instructors could further encourage the inter-team competition by awarding bonus points or some other reward to the winner, but in my experience such a "bribe" is not required.

At this point, I have each team identify their top three favorite questions from their list. While they are doing this, I provide them with access to the activity worksheet on our course management system (Moodle) by unhiding it on the website. The worksheet prompts students to fill in what they knew and did not know about their cell part.

Teams Answer Their Questions Using the Primary Literature (90 minutes)

Students are then instructed to use the primary literature to answer their own questions and to learn how their cell part relates to human disease. While some cell parts, such as those exclusive to plants or bacteria, are not found in human cells, they can be found in human pathogens and may relate to human health in other ways (i.e. probiotics, nutrition etc.).

I usually guide students to look at review articles first, but primary sources are also encouraged. If you have not already talked about how to find good sources of primary literature, this is a great teachable moment. I usually talk about this during a previous class and I have included the slides I use for this in Supplementary File S3.

As students search the literature, they begin to discover which of their questions have known answers. This step is an important part of the activity because identifying what is still unknown is a big part of a scientist's job. After all, you would hate to complete an entire research project and then belatedly realize it had already been completed a decade earlier. When the answer to the students' question is currently unknown, they are instructed to propose a hypothesis and an experiment to address it. I do not require a detailed procedure, but I do expect students to have one or more valid methods for answering their question. The best techniques can be found on the internet or in their notes from previous class discussions. Experimental flow-diagrams are encouraged. Both hypotheses and experimental plans will be graded along with the rest of the presentation slides.

Teams Prepare a Presentation to Communicate Their Findings to the Class (15 minutes)

The last step of this activity is for the team to create a presentation that summarizes information about their cell part. This presentation includes what the team already knew about the cell part, what questions they had, what they learned from their research, any proposed experiments to answer questions that currently do not have answers, and information about how their cell part relates to human disease. I stress that they should write everything in their own words and that they should cite their sources properly. See the assignment worksheet for additional details (Supplementary File S2). Students usually complete about one-half to three-quarters of their presentation slides in class and they finish the rest outside of class before the next class period begins.

Teams Present Their Findings in a Poster Presentation (30 minutes)

The next class period is presentation day. I usually begin by giving students another 10-15 minutes to put the finishing touches on their presentations. Groups find this time very helpful as it allows them to polish their projects and it is invaluable for those groups who were unable to meet outside of class.

Once the slides are complete, students use them to present the information about their cell part to each other in a "poster" session. While the format is similar to a standard scientific poster session, no actual posters are used. Instead, our active learning classroom (ALC) has large TV monitors near each group that allow them to project their slides. See the Teaching Discussion section to learn how to run this activity in a more traditional classroom.

Before beginning the "poster" session, I stress the importance of taking good notes because this presentation is the only chance for them to learn about all of the cell parts in class. I also remind them that this material will be on the exam. Presentation time consists of three, seven-minute sessions. During each session, two students from each group will present their slides (usually about 4-6) for five minutes and answer questions for an additional two minutes. Although presenting can sometimes be stressful for students, this stress can be reduced by allowing teams to select their own presenters, allowing students to present in pairs, and only requiring them to present during one session. I usually have all the teams present simultaneously to maximize the number of different presentations that can be attended. Alternatively, having every other group present can reduce background noise and make it easier to hear the presenters. Team members who are not presenting will split up and view other presentations that are happening throughout the room. The goal of each team is to effectively present their own slides while also viewing as many other presentations as possible.

In my classroom we typically have 14 teams which each contain nine students. During the cell part presentations, each team has two presenters and seven reporters during each of the three sessions. Each student can see two to three presentations (not including the presentation they helped to create); the entire team can collectively see about 21 presentations during this 30 minute period.

During the presentation session, I set a timer and announce when students should be finishing their presentations and Q&A sessions. Students are given 2-3 minutes between presentations so they can finish writing their notes and get to where they need to go. Aside from functioning as the time keeper, I also view as many presentations as I can. These presentations are often very cutting-edge and I usually learn something each time I do this activity. It is clear that the students are learning a lot, too. The peer-to-peer instruction they experience is an excellent way for students to become more familiar with the material, while helping them develop effective oral communication skills (12, 21).

Share and Compare (10 minutes) & Debrief (10 minutes)

After the "poster" session students regroup and compile their notes with their team. In this way, they all teach each other what they learned, much like a classic jigsaw activity (5). Similar activities to teach undergraduates about the scientific literature have been reported to increase student motivation and learning (21, 22) as well as build confidence (12). After they have had 10 minutes to compile their notes, I facilitate an activity debrief where we talk about how the presentations went, what could be improved if they were to do a similar activity in the future, and what questions they still have. I also ask them the most important thing they learned about cell parts, and ask them to comment on whether or not this activity achieved its stated learning goals. This debrief is a prime opportunity for students to think metacognatively as I engage them in a discussion about their own learning.

Assessing Student Performance

I administer the quiz soon after the activity is complete. The quiz consists of ten multiple-choice questions in a format that is similar to other weekly quizzes in the course. Students typically have about 20 minutes to take the quiz. Because the quiz must be prepared in advance it usually contains generic questions about cell parts that were covered in the presentations and in the reading. In contrast, on the exam I will ask them a matching question which includes more specific and detailed information that was presented by the students.

At the end of the week each team submits their completed presentations online so that they can be graded (see Supplementary File S2 for rubric). The slight time lag allows students to make improvements to their presentation slides before they submit them for grading. I find this to be an important step, as students often learn more about how to make good presentation slides while giving the presentation and while seeing other teams present. During the following week, these presentations are shared with students so they can take additional notes and use them to study for the exam. Before posting these files, I look for any inaccuracies in the presentation, to prevent the spread of misinformation. Despite doing this exercise several times, I have not yet had to make any corrections, suggesting that students are very good at identifying accurate information for their presentation.

Summary

Students have the opportunity to achieve all of their learning objectives by the end of the lesson. The pre- and post-class quizzes ensure that no required content knowledge is sacrificed, and the presentations provide additional cutting-edge information that cannot be found within the textbook. During the lesson, students ask and answer their own questions, interpret data, and improve their ability to find, read, and reference biology journal articles. Students also exercise their critical thinking skills while creating hypotheses and designing experiments. Finally, they improve their written and oral communication skills while preparing and giving their poster presentation.

TEACHING DISCUSSION

Lesson's effectiveness at achieving the stated learning goals and objectives:

I have been very pleased with the success of this teaching activity. It avoids a boring lecture, exposes students to the scientific literature, and appears to increase critical thinking and motivation. One of the keys to running this activity successfully is to place a special emphasis on the presentation. Students occasionally do not like the presentation component because 1) they generally do not like to give presentations, 2) sometimes student presentations are low quality, and 3) they sometimes distrust information that comes from their peers instead of the all-knowing instructor. I counter these problems in two ways. First, I have created a series of web videos that teach students how to organize their presentations, design their slides, and speak effectively in front of a live audience (Supplementary File S4). These videos are available to the students on the course website, and I believe that having students view these videos has greatly improved the quality of their presentations. Second, I announce that I will be monitoring the presentations closely and that I will help to correct any errors to ensure everyone has the correct information. I also stress that accuracy is important and that inaccurate statements will be penalized when I am grading the assignments. After implementing these changes, ~90% of students indicated that they preferred this activity to a lecture about cell parts.

Students commented on this activity on in-class surveys and end-of-the-semester evaluations. I do not have space to include all of their comments but here are some selected examples.

"I found the cell parts presentations were useful in gaining a more in-depth understanding of cell biology"

"I really learned a lot about the main functions of cells and have a much greater understanding of how the cells work."

"I'll need to remember cell components and cell signaling for my future career in medicine."

"I liked the focus on reading scientific papers, because that's something that everyone should know how to do with a fair amount of ease."

"[The most important thing I learned this semester was] how to achieve goals in a group, how to solve open-ended problems in biology, and how to design questions and answer them with research."

"I have learned how to think like a scientist by identifying a problem, proposing a hypothesis, and planning experiments to test the hypothesis and evaluate what the results of said experiment mean on a micro and macro scale."

"I got a great version of what the part is from students like me, rather than an expert. [This] allowed us to be more comfortable."

"I couldn't not pay attention because I was the one doing the teaching."

"It was nice to learn material from my peers and also be able to teach material to others because it shows we have an understanding of our topic."

"I really liked this activity and thought it was extremely helpful and effective. I believe it was effective because not only did I research my topic, I also presented it and learned from my classmates. Honestly this was more helpful than a lot of the lectures."

"The poster session was a lot of fun. I think it was a fast way to learn a lot!"

Suggestions for improvements/adaptations to different courses or student populations

Other topics that could be used for this activity

While this activity was designed to introduce students to cell parts it could potentially work with many different topics, including biomolecules, cell processes, species concepts, organ systems, or even different biomes. I typically assign each group their own unique part, but you could also set it up so that a few teams are working on the same topic. This allows for greater flexibility so that the activity is not dependent on the number of groups or students in the class. Groups working on the same topic could also have a mini-conference so they can share their ideas and compare their notes before presenting to the larger group.

Implementing this activity in a traditional classroom

I use this activity in an ALC that contains round tables, class laptops, and enough flat-screen TVs to allow all the groups to simultaneously project their slides during the presentation. If you are doing this activity in a more traditional classroom, you can have students print out their slides before class. Instead of displaying slides on a monitor, printed slides can be taped to a wall or can even be held and displayed one at a time. Alternatively, if you have a small classroom and sufficient time, you could have each team present their findings to the class. The advantage of this approach is that you can immediately comment on any notable errors or omissions. If white boards are not present for recording students' initial questions about their cell part, you can simply collect student responses on pieces of paper and use them to determine which team asked the most questions. If your classroom is not equipped with laptop computers for creating presentations and performing online research, you can ask students to bring their own computers, send them to a computer lab, send them to the library, or have them do the bulk of their work outside of class. Finally, while the tables in our ALC are designed to accommodate groups of nine students, there is nothing magic about this number and doing this activity with smaller groups (i.e. ~3-5) should work equally well.

Another question that I sometimes get about this activity is "Can introductory biology students really create hypotheses and propose experiments in such a limited amount of time?" The answer to this question may depend on the class, but I can tell you that our students are able to do this without any difficulty. Their abilities in this area likely stem from mini-lectures on hypothesis generation and experimental techniques that are given earlier in the course, before this activity takes place. Even if students aren't yet experts at scientific processes, I really like to include this activity as it gets students to think like scientists. For that reason, I would encourage you to give it a try in your classroom. I predict that your students will pleasantly surprise you with the quality of their thinking! That said, the generation of hypotheses and experiments is completely optional and this step can easily be eliminated without affecting the rest of this activity.

Possible Improvements

Currently teams only have to brainstorm an experiment if they asked a question that has not already been answered. To create a more uniform experience, it might be a good idea to require each team to identify an unknown aspect of their cell part and then propose an experiment to address it. Alternatively, this portion of the activity can be eliminated entirely if time is an issue.

Optional additional activity

Another activity that could be used in conjunction with the Cells: A World A Part activity is to do a cell part scavenger hunt. The hunt is designed to enable students to identify cell parts that have been drawn, rendered by a computer, or photographed using different kinds of microscopy. This strategy gets them away from the idea that all mitochondria look exactly like the one in their textbook. To do this activity, you must first assign a different cell part to each individual team member. Most cell parts will be used more than once in the classroom, but members of the same team should all have different cell parts. Students search for their favorite online images of their cell part and then the team compiles these images together on a single PowerPoint slide. In my classroom we have teams of nine, so each team creates a slide with nine unidentified cell parts. Teams then display the images they found on their monitors and other teams rotate around the room to guess what each image represents. Teams need to know whether or not they have guessed right so each team must leave behind the correct answers on the next slide, or leave behind a group member to inform the other team when they have guessed right. I have used this activity several times and students always enjoy it.

SUPPLEMENTAL MATERIALS

- Supplementary File S1. Assignment Worksheet: This file contains the worksheet that guides students through this activity. It lists the questions they need to answer and provides instructions for creating the presentation. It also includes a rubric so that the students know how they will be graded. This worksheet can be printed before class if desired or made available online if students have access to computers.
- Supplementary File S2. Lesson PowerPoint Slides: This file contains the slides used in class while doing this activity.

These slides introduce the activity and are also useful for the activity debrief at the end of the lesson.

- Supplementary File S3. How to Find Information: This is a PowerPoint presentation designed to coach students about how they can find information for whatever project they are working on. This lecture is a great way to introduce them to different ways to find sources. Usually students get this lecture well before doing the "Cells: A World A Part" activity.
- Supplementary File S4. Useful Web Resources: This document contains a list of helpful web-links including links to the video lectures about how to give a good presentation and links to other websites that are helpful resources for cell biology.

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