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Not All the Organelles of Living Cells Are Equal! Or Are They? Engaging Students in Deep Learning and Conceptual Change

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Abstract
The cell is the fundamental basis for understanding biology much like the atom is the fundamental basis for understanding physics. Understanding biology requires the understanding of the fundamental functions performed by components within each cell. These components, or organelles, responsible for both maintenance and functioning of the cell comprise to form a dynamically stable ecosystem. The secret of achieving this noble and desirable efficiency rely on the structural and functional variations of the organelles within the cell; they each carry out specific jobs within the cell resulting in a smooth, running process that would be the envy of any industrial manager. In this role-playing learning activity, we aim to engage students in deep learning that leads to cognitive and conceptual change by forcing them to be and to actively act as those organelles within the cell. It is centered on the idea that a number of organelles within the eukaryotic cells are strongly "protesting" the "privilege" that mitochondria and chloroplasts have within the living cells (both in single and multi-cellular organisms). They are protesting the structural and functional privileges that other organelles lack, but the mitochondria and chloroplasts have. Students will have to understand an explore the reasons for the differences among all the organelles and how they differ in importance and function, especially in regards to interactions between organelles within each cell and how it contributes to the life of the cell as a whole.. After all, as it has been stated by NGS (2007) "a human cell reveals our inner architecture" (p. 40).
Keywords: Living cells, organelles, role-playing, analogy, instructional approach, intentional learners, student success.

1. The Scenario: Not All Organelles are Equal! Or Are They?

This role-playing learning activity centers on the idea that a number of organelles within the eukaryotic cells are strongly "protesting" the structural and functional "privileges" that mitochondria and chloroplasts have within the living cells (both in single and multi-cellular organisms). On the other hand, both the chloroplast and mitochondria are not in a position to ignore such a strong protest, and must, therefore, defend themselves. They need to provide a convincing argument to support their role within the cell including how, without their existing unique structure, function, and position with living cells, the cell cannot maintain themselves. Their arguments must also include how their contribution is essential to other organelles and to the lifespan and function of the cell itself. The "claim" and the "grievances" have been made by a number of the organelles and were officially submitted to the nucleus of the eukaryotic cell. The reason the grievance was submitted to the nucleus (the "judge") is because it is the largest of the membrane-bounded organelles which characterize eukaryotic cells, and because it contains the bulk of the cell's genetic information through which it directs protein synthesis and cell reproduction. However, due to the nature of the complaint, the nucleus cannot ignore it, and thus decided to convey a "cell-hall" meeting to deal with this grievance and to mediate the conflict between the protesting organelles and the mitochondria and chloroplasts.

The nucleus called on all parties to prepare and attend the cell-hall meeting. The nucleus also allowed the defending mitochondria and chloroplasts to seek help and support from prokaryotic cell communities. The remaining organelles were also allowed to seek help and support from single cells of eukaryotic organisms. Plasma membrane and microtubules are forbidden from taking positions on any side of the claims and the grievances as they are needed by all cells to maintain the cell integrity.

The protesting organelles have no doubt about the importance of mitochondria and chloroplast in living cells. They understand that mitochondria are the sites for much of the metabolism necessary for production of ATP, lipids, and protein synthesis. They also understand that the number of mitochondria varies between one and 10,000 depending on the type of the cell, and with averages of about 200. For example, each human liver cell have over 1,000 mitochondria. By the same token, the protesting organelles know that chloroplasts are the sites where photosynthesis takes place, and without them, the trapping of light energy and synthesizing sugar from carbon dioxide and water will both cease. There will additionally no release of oxygen which most living forms have evolved to depend on. Unlike mitochondria, the number of chloroplast in living cells is much lower than that of mitochondria. "A unicellular plant may have only a single large chloroplast, whereas as a plant leaf cell may have as many as 20 to 100" (Bobick and Balaban, 2003, p. 248).

Mitochondria and chloroplasts proudly continue to remind every organelle of their important role. They, along with their ancestors, the bacteria and cyanobacteria, were the only living forms in planet earth for millions of years, long before eukaryotic cells were evolved. However, it is not clear whether or not this is an efficient organization. They need to be aware that most organelles and their friends within the cell need to be convinced of the mitochondria's and chloroplast's importance within a living cell. If mitochondria and chloroplast were to leave the eukaryotic cells and go back to living as single cells, they would not receive sympathy from such a threat. It would not support cooperation or collaboration with other organelles in a sustainable ecosystem of the living cell. This is important since while many of the other organelles are sure about the place and loyalties to the host cell, they have some doubt of the loyalty of mitochondria and the chloroplast to the host cell. Borrowing Bryson's (2003) analogy:

> *… even after a billion years, mitochondria behave as if they think things might not work between us [mitochondria and host cells]. They maintain their own DNA. They reproduce at a different time from their host cell. They look like bacteria, divide like bacteria, and sometimes respond to antibiotics in the way bacteria do. In short, they keep their bags packed. They don't speak the same genetic language as the cell in which they live. It is like having a stranger in your house, but one who has been there for a billion years. (p. 300)*

2. Background and Introduction:

Isaac Asimov (1988) made comparisons of the living cell as a society of individual beings (Cited in Pruitt and Underwood, 2006, p. 89). Further drawing from this analogy, Rensberger (1996), illustrated the point by saying that cells are not as simple as they are depicted in textbook diagrams. Rather, they are analogous to a city being aerially viewed. Cells are resemble the compactness and diversity of a city with vehicles and people moving around and performing their duties (Rensberger, 1996, p.71-74). When viewed under a microscope, cells are highly complex and sophisticated Movement of various organelles within the cell doesn't even begin to describe the complex movements of proteins, organelles, and structural elements necessary for a healthy cell.

> *If you take a single cell and put it under a powerful microscope, you'll see something that might remind you of an aerial view of a city --- innumerable objects zooming of the view of city streets from high atop a skyscraper. Like city streets jammed with cars, people, and buses, the cell's innards are crowded with objects of many shapes and sizes, many of them moving around. The image is nothing like the typical textbook diagram of a cell, which shows a few lonely objects draining in an empty intracellular sea. In a real cell there is no vacant space. Under the microscope, you'd see thousands of tiny spheres, each a hollow container of chemicals, jostling about. Some jump crazily. Some glide in straight lines – some smoothly, some in fits and starts. Dark, sausages shaped objects loom into sight, turn a corner, and slither back down out of the microscope's focal plane. … That's life – dynamic even at its most fundamental level, a ceaseless concert of motions and thousands of [non-random] simultaneous chemical and physical reactions. (*Rensberger, 1996, *p. 71-74)*

Cells are central to the life of every organism, simply because all life is composed of cells and cells arise only from other living cells. The cell is the smallest entity capable of exhibiting the characteristic of life. It is the basic functional unit of all living things, and thus, with their unique cellular and sub-cellular structure's function in the duration of the cell's life, are essential components and the cornerstone of understanding biology, chemistry, and other related fields.

As the basic functional unit of all living things, the cell is bound by a plasma membrane that separates it from its surrounding environment and encloses its cytoplasm and its specialized parts. Internally, some cells are relatively simple, yet others have extensively compartmentalized bodies with very sophisticated internal structures differentiated for specific functions. Some of these compartments are also surrounded by plasma membranes. This delineation serves to physically separate the various metabolic reactions that occur within the cell. These bodies or compartmentalized components are called organelles, each with a characteristic structure, biochemical composition, and function.

Based on the cell structure, life forms are either prokaryotic or eukaryotic. Prokaryotes such as bacteria and cyanobacteria consist of only a plasma membrane, DNA, ribosomes, cytoplasm, and often a cell wall, but lack specialized organelles. Eukaryotes consist of a nucleus and organelles within the cytoplasm that serve to physically separate the various metabolic reactions that occur within the cell.

In addition to a nucleus, most eukaryotic cells also have ribosomes, endoplasmic reticulum, a Golgi apparatus, lysosomes, mitochondria, and peroxisomes. Plant cells have also chloroplasts and large vacuoles. Filaments, microtubules, and intermediate filaments are protein polymers that hold the cell together and the organelles in place in the cytoplasm. These proteins also play a role in cell motility and organelle movement within the cytoplasm. A major challenge in the field of cell biology is understand the collective and individual organelles within the cytoplasm and its distribution throughout the cell.

> *These organelles are suspended in a gel-like cytoplasm matrix composed of three types of protein polymers called actin filaments, microtubules, and intermediate filaments. In addition to holding the cell together, the actin filaments and microtubules act as tracks for several different types of motor proteins that are responsible for cell motility and organelles movement within the cytoplasm. A major challenges in the field of cell biology is to learn how each organelle and the cytoplasmic matrix are assembled and distributed in the cytoplasm. This is a very complex process since cells consist of more than 2000 different protein molecules together with a large number of lipids, polysaccharides, and nucleic acid, including both deoxyribonucleic acid (DNA) and many different types of ribonucleic acid (RNA). (McGraw-Hill, 2004, p. 172)*

Furthermore, the cell has the information necessary to specify the assembly and location of each molecule in its designated compartment. Some of these molecules assemble from their constituent molecules as opposed to the membrane containing organelles which strictly arise from growth and division of preexisting cells. This occurs because phospholipid membranes can grow only by expanding from preexisting bilayers. For example, organelles such as mitochondria and the endoplasmic reticulum, which are inherited maternally, arise from a preexisting cell. Organelles can also produce other organelles, such as the Golgi apparatus giving rise to lysosomes.

The cell must also carry the information and the means by which the various organelles become ordered and compartmentalized. This ensures that they carry their function appropriately and interact appropriately with other molecules or organelles both extracellularly and intracellularly (McGraw-Hill, 2004, p. 172).

Through intense scientific research on each of these organelles' function and the specific chemical reactions that take place within them, scientists were able to recognize a number of important general principles that contribute to the understanding of the complex processes of life.

Table 1:
Cell parts and their functions and resembles analogies

(Pruit, and Underwood, 2006, p. 105)

Organelles/Parts	**Analogies**	**Function**
Nucleus	Main Office	*Controls cellular activity and stores its hereditary information.*
Nucleolus	Building Department	*Organelle within nucleus that controls synthesis of ribosomes.*
Endoplasmic reticulum	Department of Transportation	*Extensive system of membranes that is either smooth or rough, where many proteins and other products are synthesized.*
Ribosomes:	Factory and small Machine Shop	*Organelles attached to ER or that float free in cytosol that synthesize proteins.*
Golgi complex	Packaging Center for developed products	*Modifying and packaging proteins for export from cell & also forming secretory vesicles.*
Vesicles	The Grocer and Butcher in the city, storage closet, Department of Commerce	*Organelles that store and transport cellular products and raw materials.*
Lysosomes and peroxisomes	Custodians, Horse drawn wagons	*Vesicles that store digestive enzymes.*
Mitochondria	Power plant, Department of Energy	*Cell's powerhouse where reactions occur that provide energy for the cell.*
Chloroplasts	Windmill, solar panels	*Organelles found in plants and algae where the reactions of photosynthesis occur.*
Centrioles	Secretary	*Associated with nucleus of all animal and some plant cells that facilitate the organization and construction of the cytoskeleton.*
Cytoskeleton	Support beams	*System of microfilaments, intermediate filaments, and microtubules that provide internal cell structure.*

3. Learning Activity: Not All the Organelles are Equal! Or Are They?

As previously stated, many organelles have been raising the issue of unfairness of how they, within eukaryotic cells, are treated in comparison to mitochondria and chloroplast. They claim that mitochondria and chloroplast within the living cells have structural and the functional privileges that the other organelles don't have (both in a single and multi-cellular organisms). The mitochondria and chloroplast asked the protesting organelles to go to the nucleus to address the issues if they are unhappy with their existing roles within a living cell, instead of wasting their time and energy trying to complain against them. The protesting organelles accordingly took their claims directly to the nucleus of the eukaryotic cell.

In this role-play learning activity, the class is divided into ten groups of 3-4 students each. Each group of students assume a role of an organelle to adopt, research, and represent in the "Cell-hall Meeting" in front of the nucleus. One group of students will represent the nucleus and another group will represent the media.

3.1. Goals and Objectives of the Activity:

The goal of this activity is to provide students with the opportunity to enhance what is taught in a given biology course. The idea is to extend student learning beyond both textbooks and the classroom, so the student can foster their development of their understanding of the role of organelles and non-organelle parts of living cells. In addition, students should be able to clearly understand how these organelles, individually, and collectively, contribute to the maintenance and homeostasis of the cell. Understanding how the distribution in any one of them might affect the whole cell, within a given tissue, organ, or even the organism itself is also crucial. We believe that by engaging with the activity, the students will keenly note the significance in providing pedagogical platform to:

- Work effectively in groups, coauthor and revise peer response, a paper or report to a question.
- Have space to plan, think, produce, and present the outcomes of their selected research thought process.
- Brainstorm, research, and write an effective opening and closing crystal clear statements, research papers, etc.
- Receive guidance and constructive critiques for peer learning throughout the different stages of role-playing process.
- Experience a situation that might resemble a case in real life situation.

Another objective is to actively engage students in a library investigation, conduct literature research, and collaborate in group work, to both achieve understanding and retain new information for application to different situations. The aim is to provide an opportunity for students to become deep learners by engaging in active learning through the investigation of cell's organelles and their roles in the cell's life (Cherif, et. al. 2001). As Houghton (2004) has argued, deep learning promotes understanding and application for life and "involves the critical analysis of new ideas, linking them to already known concepts and principles, and leads to understanding and long-term retention of concepts so that they can be used for problem solving in unfamiliar contexts" (p. 5).

3.2. Pedagogical Strategies

The activity can be assigned as a group research project, individual term paper, and or as a group or individual class presentation. It may be helpful for students to start conducting their research in preparing to actively engage in the learning activity by starting with "Get To Know Your Chosen Organelle". In this article, we describe one of the suggested strategies, one of which is to use the assignment to produce a group research paper and presentation through the role-play platform. Throughout the whole process, there is also a focus and emphasis on the development of needed communication, collaboration, critical thinking, and creativity that are all needed for successful living in the 21st century.

3.3. The Organelles' Communities:

In this role-play learning activity, the class is divided into ten groups of 3-4 students each. Each group is assigned one of the following organelles or non-organelles cell parts to adopt, research, and present:, Centrosome, Chloroplast, Endoplasmic reticulum, Golgi apparatus, Lysosomes, Mitochondria, Nucleus, Ribosome, Vacuoles, and the media group. Unlike most role-play activities, after the members of each group individually completes their research, they will meet to share researcher's outcomes and informed perspectives among themselves. They will be directed to decide with an agreed perspective that reflects their collective informed opinions about their specific claim and defend against other groups' claims and perspectives.

The members of each group work together for three weeks using the guidelines that have been presented to each group. They will be given a starting point to help them conduct their research. In the fourth week, the members of each group meet together and have an objectively informative discussion amongst themselves to come up with a single informed claim and perspective that reflects their collective thoughts about the claim at hand. They will then present, face-to-face, their claims and perspective in an informed discussion to use and validate the defenses provided by other groups. The members of each group will write a 3-4 page paper to be submitted to the instructor on their research, the outcome of their own group's research, where they stand on the claim that mitochondria and chloroplast have special privilege within the living cells, and that none of the other organelles and non-organelles parts have.

3.4. Get to Know Your Chosen Organelle:

Each group must conduct research on its chosen organelle beyond what lies in their textbook. In their research, the members of each group must cover:

1. Structure and the function of the organelle, and the relationship between both, contributing to its efficiency.
2. The latest discoveries and information that come from advance research in cell biology, especially on the chosen organelle.
3. The relationship between the chosen organelle and the organelles that are linked to it directly, for example, ribosomes and the endoplasmic reticulum.
4. Quantitative data and information related to the chosen organelle might be helpful to include in the conducted research as well.

5. Convince, through their research and in their research paper, how and why their chosen organelle is the most important one in a living cell; as well, they need to support their rationale why their organelle is the most needed for the survival of the cell.
6. Describe what activities the chosen organelle conducts within the living cell and how.
7. Explain how a comparison of the structure of their chosen organelle to the mitochondria and/or chloroplast might help in supporting the group's cause and claim.
8. Briefly describe some of the recently discovered information that contribute to the unique qualities of the group's chosen organelle, and its importance in the living cell.
9. The name of scientist(s) who discovered and/or made significant contribution to our current understanding of the structure and the function of the chosen organelle. For example, the Italian physician Camillo Golgi (1843-1926), who won the 1906 Nobel Prize for the identification of nerve cells, was also the one who identified the structures including Golgi complex (a cell organelle concerned with modifying and packaging proteins), Golgi cell (a type of nerve cell), and Golgi tendon organ (a sensor that detects changes in muscle tension)" (p. 14).
10. What the members of each group have personally learned by conducting this research on the specific chosen organelles.

4. Procedures:
4.1. Conducting the Learning Activity:
4.2. Before the Activity

Students must conduct and complete their research. The instructor of the class reads all the papers, provides feedback, and raises challenging questions, if needed. Then, the instructor gives the students one week to work on their paper again, using his/her feedback, and informs them about the day of the "Cell-Hall Meeting". The instructor informs the students in each group to prepare:

1. One-two minute written statement that will be read at the beginning of the debate.
2. One minute closing written statement that will be read at the closing of the debate, to support their own perspective.
3. A few key points that represent the core of their main argument.
4. Illustration, animation, etc. are optional.
5. Encourage students to use analogy in explain their claim and the reason beyond it.

4.3. Before the Enacting Procedures:

1. Divide the class into ten groups. Each group consists of a leader plus a few members based on the needed number of adequate representation.
2. Inform the students in the scenario that a number of organelles within the eukaryotic cells are strongly protesting the "privilege" that mitochondria and chloroplasts are have within the living cells. The claim and the grievance was submitted to the nucleus of the eukaryotic cell which in turn, called for a "cell-hall" meeting to deal with the grievance and to mediate between the protested organelles on one hand and mitochondria and chloroplast on the other hand.
3. Inform the students that as active members of their respected groups, they should identify the significance of making the right claim and how their claim is the best for their group. They should also predict how members of the other groups would react to their final claim.
4. Give the groups 2-3 weeks to prepare for their class presentation. In addition to working outside the class time, make sure that each week they set aside 10-15 minutes of the class time for the members of each group to join together and discuss their work and preparation. This way, you ensure that the groups are working on task and will be ready on time for the day of the presentation (Cherif, et. Al, 2001).
5. Ask the members of each group to meet and divide the roles among themselves by selecting a leader, as well as strategy of how they would like to represent their claim. In addition, the members of the nucleus group must make their own choice about the type of roles and regulation they would like to make in successfully and objectively conduct the hearing. This type of involvement is very critical in ensuring a high level of "Student -Involvement in the Learning Activity".
6. For the presentation, each group must:
   a. Have a well-researched presentation and strategy of how to present the claim of their respective group and reaction to the decision they would like to make.
   b. Explain how the members of the other organelles react to the decision they would like to make.
   c. Explain how various organs and organ systems within their own organism might react to their group's claim, respective and reaction to the decision they would like to make.
   d. Prepare a well-researched student hand-out as well as an illustrated poster.

e. Integrate the use of technology such as PowerPoint, animations, interactive activities, etc. into the presentation. Students should present their plan and strategy, show how they will work, and convince everyone that their decisions support their community's beliefs and understandings.

4.3. During the Presentation:

1. The groups take turns presenting to the whole class the significance of their claim, their arguments and why they decided to take this stand. They also need to predict how the respected mitochondria and chloroplast would react to their claim and grievance. They also need to anticipate what type of questions the members of nucleus (board or judges) might ask them and how they might respond to them.
2. The leader of each group introduces the members of his or her team, and provides a brief introduction. Then, the leader of the group can call on the members of his or her group to talk about the significance of their claim, the reason behind the claim, as well as the prediction of how the respected mitochondria and chloroplasts might react to their claims and why.
3. The members of the other groups can ask up to three questions after a given group finishes their presentation. The members of each group must also take notice of all the questions that were asked by all the groups.
4. When all the groups finish their presentations, the media group reports on the events and provide a list of questions that the members of the group failed to raise, answer, and/or shied away from discussion during the trial.

4.5. After the presentation:

1. Following the class meeting, the members of each group must bring answers to the questions that are raised and presented to them by the media groups, and or the nucleus.
2. Each group is given 3-5 minutes to address the class one more time. In this short final remark, the groups must have a written statement that can be read to support their claim, argument and the reasons behind it. The written statement doesn't have to be shared with the other groups beforehand. This is a very important stage in the activity and is related to the "Creative Domain" of McCormack and Yager's (1989) taxonomy for science education, as we will see in the coming assessment section and table 6.
3. After all the groups present their final remarks, the groups are asked to evaluate in writing the performance of each group.

4. Homework Learning Activity:

In this learning activity, students are provided a copy of table one and given one week to conduct library research to answer the following questions in paragraph or list format:

1. Differentiate between viruses, viroids, prions, and bacteria, paramecium, oak tree, and a cat.
2. Why do we often include viruses, viroids, prions with microbes, but we don't qualify them as "living" entities?
3. If you have the means, the know-how, and the will, what would you:
    a. Add to the existing structure of the prokaryotic cell and why?
    b. Take out from the existing structure of the prokaryotic cell and why?
    c. Modify in the existing structure of the prokaryotic cell and why?
    d. Add to the existing structure of the eukaryotic cell and why?
    e. Take out from the existing structure of the eukaryotic cell and why?
    f. Modify in the existing structure of the eukaryotic cell and why?
4. Describe what endosymbiosis is and how this theory has changed our understanding of living cell in general and biology in particular?
5. It has been claimed that the Junk DNA in our chromosomes may have come from ancient viruses that managed to insert their hereditary blueprint into our ancestors' DNA (Shukman, 2012). Conduct internet research to investigate the origin of the DNA in mitochondria and chloroplast.
6. What have you learned from this learning activity?

5. Assessments

McCormack and Yager's (1989) "taxonomy for science education" can be used as a framework for assessment. This could be accomplished as both formative (conducted during instruction) and summative assessments (which conducted at the end to measure what is learned). This is a good framework for student achievement, and for assessing student performance and understanding, as well as for the effectiveness of the activity. The Table 6 summarizes the McCormack and Yager's (1989) taxonomy for science education. We have found this to be very effective in enabling teachers and students to explore how and why each group formulated and supported its claim, and whether this whole grievance could have been approached in other ways (Joyce and Weil, 1986). Furthermore, learning activities and teaching approaches should always aim to capture the student's interest and spark motivation for learning and knowledge creation among students. To achieve this, students should be given the opportunity to be involved in the planning, implementation, and assessment of a given learning activity. To make the teaching approach of the given learning activity more productive, instructors should allow students to participate in executing a learning activity. Specifically, addressing the five factors essential in a typical role-playing situation:

> 1) The problem to be solved; 2) the characters to be played; 3) the roles to be followed; 4) essential information to be gathered and; 5) procedures for the play to be adapted" (Cherif and Somervill, 1994, 1995). Therefore, at the first level of "Student-Level of Involvement" in the "Role Playing Teaching Model" as shown in Table [2], students carry out pre-assigned activities: they are actors for a scripted play. When students are involved in the planning of role-playing activities they are able to have a greater educational experience from what may seem a simple role-playing activity. For the highest productivity, instructors should lead students toward level 6, even if that level cannot be achieved. As the difficulty level increases, so does the amount of time, effort, and best of all, enthusiasm among the students. The final level of student involvement is critical assessment (Cherif, et al., 2009, p. 345).

Table 2- Student-Level of Involvement" in the "Role Playing Teaching Model

The Level of Involvement	**Problem to Be Solved**	**The Characters in the Play**	**Role of the Characters**	**Essential Information**	**Procedures for the Play**
I	**Given**	**Given**	**Given**	**Given**	**Given**
II	**Given**	**Given**	**Given**	**Given**	Not Given
III	**Given**	**Given**	**Given**	Not Given	Not Given
IV	**Given**	**Given**	Not Given	Not Given	Not Given
V	**Given**	Not Given	Not Given	Not Given	Not Given
VI	Not Given	Not Given	Not Given	Not Given	Not Given

* *While individual students are expected to achieve various levels of involvement in the learning activity based on the grade levels, intellectual maturity, etc., the activity should be considered successful if, for example, AP classes can reach level I or II, freshman in college can reach level III and upper-classmen can reach levels IV and above.*

In this activity, the problem to be solved and the characters to be played are given to the students. However, the roles to be followed, the essential information to be gathered, and the procedures for the play to be adapted are part of the learning activity and the students responsibilities. Thus, it is at the fourth "Student-Level of Involvement" in the learning activity (Cherif, et. al, 2009).

Tables 3, 4, and 5 have been used successfully as tools to record information and to monitor the level of cognitive involvement of the members of a given group during role play learning activities. For example, using table 3, instructors can record the type of questions being asked by the members of a given group as well as the relevancy of the questions to the subject matter and to the point being addressed. Furthermore, using table 4, instructors can record the number of questions being asked by the members of a given group to the other groups (Cherif, et. al., 2009). In addition, instructors can use table 5 to record the type of questions or conditional statements and their values for assessment purposes.

6. A Pre- and Post-test Homework Assignment:

To reinforce the learning objectives of the activity, and to allow for deep learning and conceptual change, ask the students to answer the following questions (Adopted from Cherif, et. al, 2015), either individually or in groups.

7.1. Pre-test Homework Assignment:

1. What will you do to make sure that the claim and data and information that you will use to support your claim would be the one favored by each one in your class?
2. What will you do to make sure that you are selecting the right data, information, and arguments for what you choose to claim?
3. If you decide to select another part of the cell (organelle or non-organelle part) to represent, which one will you select and why?
4. What do you think you will learn by engaging in this role-playing learning activity at both the academic and personal levels?

7.2. A Post-test Homework Assignment:

1. What have you learned from the activity at both the academic and personal level?
2. If you had to do this all over again, what would you change or do differently and why?

3. Knowing what you already know, how would you argue against the perspective and the predicted reaction of other organelles of the cells?
4. If you could have selected an actual professionally known person from your own community to represent your chosen organelle, who would you select and why? How might this help you to convey the perspective of your group?
5. What type of evolutionary conditions or events triggered the development of eukaryotic cells like those found in modern plants and animals, etc.?
6. What structural evidence indicates the complexity of the modern living cells?
7. Why cannot prokaryotic cells be members of the board to mediate between the organelles and mitochondria and chloroplast?
8. If you have the means and the will to reconstruct, structurally and functionally, your chosen organelle what would you do and why? How do you perceive the relationship of your chosen organelles with other organelles and the nucleus?
9. If you have to reconstruct the ideal living cell, what do you include and why?
10. When do we use the term "Plasma membrane" and the term "Cellular membrane" and why?

7. Making the Connection: Short Essay Critical Thinking Questions for Students to Consider.

1. It has been said that "a human cell reveals our inner architecture" (NGS, 2007, p. 40). Write to a friend explaining what this statement means.
2. After researching the meanings of "apoptosis" and "necrosis," compare and contrast the terms, and provide examples of each.
3. In our proposed scenario, all organelles and cell parts are forbidden to make direct or indirect connection with the enzyme "caspases." What does this enzyme do, and offer a suggestion why the cell parts are told to avoid interacting with this specific enzyme?
4. Just as 'the atom is the basic unit of physics, so the cell is the basic unit of biology" (NGS, 2007, p. 14). Why do you feel this is so?
5. It has been stated that organelles "… that carry out specific jobs within the cell is a smooth – running process that would be the envy of any industrial manager." (NGS, 2007, p. 14). Share your thoughts on this matter. Do you agree or disagree with this statement, and explain why?
6. Perform some basic research on cells, focusing on what human cell is the largest, and which is the considered the smallest. Follow with writing, the similarities and differences between these two cell extremes. In your writings comparing and contrasting these cells, follow with a summation of what you have learned in general about the living cell.
7. Research, and write about, what happens to dead or dying cells, in the body. Include in your response, cells such as red blood cells that survive for only a very short time.
8. Research the life span of various human cells, and then write a short "article" to the local newspaper or a "letter" to a friend informing him/her about the outcome of your research. For example, skin cells live for 19 days, sperm for 2 months, red blood cells for 4 months, liver cells for 8 months, and bone cells for 15-25 years; what a unique disparity in the life spans of these different kinds of cells.
9. What do mitochondria and chloroplasts have in common?
10. What does the plasma membrane, mitochondria and chloroplasts have in common?
11. What types of evidence did scientists discover to prove that the nucleus controls everything in the living cell?
12. Why do you think the nucleus made it clear that the plasma membrane, cytoplasm, and microtubules were forbidden of taking any part of the disputed claims between the mitochondria and the chloroplasts, and the rest of the organelles of the cell?
13. It has been said that like the atom is the fundamental basis for understanding physics, the cell is the fundamental basis for understanding biology. Why do you think this comment is accurate?
14. Conduct research to learn more about Hela Cells, and then write a few paragraphs explaining to your friend the significant contribution of Hela Cells to our understanding of cell biology in general, and cancer in particular.
15. What does Matthias Schleiden, Theodor Schwann, Rudolf Virchow all have in common with cell theory as we know it now?
16. How do scientists prove that life is a property of cells, and that it passes on to new generations of cells?
17. How do scientists reach the conclusion that the cell nucleus is the central repository of information not only for constructing a new cell, but also for building an entirely new many-celled individual?
18. Rudolf Virchow has been cited many times by saying that "all diseases were the result of problems arising within cells." Based on your understanding of the cell, its structure and function, how would you explain the importance of Virchow's statement in regards to understanding biology and biological principles?

19. What type of discovery did Lynn Margulis (1938-2011) make that contributed significantly to our understanding of the modern living cells? And how did she come up with this insight?
20. Distinguish the difference between anabolism and catabolism processes; follow with explaining how the structure of mitochondria and chloroplasts are ideal for, and complement, the anabolic and catabolic process. Use illustrations to demonstrate your understanding of the processes.
21. How do cells come together in the formation of tissues? How do tissues come to gather to form organs? How do organs come together to form organ systems? How do organ systems come together to form organisms? Can you think of any analogies for each category to illustrate these processes?
22. The cells in your liver and in your skin look different and do different functions, and yet, they both developed from the same undifferentiated cells in the embryo. Conduct research to find out how does a cell know what "cell" to be?
23. Conduct research to find out what are "team cells" and look into their role in tissue engineering.
24. What do germ plasma cells, and many kinds of cancer cells, have in common?
25. It has been said that cellular life is controlled by two main nucleic acids. Identify these two nucleic acids and explain how they affect/control cellular life of living cells.

8. Summary and Final Remarks:

Understanding biology and related fields (e.g, health, medicine, molecular, and biochemistry to name a few) requires the understanding of the fundamental functions performed by components within each living cell. These components, or organelles, responsible for both maintenance and functioning of the cell comprise to form a dynamically stable ecosystem. Therefore instructors who teach these topic must not only make their courses relevant and interesting to their students, but also provide the opportunities and allow the students to demonstrate their understanding of the intended learned concepts. In other words, instructors need to be pedagogically continuous 'inventors,' who continuously engage in search and research so as to generate better instructional tools--- ones that will both maximize access and success for their students. As instructional strategy of interactive and experiential learning, role-playing learning activities, when designed with a clear educational goal in mind (McSharry, and Jones, 2000), effectively integrated into the learning materials and instructional strategies, and effectively implemented and assessed, can be a powerful tool in helping to make a conceptual change in the mind of students. Although role-playing learning activities take time, they allow for deep learning of these important topics especially among freshman, sophomore students. By introducing living cells and their organelles' structures and functions through role-playing instructional approach we aim to motivate students to develop into intentional learners who are capable to take responsibility for their own learning by continuously adapting to new environment, integrating knowledge from different sources, and continuing learning throughout their lives (AACU 2002 Greater expectations Report). As teachers, instructors, educators, and academic leaders, we need to continuously involve ourselves in researching and searching for better ways on how to know our students, and focus on their tangible learning needs and personal interests. Involved in this endeavor, is learning how to select the most appropriate learning materials needed to teach our students, so that we are here to help them reach their learning potentials and life goals (Cherif, Roze, and Gialamas, 2016; ASCD, 2016). It is imperative for us to stay focused on how to enhance our own instructional skills, strategies, and approach, so as to inspire and motivate students to learn; it is only here that we can contribute to a culture of learning--- so as to make learning success as a desirable personal need and habit during the school years and beyond.

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Appendix 1

Table 3
Individual group questions analysis and account.
(Cited from Cherif, et.al, 2009, p. 350)

	Type of Question or Conditional Statements	Extremely Relevant	Relevant	Less Relevant	Not Relevant	Total of Questions
1.	Why					
2.	How					
3.	What do you think if...?					
4.	Which					
5.	What					
6.	When					
7.	Where					
8.	Is/Are					
	Total of questions and or wondering statements					

Table 4
Tracking the number of question asked by each group of other groups
(Cited from Cherif, Michel, Movahedzadeh, Aron, Adams, and Jedlicka, 2009, p.351)

	Nucleus	Chloroplast	Centrioles	Endoplasmic reticulum	Lysosomes	Golgi apparatus	Mitochondria	Ribosome	Vacuoles	Media Group
Nucleus	X									
Chloroplast		X								
Centrioles			X							
Endoplasmic reticulum				X						
Lysosomes					X					
Golgi apparatus						X				
Mitochondria							X			
Ribosome								X		
Vacuoles									X	
Media Group										X
Total # of questions										

Table 5
Type of Questions or conditional statements and their values for assessment purposes
(Cited from Cherif, Movahedzadeh, Michel, Aron, and Jedlicka, 2011, p.20)

Type of Question	Extremely Relevant			Relevant			Less Relevant			Not Relevant			Total
	# of Questions	Value Per-question	Total Values	# of Questions	Value Per-question	Total Values	# of Questions	Value Per-question	Total Values	# of Questions	Value Per-question	Total Values	
Why How		5			4			3			1		
What do you think if...		4			3			2			1		
Which		3			2			1			0.5		
What When Where		2			1			0.5			0		
Is Are		1			0.5			0			0		
Total													

Appendix 2

McCormack and Yager's (1989) taxonomy for science education as a framework for assessment which could be accomplished as both formative (conducted during instruction) and summative assessment (which conducted at the end to measure what is learned), is a good framework for students achievement, and for assessing students' performance and understanding, as well as for the effectiveness of the activity. Table 10 provide summary of McCormack and Yager's (1989) taxonomy for science education as a framework for assessment.

Table 6
Summary of McCormack and Yager's (1989) Taxonomy for Science Education as a Framework for Assessment

	Domain	Description	Type of Questions That Can be Looked At.
I	**Knowledge Domain**	Students acquire knowledge of the subject, an understanding of relationships between the bodies of knowledge, and give reasons for their approach to solving the problem.	What concepts did students learn and how well did they understand them? How well did the students integrate knowledge from different subject areas? To what extent did students demonstrate the understanding of multiple relationships of various bodies of knowledge? Were the students able to disprove or verify some of the supporting theories used in the role-playing activity? What kind of explanations did students offer for the relationship they observed and understood?
II	**Process Domain -**	Students learn how to collect, organize, and analyze data; develop strategies for building rational arguments and thoughts; state problems and generate valid conclusions; participate in team-work; interpret meaning from the project.	How did members of a given group compile data and information? Was there cooperation in putting the information together? How efficient was each group in presenting and communicating the collected data and information? Was their delivery of statements and arguments smooth and coherent? How well did the students use knowledge meaningfully? Did all members participate in the activity?
III	**Creative Domain**	Students apply creative thinking to the project; cultivate the ability to recognize, evaluate, and use data and information provided by the other parts of the role play; learn to modify a given design as needed.	In what new ways did students use objects and ideas generated during the enactment of the role-playing to enlarge their understanding? How imaginative were students in identifying relevant problems, solutions, and conceptualizing new ideas?
IV	**Attitudinal Domain**	**-** Students learn to listen closely and comprehend the other parts of the role playing. They also learn cooperation in a group performance and self-evaluation.	How persuasive were group members in articulating their positions in order to change the attitudes of the others? How effectively did each group function? Did students' sensitivity and respect for others develop during the process? Did members of a given party demonstrate skills and abilities to resolve conflicts with others constructively? How might each group have functioned more effectively?
V	**Application and Connection Domain**	Students learn to generate alternative approaches, problem-solving strategies, and solutions.	Did they come up with practical and workable solutions? To what extent did the students utilize their personal experiences and collective group understanding in making decisions related to the activity? How well did the students integrate knowledge from different disciplines in problem-solving strategies? How well did the students learn to negotiate constructive solutions to conflicts?