

“A Cellular Encounter”: Constructing the Cell as a Whole System Using Illustrative Models



RECOMMENDATION

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ABSTRACT

A standard part of biology curricula is a project-based assessment of cell structure and function. However, these are often individual assignments that promote little problem-solving or group learning and avoid the subject of organelle chemical interactions. I evaluate a model-based cell project designed to foster group and individual guided inquiry, and review how the project stimulates problem-solving at a cellular system level. Students begin with four organism cell types, label organelles, describe their structures, and affix chemicals produced or needed for each organelle's function. Students simulate cell signaling, cell recognition, and transport of molecules through membranes. After describing the project, I present measures of student participation and a rubric, compare individual versus group work, and highlight future modifications, including alignment with the Next Generation Science Standard of “Structure, Function, and Information Processing.”

Key Words: Biology; guided inquiry; cell model; group and tactile learning; organelles.

○ Project History

In fall 2008, I introduced a cell-modeling project in a middle school science magnet curriculum. As I used it, I sought ways to increase learning and guided inquiry through group and individual discussion and participation and through tactile work. However, to discover the merit in these changes, they had to be tested in the classroom.

The project described here, “A Cellular Encounter,” is titled to avoid confusion and comparisons between it and other cell projects. Topics include cell signaling, membrane permeability, chemical reactions and the organelles in which they occur, and a culminating question comparing the study of the cell to life itself.

Responding to student feedback, peer review of the project with experts, reviews with teaching colleagues, and insight gained from presenting it publicly (see Acknowledgments), I made further changes for 2013,

keeping in mind the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013). For example, the standard for Cell Structure and Function (MS-LS1-2) states the need “to develop and use a model describing functions of a cell as a whole, and ways parts of cells contribute to functions. Emphasis is on the cell functioning as a whole system and the primary role of identified parts of the cell, specifically the nucleus, chloroplasts, mitochondria, cell membrane, and cell wall.”

Here, I report on recent modifications, observations, results, and evolution of the project. I also cover learning approaches, participation, student roles and performance, methods of individual and group assessment, and grading rubrics.

○ Alternatives for Constructing Cell Models & Projects

Depending on the grade one teaches, either a basic or a more advanced lesson describing the structure and function of the cell is required. Many of these lessons include viewing various cells under the microscope and an individual cell project. When I first taught the project, students made a model cell, either plant or animal, from Styrofoam. Once the model was constructed, students labeled cell parts and organelles (an example is at <http://niki319.blogspot.com/2008/02/cell-model.html>).

Another option is to explore cell structure and function through a web quest; one such quest is called “Celebrate Cells” (<http://www.can-do.com/uci/ssi2001/cells.html>). A different approach involves making a “cell city” to explain the functions of organelles and the cell (Grady & Jeanpierre, 2011).

Undergraduate options include a group project in which students select a disease and then explain how it affects the cell and its organelles. For this teacher, project-based cell biology moved students away from a content-only curriculum to one equally focused on

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“communication, leadership, teamwork,” and other skills useful over their lifetime (Wright & Boggs, 2002). It contains detailed rubrics for the cell and organelle’s structure and function, and, in this case, what happens to these entities when hit by disease.

○ Project Design

Four objectives led to the current version of the “Cellular Encounter” model. The first was an attempt to make the cell model, and its design process, more dynamic than the fixed or static versions summarized above. Guided inquiry, a form of active learning (Lee, 2010), was introduced as a means for each student group to design, draft, and place compounds and membrane details on the scale model.

With this approach, the final product was based on a “shared process within the classroom community” (Khourey-Bowers, 2011). The large-scale model of the cell let a group of students comfortably decide where to place chemical compounds, how to direct them toward the correct organelle, and how best to organize their flow through the membrane.

The second objective was for students to understand the cell as a whole, coordinated system, with all organelles supporting the basic characteristics of life (see NGSS Lead States, 2013). Through this model, students are able to see how the reactants and products used in organelle chemical reactions interrelate instead of studying organelles in isolation and as unconnected to each other, and how they serve the needs of the cell.

The third objective was to reinforce prior learning of the fundamental characteristics of life and chemical reactions that occur in a cell. In our science curriculum, the “Cellular Encounter” model comes after the study of chemical reactions, elements, and compounds. Here, students focus on five major elements of life (carbon, hydrogen, nitrogen, oxygen, and iron).

However, if cell science were taught from both curricular plans and the organization of the textbook, students would not have been asked to relate their now prior knowledge of chemical reactions with the actual sites of chemical processes in the cell. In “A Cellular Encounter,” chemical reactions are seen as part of the cell’s “factory,” capable of making ~20,000 compounds.

Consequently, tables found in the student packets reinforced student knowledge of specific chemicals of life needed or produced by the cell. For example, in the initial table, students are asked to determine the roles of carbohydrates, lipids, proteins, nucleotides, nucleic acids, and water and how cell organelles use them. The compounds just listed are then used in Table 1; the third column is

left blank because student groups must determine the organelle(s) housing the respective chemical reaction.

In our curriculum, “A Cellular Encounter” reinforces and coincides with the introduction of the microscope to study asexually reproducing organisms, such as hydra and yeast (budding), bacteria and amoeba (fission), planaria (regeneration), and strawberry (vegetative propagation). To ensure that microscopic images were not an isolated experience, special attention was given to the use of specific organisms (Greene, 2005). This occurred by having students design and draft their models using organisms we have studied, not generic cell types.

The fourth objective was to stimulate individual ownership and participation with rubrics and information that facilitated students finding their own answers, rather than constantly and automatically deferring to the teacher. The specificity of tangible requirements combined with the need for additional communication supported the project’s active learning (Khourey-Bowers, 2011).

○ Implementation

To implement the project, a suitable format for a scale-model cell was needed. It had to provide ample room for interactive group work, foster student-to-student learning, challenge advanced learners, and be suitable for scaffolding for learners with special needs. I experimented with various media, and tested alternatives in other class settings. Eventually, I selected KELVIN DesignGrid Paper (17 × 22 inches; http://www.kelvin.com/mm5/merchant.mvc?Store_Code=k&Screen=PROD&Product_Code=420238), which provides a “drafting” approach while having a designated area for student, name of cell, and teacher approval. The graphing format of the DesignGrid paper (as shown at the product website) gave the students a sense of order and layout that preempted poor planning. However, large graph paper or posterboard could be substituted.

Students deciphered structures and functions of a particular organism’s cell to determine the specific cell assigned to each group (Table 2). Four organisms were selected and divided evenly over eight table groups. Presently, I use cell types from the following organisms for the project’s model: strawberry plant, salmonella bacteria, human cells, and hydra.

In Table 2, the teacher circles specific properties ahead of class that serve as clues about which of an organism’s cells a particular table group will study. This method of determining the organism’s cell, rather than being told from the outset, fosters guided inquiry, group decision-making, and participation. It reinforces knowledge of

Table 1. Organelle compounds and their synthesis.

| Your Cell Needs: | Compounds Needed for Cellular Chemical Reactions | Name the Organelle(s) Where the Compound Is Used or Made |
|------------------------------------|--|--|
| 1. Protein | Amino acids | |
| 2. Solar-derived glucose molecules | Solar energy; H ₂ O; CO ₂ | |
| 3. DNA | Nucleotide molecules | |
| 4. Grow cell wall | Cellulose molecules | |
| 5. Repair cell membrane | Lipids + proteins | |
| 6. Energy from food | Glucose + oxygen | |
| 7. Waste removal | Enzymes + wastes | |

Table 2. Basic properties of specific organisms and their cells used in determining which of four possible organisms belong to a given table group.

| | Unicellular | Multicellular | |
|-------------------------------------|--|--|------|
| | Prokaryote | Eukaryote | |
| | Heterotroph | Autotroph | |
| | Cells are organized; stick together in the right place | Cells are individual or don't "stick together" | |
| Primary form of reproduction | Asexual | Sexual | Both |
| Cell/nuclear division: | Mitosis | Meiosis for sexual reproduction | Both |
| Organelles and DNA: | | | |
| ◦ Nucleus | Present | Absent | |
| ◦ Cell wall | Present | Absent | |
| ◦ Chloroplast | Present | Absent | |
| ◦ Mitochondrion | Present | Absent | |
| ◦ DNA | On chromosomes, inside a nucleus | On chromosomes inside the cell itself, lacking a nucleus | |

each cell's properties by using prior knowledge, notes, textbooks, and group decision making. For this reason, group scores and participation were allocated, even though some school districts are moving away from this type of grading.

Once the organism and cell type were agreed upon by each member, the group sought out their "matching" cell type among the other table groups of four students each. This required students to walk from one table to the next, comparing results from their cellular clues, until the matching cell was found. These matching-cell-type tables then had to communicate with one another to obtain chemical compounds needed by organelles. This ensured that each group of students was up and communicating with its matching cell.

The next step was experimenting on how best to draw the cell and its membrane while allowing for the passage of compounds. Membrane permeability and chemical exchange required special attention to make them tangible to students. Even though the membrane was described as a "gatekeeper" or, more specifically, a fluid mosaic structure, what this means chemically and how such things work remained a mystery for many learners. Therefore, I asked that they construct "channels" for molecular exchanges in their models.

Students visualized channels in the membrane by erasing four small areas of the membrane drawn in pencil. By erasing these bits of the membrane, they could see how channels permeate the membrane and how chemical compounds and waste can be exchanged. This way, by the time students enter high school, they are familiar with the permeability of membranes, what type of compounds pass through it, and how it serves as a gatekeeper. While not explaining the details of protein channels and transport proteins that they learn in high school, this model provides the first step in preparation for later AP Biology studies (see College Board, 2011).

In subsequent modifications, membrane permeability will stress that water enters through channels, whereas carbon dioxide, oxygen, and lipids diffuse directly through the membranes. Sugars, amino

acids, nucleotides, and proteins will use other transport mechanisms, as appropriate for seventh grade.

The structure and function of key organelles were reinforced by the project, as were connections between cellular processes and their functions in a whole cell system. For this reason, the drawing had to be large enough to accommodate eight organelles, to affix appropriate compounds to the organelles, or to depict compounds entering the cell through the membrane.

For each cell model, compounds were lined up to enter or leave the cell, or to be used by particular organelles. This exchange was accomplished by table groups working with their "cellular" partner table. Because the compounds and other cellular needs came from their matching cell, students got up and carried out the process of cellular exchange and communication to obtain and use required compounds.

The molecules or compounds included in the project were sugar, protein, amino acid, oxygen, lipids, water, carbon dioxide, and nucleotides. These compounds were included to reinforce prior lessons on chemical reactions that were now related to the organelles in which they take place. Waste is included in the model as it is removed from the cell by the lysosomes and made ready by intracellular digestion to be released back into the cell in the form of vesicles. Sunlight is included for the chloroplast and enzymes as necessary for many reactions.

Symbols were compiled representing each compound listed above. Students obtained compounds from their matching cell table, cut these out, determined where they entered the membrane, and affixed some of these compounds to organelles for chemical reactions. For example, four symbols for amino acids were cut out, with two flowing through the membrane and two others placed on the ribosome, where they were used to build proteins (see Figure 1).

To demonstrate cell-to-cell communication, recognition, and signaling, students matched unique cell-surface receptor sites with the correct signal molecule. The paper cutouts for the receptors came from one table, but the matching signal molecules had to come from

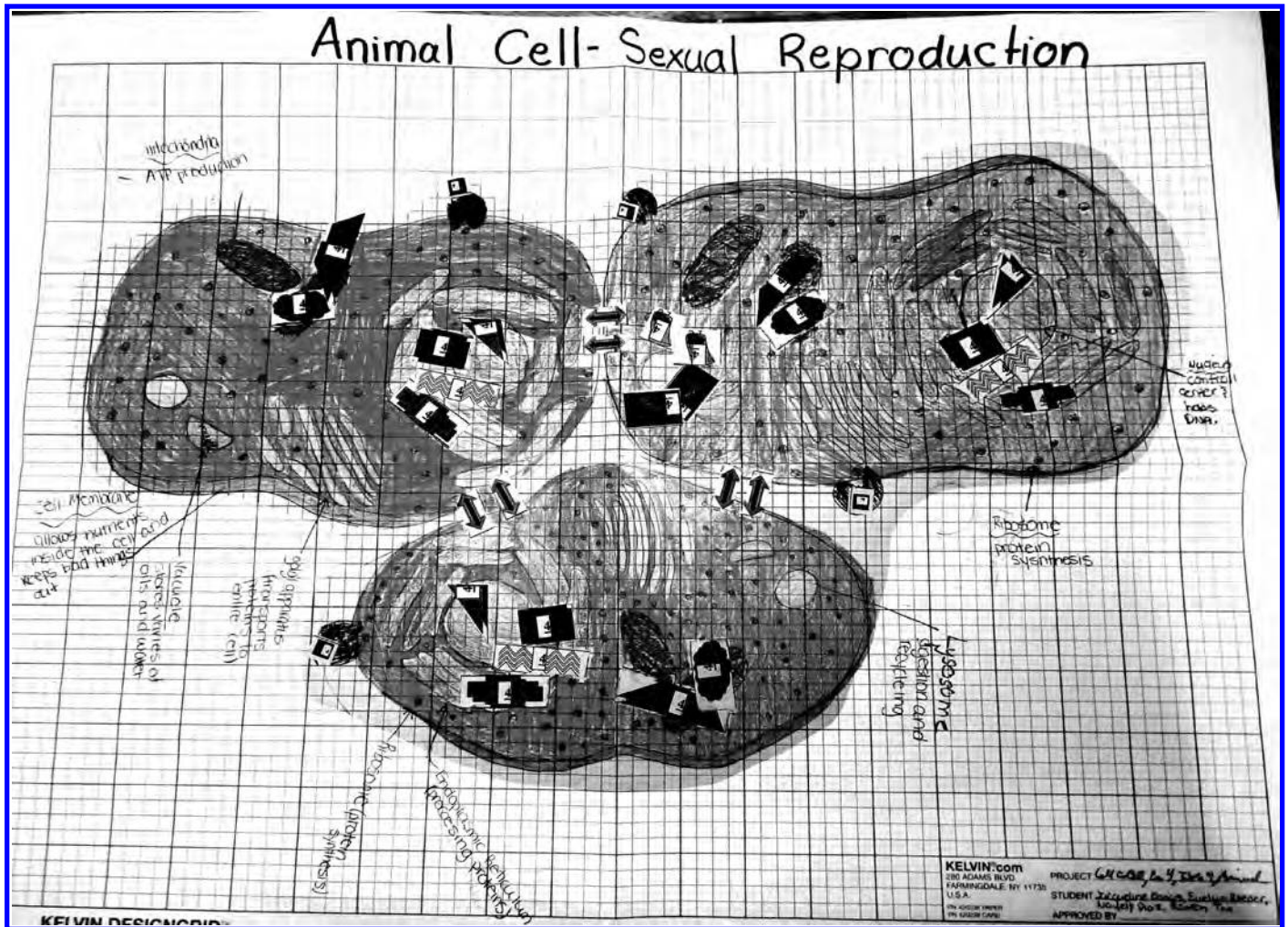


Figure 1. Student-generated model for animal cells.

the cell's companion table, indicating that the students had “acted out” cell communication. Each table group’s scale model had to have four sites, with the correct signal placed on them. Once applied, these were easily seen and graded to ensure that “cell communication” occurred.

○ Assessment Tools

“A Cellular Encounter” became the culminating project for our unit on cells, requiring three full 90-minute classes. Grading of the project was based on the following assessment tools:

1. a group score for the final scale model drawing using a project rubric
2. an individual grade for the project packet, and
3. a grade provided by the teacher for observations of group decision making and individual participation.

○ Grading Rubric

The rubric used to grade student knowledge, performance, and the accuracy of the model is shown in Table 3. The total score for this part of the assessment is 50 points. The second 50 points come

from individual responses to the final, open-ended questions, with points awarded for use of evidence in the answer and completeness of response.

An example of one version of the animal cell model is presented in Figure 1. The range of organelles selected is clear, as are the channels through the membrane. Requisite compound symbols are attached to each organelle or in transit through the membrane. As noted above, further specificity can be added to capture exactly what type of mechanism is used by each specific compound to enter or leave the cell.

As for the nucleus, symbols for nucleic acid molecules were correctly located; however, no further activity with the nucleus was planned for this version of the model. These nucleic acids can be seen attached to the nucleus of the animal cell. This cell model also notes the ATP production occurring from the mitochondrion. There is clearly a place where other symbols could be inserted in the nucleus, such as mRNA molecules making their way to the ribosomes, or DNA itself, and copies to show how and where it is replicated. Although these extra symbols were not included, students were familiar with the nucleus as the cell’s information and control center and were thus able to consider how protein synthesis might occur and how these proteins would be packaged to leave the cell.

Table 3. Rubric for cell model completion, group understanding, and accuracy.

| Guideline | Directions | Student Check-off | Completed as directed (5 points) | Completed with details lacking (3 points) | Incomplete or did not follow directions (0 points) | Total Score (completed by instructor) |
|--|--|-------------------|----------------------------------|---|--|---------------------------------------|
| 1. Identification A | Each student's name and group should be on drawing, neatly and clearly written | | | | | |
| 2. Identification B | Name of organism, type of cell (plant, yeast, animal, bacteria), and mode of reproduction written clearly | | | | | |
| 3. Planning | An overall plan for drawing and labeling should be evident for <i>three cells, each touching the other</i> | | | | | |
| 4. Eight Organelles | Each organelle labeled correctly and explanation of what it does | | | | | |
| 5. Size | Drawing takes up entire paper | | | | | |
| 6. Cell protein signal receptors | 4 per cell, must match "partner" cell drawing | | | | | |
| 7. Plasmodesmata and/or other pathways in membrane | 4 openings in membrane for passage of needed cellular molecules using cut out shapes | | | | | |
| 8. Placement and numbering of cellular chemicals | Correctly numbered molecules must be placed within membrane receptors, affixed to correct organelle, or on gap junctions | | | | | |
| 9. Group participation | Each person helps group tasks | | Full group | 2 or 3 only | 1 or 2 only | |
| 10. Demonstrated understanding | Understanding of the cell, its communication, and its chemical processes | | Complete understanding | Some understanding | Lack of understanding | |
| Overall TOTAL | | | | | | ____/50 |

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○ Analysis & Reflection of Student Work

The project was undertaken by 141 students in five periods. This required 35 table groups with an average of four students per group. I rated the groups on their participation, supportive work habits, and whether or not one or two students were carrying out the work of others.

Approximately 50% of the groups had a score of 5 for participation. The other groups, despite warnings and encouragement, worked consistently with less-than-full participation or with full

participation only at limited times. Despite the other 50% working at less-than-optimal participation, all cell drawings were completed and turned in for grading.

Students were initially presented with two concluding essays. The first asked, "What can cells tell us about life?" The second asked the students to choose one particular organelle, describe its function in a cell, and tell what would happen if the cell did not have this particular organelle. The first question proved much harder to answer than the second. The students had numerous queries, including what is a good answer, what does the question mean, and where should

they look for answers. Because I had experienced these questions before, a number of topics were included for them to consider:

- Six characteristics of life
- Functions and properties of the particular cell type they studied
- How and why cells communicate with each other
- Use of facts and observations from the project as supporting evidence.

Unfortunately, many students just began listing these things without ever addressing or coming back to the actual question. For many students, my comment was that “they had not answered the question.” Even though we studied how and why cells are the fundamental cornerstone of life, for many students, answers to this question were not able to provide an adequate parallel between cells and life.

Those who succeeded with the first essay question did so by connecting many of the themes of cells and life that we had studied or that were brought out in this project. For example, one student wrote that

This communication/interaction is important because these cells work together to keep the organism alive and it is necessary to help the cell and its organism complete its everyday functions. If these cells did not communicate or share with each other they wouldn't be able to function.

A second example states that

Cells tell us why we're able to exist. All cells are able to reproduce through mitosis and meiosis, obtain and use energy, produce waste, grow and develop, and respond to the environment. This shows us that there are certain requirements for life to occur. Also, we know that cells trade compounds such as amino acids and communicate through chemical signals.

In the third year, I had each group draw their cell in draft before moving to the final product. I provided sheets of paper for the draft that were about half the size of the final paper. I asked for them to have me sign off on the draft, and when completed, I handed out the special drafting paper. Insisting on a “first draft” clarified misconceptions that students faced while beginning their scale drawing.

○ Current & Future Modifications

New concluding questions were prepared for 2014 to stimulate inquiry. This change came from reviewing use of such questions in a crayfish dissection. By asking such questions, students were seen to more actively engage with the project (Goldstein & Flynn, 2011). One question was prepared in line with the NGSS Clarification Statement for cell models. This open-ended response question was “How might you explain the making of a protein, beginning with the cell's DNA, until it is ready for transfer through the membrane?” A second question was added to strengthen skills in evidence-based solutions: “What evidence can you present for the connection between the organelle's function and the cell's function, and what would happen if a cell did not have this organelle?” These two questions, coupled with the improved accuracy of the cell model itself,

combined to increase the rigor of the model and to enable analysis guided by NGSS.

To further diversify the project, other cell types can be added that are related to microscopic and cell lessons, such as HeLa cancer cells or cells transformed through recombinant DNA technologies. Next, to strengthen ownership when studying organelles, each student will select one organelle from their cell drawing and write a description of that organelle on a file card in the first person, describing what the organelle does and how it helps the cell. These cards will be glued to the drawing and used for oral presentations.

Students could also be asked to demonstrate cell reproduction asexually, such as by budding, or cell division through mitosis. This would permit duplication of genetic material and show how it separates and cells divide, with format and rubric modified accordingly.

Final Note: Because the entire packet for the model was too lengthy for this publication, please contact me (cohenji@comcast.net) if further information, rubrics, or example assessments are needed.

○ Acknowledgments

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