An Interactive Exercise To Learn Eukaryotic Cell Structure & Organelle Function

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How often have students nodded their heads knowingly during your lectures, only for you to discover moments later—during after-class questions or in office hours—that they did not grasp even the most basic concepts of the topic being taught? This is due, in part, to fundamental differences between teaching and learning (Barr & Tagg 1995). While the standard lecture format used in most institutions focuses on teaching—what the instructor does—there is a need to pay greater attention to learning—hopefully what the students are doing.

Cell biology and biochemistry are the main areas of our own research. An understanding of eukaryotic organelle structure and function is fundamental to a broad range of topics. For example, an understanding of cellular energetics requires a knowledge of mitochondrial structure; a discussion on mitosis and meiosis depends on familiarity with nuclear and cytoskeletal architecture; and a presentation of protein secretion relies on an intuitive topological sense of organelles, including the endoplasmic reticulum and Golgi complex. As researchers in the field of cell biology, we have immersed ourselves in these issues because we find these subjects fascinating. It is understandable yet still frustrating when we see students in Introductory Biology bored or confused by the subject of eukaryotic cell structure and function.

We have used multimedia approaches to generate greater enthusiasm for the subject, even going so far as to make a video on the topic of protein translocation. While students appreciate alternate methods of presentation, these visual aids have not fostered a significantly better understanding or appreciation of the material. Another approach we have adopted is a cooperative learning strategy. In cooperative learning, the students work as a group and learn the material by constructing the answers for themselves, as opposed to being told the answers by the instructor. This active process is a more effective way of learning than the passive process that accompanies note-taking during the standard lecture format. In our experience, students have found that learning through problem solving is fun, better for comprehension and retaining information, and that it increases their appreciation for their own role in the education process (Klionsky 1998). Here we describe a problem-solving exercise useful for covering the topic of eukaryotic cell structure and function, highlighting the dynamic aspects of movement through the cell.

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Cooperative Learning

Substantial evidence shows the value of cooperative learning in improving individual comprehension, as well as for developing skills needed in group interactions (Cooper 1995; Hom & Silvia 1996; Lord 1994; Malacinski & Zell 1995; Martin 1995; Sallee 1979). Despite the advantages to this approach, there can be major difficulties when applying cooperative learning to a large introductory course. Students often feel they are missing out when not being taught through the standard lecture format (Klionsky 1998; Orzechowski 1995). In addition, the physical structure of the large lecture hall makes small group interactions difficult: fixed chairs cannot be rearranged to delineate groups, and even with voices kept low it is difficult to hear with large numbers of people talking at once. To overcome these problems, we instituted a cooperative learning approach for the discussion sections of an Introductory Biological Sciences course. These sections consisted of approximately 24 students each. The sections met weekly during the quarter and we used a problem-solving exercise each week.

The main challenge to a cooperative learning approach in the discussion sections was designing problems that maximized student interactions. Examples of problems and exercises that enhance group interactions can be found in the literature (Bealer & Bealer 1996; Chayoth & Cohen 1996; Rode 1995; Stencel 1995; Stewart 1996). One topic we had not seen covered is eukaryotic organelle structure and function. While this subject area is a significant focus of much current cell biology research, textbooks often present it in a dry manner, typified by a sequential written march through the organelles. Our students view this material as one more set of facts to be memorized, and thus often approach it with a negative attitude. As a result, important concepts such as vesicular movement through a cell or protein targeting are poorly understood. Similarly, there is no appreciation for the dynamic aspects of cellular transport. We have developed a simple exercise that works well for cooperative learning while providing an enjoyable and engaging opportunity for students to learn about cell structure and function.

Procedure

We established cooperative learning groups in the discussion sections at the start of the academic quarter. Each group consisted of four to five students chosen randomly. The purpose of assigning students to a group on a random basis was to ensure the diversity of the groups and to prevent groups that consisted of pre-existing cliques. In our experience, the latter tend to be distracted by socializing and sometimes exclude participation by all members of the group. These groups were maintained throughout the quarter. The discussion sections were held in rooms where the chairs were formed into circles to facilitate direct interaction. The rationale behind the cooperative learning approach was explained the first day. Students were encouraged to interact through simple questions such as their reasons for taking the class, topics they were interested in, and by exchanging their names. Each group was asked to designate a spokesperson who would represent the group to the entire discussion section. The spokesperson changed weekly to ensure everyone an opportunity to speak in front of the section. Because the spokesperson was expected to explain the reasoning behind the group's answers, the students found it beneficial to discuss the answers thoroughly and actively participate in their formulation.

The standard lectures presented to the entire class provided an overview of cell structure and function, and also went into depth on subjects such as protein translocation across membranes. In the discussion section we provided each group with a diagram (Figure 1) and an outline of a eukaryotic cell (Figure 2). Then we presented the following scenario: The group has boarded a bathysphere, been miniaturized to a subcellular size, and injected into a human body (Asimov 1966). The diagram represents the readings from the navigational instruments and sensors on the vessel. They are able to measure qualities of the immediate molecular environment such as the presence of phosphate and carbohydrates, hydrophobicity/hydrophilicity, and the ambient pH. From this information, the students were asked to plot out the course taken by their ship as it entered a single cell and explored the cellular environment. The spokesperson was then asked to explain the group's answer. In particular, all hydrophilic regions had to be mapped according to which intracellular space, that is, which organelle, was being traversed.

Student Responses

Many answers to this problem were possible; the path we used to generate the data is shown in Figure 3. Students consistently gave this exercise high rankings. They enjoyed the opportunity to solve a puzzle while imagining their subcellular journey. This exercise allowed the students to develop their deductive skills while learning about cell structure and function. Significantly, it reinforced the basic chemical principles and qualities comprising the foundation of knowledge necessary to understand all biochemical and macromolecular interactions, by requiring the students to work with these principles first hand.

The students quickly reasoned that the phosphate peaks were due to phospholipid membranes. There were many interpretations, however, as to which membranes were being traversed. The differing responses from group members, and later from spokespersons, ensured a broad coverage of organelles and a lively discussion. For example:

1. The high phosphate at 3 hours was meant to represent nucleic acid in the nucleus. An alternative answer provided by students was that it reflected high ATP levels in a mitochondrion, leading to an unexpected discussion of energetics. As an added twist, the navigational chart reflected the presence of carbohydrate—deoxyribose from the nucleic acid or, in the case of the mitochondrion, ribose from the nucleotide. By presenting two different chart readings, with clear changes in the phosphate to carbohydrate ratio, we could have easily segued into the topic of nucleic acid structure and synthesis.
2. The longer hydrophobic stretch at the 4-hour time point indicated movement through the hydrophobic core of a bilayer parallel to the plane of the membrane. This simple variation in the imaginary ship's path lead to a discussion about the essential nature of the bilayer as being a hydrophobic core with hydrophilic surfaces. An imaginative response given by some students was that this thicker region of hydrophobicity was due to the presence of a double membrane, such as at a contact site between the mitochondrial inner and outer membranes, or perhaps the nuclear envelope. These answers are technically incorrect; movement through two membranes would show additional phosphate peaks, while transport through the proteinaceous translocation channel would reflect a hydrophilic environment. Nonetheless, this answer primed further discussion of cell structure focused on what was now an obvious point of confusion for some students, and, as above, led to an unexpected topic, in this case on mitochondrial protein transport.
3. The low pH was intended to indicate the lumen of an endosome or lysosome. Alternative answers included entry into the mitochondrial intermembrane space where the pH would drop due to proton pumping by the electron transport chain. Again, the navigational chart indicated that the compartment had a high carbohydrate content, suggesting it had received material from the secretory pathway or contained ribose/deoxyribose. It was exhilarating to see the students had grasped cellular energetics sufficiently to propose a low pH in the intermembrane space.
4. A careful count of the number of membrane bilayers revealed that the ship exited the nucleus after the 3-hour time point without crossing the nuclear envelope. This was meant to indicate movement through a nuclear pore. However, one group that placed the ship inside a mitochondrion reasoned that the exit must have occurred through a translocation channel. Significantly, the students understood that the ship was moving through a hydrophilic environment and that could only be accomplished by transit through an aqueous pore or a proteinaceous channel.

Interactive Learning Promotes Greater Participation & Comprehension

The main advantages of implementing an interactive learning style in the discussion sections came from working with a smaller group of students. The

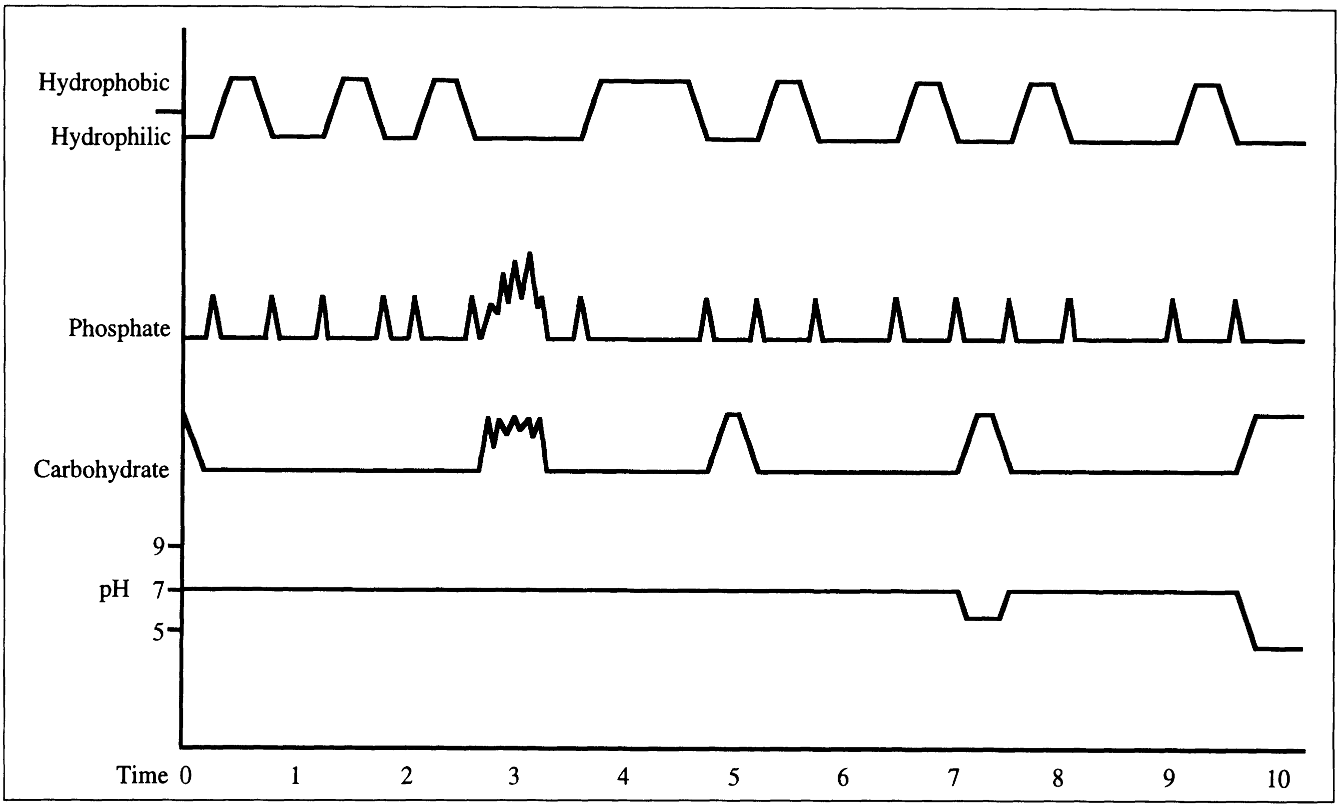

Figure 1. Navigational chart readings from the bathysphere.

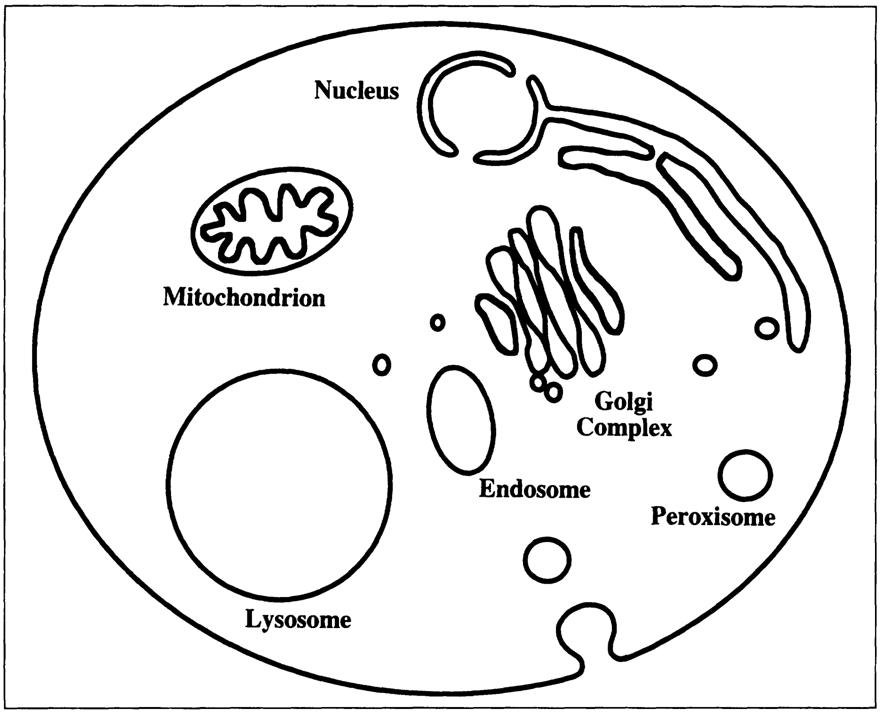

Figure 2. Eukaryotic cell template for students to map out the bathysphere's course.

instructor in the discussion section interacted with each student more closely, allowing us to better understand their individual needs. The time needed for responses was reduced, allowing us to cover more material. Maintaining the same groups throughout the quarter increased their identity as a unit and their individual comfort levels, both of which helped them to overcome inhibitions to speaking in front of the entire section.

The students found the problem-solving approach a useful supplement to the in-class lectures and a major improvement over the standard discussion sections. By avoiding a formal lecture presentation, the discussions were able to proceed in a greater number of directions. Perhaps most importantly, the direction was driven by the needs and interests of the students themselves. This student-driven discussion favored widespread participation because everyone had the opportunity for frequent input and was assured of individual attention.

In contrast to our traditional study section format, we purposely omitted quizzes from the problem-solving discussion sections. In our opinion, the elimination of a direct grading component further enhanced student interaction by eliminating overt competition between students (Malacinski & Zell 1995). Comments from the students included:

> *[The professor used the collaborative learning] section to challenge students with critical thinking. Students had to apply their knowledge of biology and work out an answer in a group setting.*

> *. . . style was posing questions to the students then letting them debate them in groups. This technique drilled the information into us better than any normal section where the students ask the T.A. questions.*

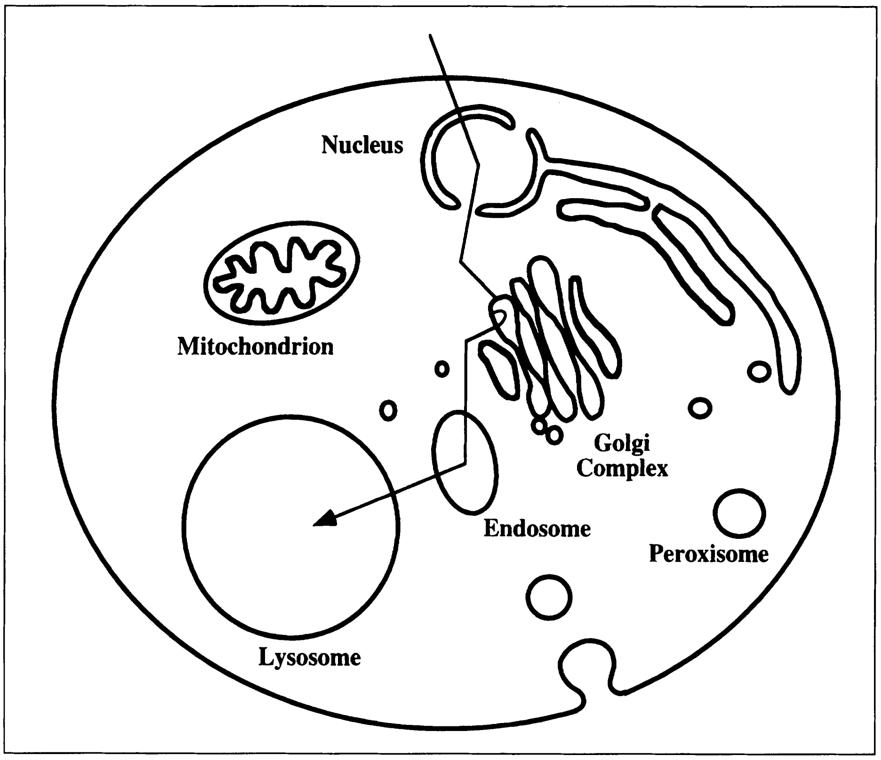

Figure 3. The course of the bathysphere taken through a eukaryotic cell to generate the data in Figure 1. The vessel crossed the plasma membrane and entered the nucleus. Exiting through a nuclear pore, the ship entered a membrane (we chose the trans Golgi complex) and traversed along the hydrophobic core prior to entering the lumen. Exit from the Golgi complex was followed by entry into the endosome and finally the lysosome.

... demanded that his students work together in order to solve the problems presented ... required total student participation.

... allowed the students to take the questions in any direction ... technique worked in bringing all the students into the discussion and allowing every one to be heard.

Lack of participation was never a problem because we were all interested and challenged by the topics and the group questions.

The data or the type of data used in this exercise can be altered to provide numerous variations or to focus on particular regions of the cell. For example, the problem as we have presented it deals exclusively with biochemical parameters. Hence, there is no way to differentiate among different types of proteins with the instrumentation available on the bathysphere. An important area of current research in eukaryotic cell biology, however, is the cytoskeleton. One possible way to introduce the cytoskeleton would be to include instrumentation that measures both speed and direction. The chart recordings could show that movement was both faster and transversely directional when the bathysphere entered a dynein or kinesin "motorized" vesicle attached to a microtubule.

We have found this exercise to be applicable to an Introductory Biology course. In addition, it is extremely useful for engaging the students in group discussions, allowing thorough coverage of cell structure and function, and bringing about a better understanding of transport through the eukaryotic cell than is achieved through individual study or formal lecture presentations. Finally, by customizing the equipment on board the bathysphere, it is possible to explore and integrate many different ideas and techniques from the fields of cell biology, biochemistry, chemistry and physics. This exercise has widespread potential and could be applied to a course of any level from any one of these diverse disciplines.

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