MODEL BASED INQUIRY IN AN INTRODUCTORY MOLECULAR AND CELLULAR BIOLOGY LABORATORY SETTING

BY

ILIANA NICOLE ROSAS

A Thesis Submitted To The Honors College In Partial Fulfillment Of The Bachelors Degree With Honors in MOLECULAR AND CELLULAR BIOLOGY

The University of Arizona Tucson, AZ

MAY 2016

Approved by:

______________________
Dr. Molly Bolger
Department of Molecular and Cellular Biology
Abstract
The cycles of reasoning of “Model Based Inquiry” (MBI) were used to create a lesson plan for undergraduate Molecular and Cellular Biology Laboratories at the University of Arizona. The implementation of this lesson plan was performed in a pilot lab using the unicellular organism Chlamydomonas, and students were audio and video recorded. Researchers paid specific attention to students’ observations and recognition of data patterns, the development of explanatory models to explain these and in accordance with previous knowledge, the use of such models as predictive tools, and the revision or reinvention of models when additional information was given. Some limitation of the implementation of the lesson plan involved low attendance of students, and improper adherence to the lesson plan by the instructor. Even so, there was evidence of Model Based Inquiry performed by students as they investigated Chlamydomonas through microscopes and phototaxis assays.
Introduction

Model based Inquiry

Some educational research scientists have suggested the use of Model Based Inquiry (MBI) to provide students with an opportunity to explore scientific problems more legitimately. Model Based Inquiry or Model Based Reasoning consists of a cyclical method of investigating hypotheses, testing, and revising explanatory models. The purpose of such practices is to move toward allowing students to experience science first hand and achieving understanding of concepts practically. This practice also allows the development of students’ confidence in their hypotheses and willingness to share and defend them. So why is it necessary to find another method of exploring science; a way that allows a ‘more legitimate’ experience? There are difficulties with traditional classroom environments and a teacher – student system that limit the creativity and understanding of students. This includes the limitation of an instructor describing a process or concept as opposed to the student experiencing it for themselves.

According to Stewart et al. when discussing MBI, “Teachers create models that have particular shortcomings in order to prompt discussion by students.” (2009) By allowing students to struggle through actual problems – ones which at times even the instructor does not know the answer to— they must experience the frustration of hypothesizing, revising, and investigating their ideas as well as defending them to other students. In addition, the concepts are better understood which allows for improved recall. In this system, the ‘teacher’ is more of a guide to their process and does not necessarily indicate to students that they are ‘correct’ or not so. The instructor might also facilitate the understanding of some material by asking guiding questions to students in the attempt to steer them from rabbit-hole arguments or guide them when they feel unable to move forward in their thinking. With MBI and student awareness of the cycle of revision of their models as they gain new information, students may become aware that the approaches to pursuing answers and their reasoning are as important as their final model. According to Passmore et al., another benefit of MBI is to present “an authentic context that requires them to make connections and use one set of ideas to lead them in their investigation of new ideas.” Students accomplish this by applying previous knowledge when developing a model, as well as implementing additional knowledge that the instructor holds back at first. As such, students may gain an improved understanding as to the process of answering a scientific question and not solely focus on the conclusion.

A Model Based Inquiry pilot laboratory was created for Molecular and Cellular Biology at the University of Arizona with the purpose of testing the viability of MBI in such labs. The focus of researchers through the lab and during analysis of data, was how students recognized patterns, how they began to develop explanatory models satisfying their previous knowledge, how they might make predictions of what might go wrong in mutant organisms based on their explanatory model, and how they revise their models when exposed to new information.

Passmore’s Practice Framework

Model based inquiry also allows a system that is general enough to be applied to multiple sciences whereas some other approaches might only work for experimental sciences, physical sciences, or a specific type of problem in multiple sciences. Passmore, Stewart, and Cartier claim “The development, use, assessment, and revision of models and related explanations” play “a central role in scientific inquiry and should be a prominent feature of students’ science education.” (Passmore et al. 2005) They created the Practice Framework to help students investigate problems in a manner that they claim to be more realistic as opposed to the traditional
“scientific method”. Students can develop explanations with the data patterns and their models. It is these explanations that are then evaluated. The Practice Framework “emphasizes that scientific understanding is embedded within, and inseparable from, the processes by which explanations and models are created, used, assessed and revised.”

Models allow scientists to organize their explanation of data and then form predictions from that model. Passmore et al. state: “Of particular value is the emphasis on the role of models in: asking questions, recognizing data patterns, constructing explanations for data, and in providing criteria for judging knowledge claims.” (Passmore et al. 2005)

![Diagram showing the cycle of scientific inquiry.](image)

**Figure 1**: A phenomena is observed from which specific data patterns and models can be developed. Explanations encompass both models and data patterns. These explanations are then evaluated for model-data fit, predictive power, consistency with other ideas, and fruitfulness. The explanation allows the development of further questions worth pursuing.

In the Practice Framework, Passmore et al. describe the utility of models as not only to explain phenomena and data patterns, but also as a resource to the development of novel questions, and an organizational system that can be used to test consistency with other ideas. More relevant to students’ pursuit of scientific understanding: “the Practice Framework emphasizes that scientific understanding is embedded within, and inseparable from, the processes by which explanations and models are created, used, assessed and revised.” (Passmore et al. 2005) When students experience the development, revision, and utility of models, they can better understand the scientific process and the potential uncertainties of their concluding model.
More on the Utility of Models to Facilitate Student Scientific Development

According to Richard Lehrer and Leona Schauble, scientific practices consist of diversity in the methods of production, yet scientists’ work involves the building and refining of models. Lehrer et al. argue that there are other important objectives in facilitating the development of new scientists. These include “finding ways to help students understand and appropriate the process of scientific inquiry” which can be accomplished by providing students with moderately difficult questions; “emphasizing the development and use of varying forms of representations and inscriptions” which can be achieved by having class discussions relating the different models students have developed; and “capitalizing on the cyclical nature of modeling” – this can be done by exposing students to more information sequentially and allowing them to investigate and revise their hypotheses. It is also important to make students aware of the process in which they are participating. This might be done by having a class discussion on metacognition in the hope of making students aware of their thinking and reasoning strategies. This would allow them to recognize the cycles of reasoning they perform even when they do not verbalize each step.

The Role of the Instructor

According to Lehrer et al., when students are exploring a question through Model Based Inquiry, the instructor was not “a dispenser of knowledge”, instead “a senior research scientist who mentored students, encouraged new ideas, and participated in and monitored the critiquing process.” (Lehrer et al. 2006) This role allows the students to understand what is occurring through investigation and the collection of evidence instead of getting a ‘correct’ answer and trying to defend it. There are some difficulties in implementing this instructional technique as will be discussed in detail later. One such difficulty is the desire of the instructor for the student to obtain a certain conclusion, and the desire of the student to receive an answer or to have their hypothesis validated by the instructor. As such, the instructor is pressured to provide vindication or simply provide the answer, and the student is robbed of the learning experience that frustration in the pursuit of understanding provides. Another difficulty is the desire to move the class as a whole in a specific direction as has been preplanned. When a significant amount of the laboratory session depends on student hypotheses generation, it can be difficult to steer the class toward a desired conclusion without depriving the students of exploring their hypotheses fully. Usually this is mitigated by the instructor slowly guiding students over the course of several minutes dedicated to students investigating their hypotheses. The instructor can ask questions that students may not have considered to test the coherency and viability of their hypothesis. The instructor may also provide additional information – which can be preplanned – to further guide students toward a predetermined desired conclusion.

The instructor should allow students to explore hypotheses and guide students through challenging questions, but should refrain from providing answers outright.

On the Benefits of Argumentation

Instead of having students all focus on one model as the ‘correct’ one, it is important to emphasize the variety of potentially successful models and the utility of models that highlight different components of a problem under different situations. A pictographic model may better convey what a microscopic system might look like, the relative location of players, and a bit of how each player functions; while a sequential diagram highlights the order of events relative to each other, leaving out the relative locations of players in space and may only describe – but not demonstrate – how these players function.
In the context of this pilot lab, the plan was to have students argue their model with their partner so that the pair could come to a mutual model that satisfied both students – then to defend that model in a classroom of approximately 25 in opposition of other – potentially viable – models. Students were given limited information about an organism, Chlamydomonas that they presumably had no experience with. As such, there were many potentially viable models researchers anticipated students might develop. Within the time frame and resources of the lab, it would not be possible to differentiate between such models, but students could be encouraged to design tests allowing for distinction between various plausible models.

Argumentation in itself would force students to review the strengths of their particular model and also to notice weaknesses. Students might then clarify or modify their model, or could accept their partners’ explanation, or the explanation of another classmate, as more coherent and potentially more viable than theirs. The process would allow students to understand there are varying potentially viable hypotheses especially early in an investigational pursuit. Students also learn to challenge their own explanations and models so that they might fortify them before attempting to defend them to others.

**The Benefit of Model Revision to Identify Inconsistencies**
Lehrer claims “As students refine their models to achieve more consistency and coherence, they often notice unexpected implications of a particular representational choice or an additional feature of the world that their model fails to account for.” (Lehrer et al. 2006) For this reason, students should be allowed time to first develop and then explore and investigate their models and explanations. The incorporation of discussion and argumentation with their peers facilitates the evaluation of a students’ own model as well as that of their partner. This can skillfully be achieved with minimal interference of the instructor. Given even more time and the freedom of testing their model or hypotheses will allow students to realize any other features that their current model did not account for. They can then choose to revise or add to their model. If their experimental results challenge their model, they can investigate the legitimacy of their model and of the experiment to decide which is most trustworthy. Such challenges can lead to a revision of the model or even redevelopment of a model, then further testing in accordance with the cyclical nature Model Based Inquiry.

**The Benefit Of Allowing Students To Investigate A Problem By Creating, Defending, And Revising Their Own Model/Explanation**
Lehrer et al. claim that “When students are routinely asked to invent, use, and critique their own representations developed in the service of solving problems, communicating or persuading others, they learn a variety of useful lessons that are typically left unspoken or are never learned in traditional classrooms” (Lehrer et al. 2006) At the height of these useful lessons would be that there are sometimes several viable representation of a phenomenon – each with their own strengths and weaknesses depending on the specific focus. In addition, the process of verbalizing their explanation to their peers allows students to identify gaps in their reasoning and features that their model fails to explain. Students also gain experience dealing with problems to which they do not immediately know the answer. They can then reason through an answer that is coherent enough to justify verbally and pictographically to their peers – or perhaps realize that their model requires revision or reinvention to justify as coherent. Challenging students with difficult phenomena provides an opportunity with creativity and variability in the potential explanatory models – it is important that the instructor highlight the value of differing models
and (hopefully) the lack of any one model that is all-encompassing in utility. This way, students steer away from focusing on the ‘correct’ answer, and create a model that fits the data patterns, allows formation of predictions, and is revised as needed with new information – but also realize that the similar models of their peers to explain the same phenomena are also useful while they may highlight different observations. In this way, students may begin to realize multiple viable models are customary in science.

The Benefits of MBI in the Assessment of Student Learning
In addition to the benefits of MBI to students, there is also a benefit to instructors. “An emphasis on models tends to render student thinking highly visible to teachers. This visibility greatly facilitates the kind of ongoing informal assessment that should guide instruction.” (Lehrer et al. 2006) Student’s investigation to explain phenomenon and the allowance of time to develop models and communicate their ideas to their peers allows instructors an insight into student understanding. This can inform the instructor how to proceed with further activities or lecture. Challenging students with difficult phenomena to explain allows for multiple viable hypotheses. “In classrooms like this, students also learn that the point of scientific inquiry is not to find the “correct” answer. Instead, they come to see that answers inevitable lead to additional questions, and that deeper study of a phenomenon leads to deeper understanding, not mere repetition.” (Lehrer et al. 2006) So, when a laboratory of approximately 25 students begins their investigation, there are plentiful hypotheses – most of which are potentially viable at this stage. Students can then further investigate, gain new information, and modify their models accordingly. As they get a clearer understanding they ask more specific questions and depending on how many cycles of MBI, might understand the cyclical nature of a scientific pursuit to explain phenomena and understand the value of the process is as much or perhaps more beneficial than supporting any one model or hypothesis. The process of MBI and experience through cycles of reasoning allows students to develop skills they can implement in other investigative pursuits.

Our Investigation
The focus of the MBI project was to investigate the following questions:

1. How might instructors develop a laboratory experience for undergraduate biology students based on the idea of “Model Based Inquiry”?
2. How well will implementation of a laboratory lesson we design align with aspects of “Model Based Inquiry” that have been previously described for K-12 students?

In order to address these questions, a Model Based Inquiry lesson was designed for introductory Molecular and Cellular Biology laboratories at the University of Arizona.

Methods
What was Planned
The pilot lab was constructed with the goals of investigating MBI in the introductory Molecular and Cellular Biology laboratory setting, and to determine the viability of this lab topic and techniques for future MCB laboratories. The plan was to audio and video record consenting students currently in their 12th week of a 14 week semester for MCB lab during the pilot lab. The pilot was designed around the organism Chlamydomonas – a unicellular flagellate of green algae.
At the start of lab, the instructor would place the test tubes of Chlamydomonas in a box with only a small slit near the bottom running the length of the box. This slit would be exposed to a photosynthetic light. Because Chlamydomonas can phototax, the wild type would be able to move toward the light in the solution. The test tubes would sit in the box for 10-15 minutes while students look through microscopes.

First, students would be provided with some basic information on the organism including that Chlamydomonas is a unicellular form of green algae, it is eukaryotic, it is found in stagnant water, damp soil, freshwater, or seawater, and that it is capable of photosynthesis. Next, the students would observe several test tubes containing the wild type Chlamydomonas along with several mutants and notice the shaken test tubes looked indistinguishable for the most part. They would also be instructed to “Examine how your tube of Chlamydomonas reacts to light. Place your tube of green Chlamy into the dark box next to the light source. When you return to your bench (after at least 10 min.) observe the tube. Write an possible explanation for what you see.” So students observe phenomena and begin to recognize patterns. They then begin to create an explanatory model of their observations and data patterns.

Students were also instructed – on the same Microsoft PowerPoint slide – to “View Chlamydomonas under the microscope. Take a look at the live Chlamy that is under one of the lower powered microscopes. Observe the dead Chlamy that is under the high-powered microscope. Draw a picture of one Chlamy cell, including the subcellular structures that you see.” Then, students would observe the organisms under a microscope and see the Chlamydomonas’ motility and possibly some features. The students would then be asked to draw a picture of what they thought the organism looked like. Figure 2 demonstrates the slide and prompts based on the Model Based Inquiry plan.

---

**Step 1: Investigating Chlamydomonas**

- **Examine how your tube of Chlamydomonas reacts to light.**
  - Place your tube of green Chlamy into the dark box next to the light source.
  - When you return to your bench (after at least 10 min.) observe the tube. Write an possible explanation for what you see.

- **View Chlamydomonas under the microscope.**
  - Take a look at the live Chlamy that is under one of the lower powered microscopes.
  - Observe the dead Chlamy that is under the high powered microscope. Draw a picture of one Chlamy cell, including the subcellular structures that you see.

*Figure 2: The slide prompting the investigation into the Chlamydomonas organism.*
The next slide asked the students “Why is there a green band? Your ideas?” and the following question on the worksheet they were provided “What is a possible explanation for what you observed in these investigations? Write your ideas.” Next, students would be given some more information about the organism and shown some high-powered microscope videos of the organism moving. The following slide prompted students to “Make a Model Draw a picture to explain how you think Chlamydomonas performs phototaxis (swimming towards light).” At this point, students organize their knowledge, their observations, and their data pattern recognition to create an explanatory model.

Next, the instructor would tie the mutant observations for the test tubes and the low-powered microscope viewing of the mutants to genetics and ask “How do you think researchers obtain these mutants?”

Now, using their model, students would be asked to test Chlamydomonas mutants. They were prompted to make a prediction of “why a mutant might not be able to perform phototaxis. Explain how a change in the DNA could result in this change to what the organism can do.” The goal here was to have students implement their model to create predictions of the mutant organisms. Students would then observe the same phototaxis assay as they had before with the wild type. The next prompt was “observed each live mutant under the low-power microscope.” Students could then combine these observations with their model, converse with their partner and decide which model they would pursue – including a possible newly developed model or a combination of the previous two – and create a poster. Here, their argumentation and communication skills are tested as students defend their model to their partner. This poster and the model the students develop would then be shared with the class (approximately 25 students) to observe the varying models explaining the same phenomenon and discussing the strengths or weaknesses of each model. In addition, students could deliberate on the possible applications for different models based on particular aspects of the organism they highlight.

The closing discussion was then designed to first address the mutants and their differences, and transition into a discussion of genetics and how those mutants may have arisen.

What Happened

Only four students attended the first pilot lab and so two pairs were formed to work together. In addition, the assay was prepared with all tubes – including wild type and mutants together with no particular emphasis on observations before the tubes were subjected to the box with a slit for light. Also, the box assay was prepared by Iliana Rosas, assisting and observing the lab; it was not performed by students. The microscope viewing was also conducted all at once instead of the wild-type only first followed by mutants later. This organization prevented students from having multiple cycles and referencing their model to explain a phenomena, then predict future results. The small turnout contributed in part to the rushed beginning portion of the lab as it created large amounts of time that students had nothing to do where the instructor anticipated waiting on a classroom of students to view only a few microscopes. The lack of attendance also did not allow poster sharing at the end of lab because only one of the pairs stayed long enough to draw a poster. In addition, the pair that stayed until the end did not select only one model, each student elected to maintain their explanation and draw independent poster. This lack of consensus may have resulted because these students did not know each other and did not feel comfortable being confrontational with another student about their model.
**Data Collection**
**The Focus of Researchers**

First, lesson plans were collected in the form of PowerPoint slides and worksheets that were intended for students. Second, students from the Introductory Molecular and Cellular Biology Laboratory course (MCB 181) were recruited for a “pilot lab” via emails from their instructor and the research team and a PowerPoint slide added to the weekly lab slides. Five students volunteered to attend the pilot lab section for no compensation and four attended. Each student consented to participation in this research, as approved by the UA IRB. During the pilot lab, researcher collected video of the lesson and audio from the instructor and the student groups as they worked collaboratively. Copies of student worksheets and posters were also collected.

**Data Analysis**

Analysis focused first on determining which aspects of MBI were present in the lesson plan, as shown in the collected materials. Next, analysis of the pilot lab data focused primarily on what students did during the lab. Thereafter, transcripts were made of group audio recordings. Analysis of transcripts consisted of iterative reading and discussion between the author and her mentor, who was also the instructor for the pilot lab. The intent of the analysis was to examine how well MBI principles were carried out in the pilot lab and to identify instances of MBI cycles.

While reviewing the transcript, Lehrer provides a guideline of what to look for in observing the students and instructor during MBI; Lehrer claims the focus of researchers was “how the research groups made sense of the data they generated, how they persuaded classmates about the utility of their models, and how they came eventually to converge on consensually accepted procedures for deciding what counted as a good explanation and a definitive solution to a problem.” (Lehrer et al. 2006) This description served as a guide for the focus of the pilot lab project. The goal was to audio and video record students through the pilot lab session then evaluate how the students used their models, how they defended their models to their partner, and how the pair came to an eventual conclusion that satisfied both individuals. In actuality, the turnout of students was far less than anticipated and the pair of students that most data analysis comes from chose not to decide on a mutual explanation, but instead to maintain two separate models explaining the phenomenon.

**Results**

**Research Question 1: How might instructors develop a laboratory experience for undergraduate biology students based on the idea of “Model Based Inquiry”?**

To address this question, we collaborated on design of an instructional sequence that would meet the goals of the introductory Molecular and Cellular Biology laboratory course and would be based on a “Model Based Inquiry” framework. Details of the lesson plan are explained in detail in the methods section, provided in the Appendix, and outlined below. Table 1 summarizes the lesson plan components and the corresponding goal(s) regarding MBI. The key features each major element of the plan were designed for involve observation of a phenomena and recognition of data patterns, the creation of an explanatory model, the use of that model to inform predictions, the integration of new information and new patterns to inform model revision or reinvention, and the development of further questions from the MBI cyclical process. The original design of the lab was to create a potentially viable MBI process in the MCB labs at the
University of Arizona, at a level that was sufficiently challenging to students for the generation of creative hypotheses. Despite the limitation of the pilot lab having so few students as opposed to an average MCB lab, adherence to the plan would have provided students with MBI experience and researchers with data as to student’s experience with MBI.

Table one lists the expectation in MBI for each step in the lesson plan. Firstly, the students were provided with phenomena that they could begin to make observations and possibly notice patterns from. Students were then prompted with both PowerPoint slides and with their worksheets to develop an image “like in a textbook” that explain their observations. After doing so, students were provided with additional information about the organism and had the option of then revising their model if they felt the need. The plan then provided students the opportunity to put their model to practice and use it to form predictions of what could be going wrong in the mutant organisms to cause the failure of phototaxis. Students can then justify their model to their peers, first in groups, then in front of the class. In doing so, students might realize the topics that their model falls short in, and argue for the strengths of their model in comparison to that of others.

Table 1: Lesson Plan Outline and MBI purpose

<table>
<thead>
<tr>
<th>Plan</th>
<th>Model Based Inquiry</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Chlamydomonas phototaxis demonstration</td>
<td>Initial observation of phenomena and pattern recognition</td>
</tr>
<tr>
<td>2. View WT organism under microscope</td>
<td>Initial observation of phenomena and pattern recognition</td>
</tr>
<tr>
<td>3. First explanatory drawing following phototaxis demonstration</td>
<td>Development of explanation – first model – to account for observations and data patterns</td>
</tr>
<tr>
<td>4. Showing videos of the organism moving and explain anatomy</td>
<td>Students gain further information that will inform their model – they then revise or reinvent their model</td>
</tr>
<tr>
<td>5. Predict what might cause mutants not to perform phototaxis</td>
<td>Students use their model and understanding of the wild type to predict what could go wrong in mutants</td>
</tr>
<tr>
<td>6. Draw mutants</td>
<td>Students expand their model to now include potential mutants</td>
</tr>
<tr>
<td>7. Discuss their model to their partners and come to a consensus on which they will present to the class</td>
<td>On a small scale, students practice argumentation to identify the strengths and weaknesses of each model</td>
</tr>
<tr>
<td>8. Hold a class discussion of the various viable models having students argue for them and others challenge them</td>
<td>Argumentation on a larger scale and the identification of multiple potentially viable hypotheses.</td>
</tr>
</tbody>
</table>

Table 1: Table 1 demonstrates the purpose for each of the major steps designed for this MBI Pilot Lab.

Research Question 2: How well will implementation of a laboratory lesson we design align with aspects of “Model Based Inquiry” that have been previously described for K-12 students?
After analysis of the lesson as planned, we turned to data collected during the pilot lab to answer our second research question. Because only four students volunteered to participate in the pilot lab, some aspects of the lesson were difficult to carry out. However, we were able to find evidence for several aspects of “Model Based Inquiry”

### What Happened

#### Groups Made Sense of Data

The groups were initially provided with a view of the Wild Type, Mutant 1, and Mutant 2 under a microscope and also conducted a phototaxis assay. From this, they were asked to construct a single explanatory model similar to one in a textbook to explain their observations. They could speak to their partner and reason through their observations. Figure 3 demonstrates the question prompting an explanatory drawing for students’ observations, and the representation one of the students provided.

![Figure 3: Students were asked to draw an explanatory picture to explain their observations with the phototaxis assay. The plan was to only discuss the wild type at this point, however students had also seen the mutants in the enacted pilot lab.](image)

#### Investigative Pursuit To Explain Phenomenon

Students were tasked to continually investigate Chlamydomonas and revise their models. After creating their first explanatory drawing, they were given more information about the organism and had to draw models to explain the two mutants based on their observations. Initially, students focused on creating models that explained the entire system of the phototaxis assay. This resulted in less emphasis being placed on the organism and the details or parts of the organism that would cause the sensing, signaling, and movement toward light. Students then attempted to incorporate the information from the microscopes and the phototaxis assay to create a model and explain what they say. It became evident in this discussion that the students had a limited knowledge of the key players: the eye spot in particular. When attempting to make sense of the phenomena, Student 1 discusses chloroplasts instead of eye spots as the receptor of
exterior environmental information: “And what is gonna ‘like’ the light is like the actual organism because it has like chloroplasts in it like we talked about umm and it’ll need the light to do photosynthesis – ummm to be able to live.” (Line 103) While the underlying knowledge wasn’t there, and this student did not change this perception even after the discussion of the organism and it’s major parts (the eye spot and the flagella – signaling was not discussed), this student still reasoned through the observations and explained them adequately with no fault in logic. This laboratory was sufficiently difficult for these few introductory Molecular and Cellular Biology students so the answer was not obvious and students could apply their limited knowledge and understanding of photosynthesis and fundamental biology topics to create a viable explanation. If implemented in the planned manner, it may be successful in creating cycles of reasoning as well.

**Limited Argumentation**

Students in this pilot lab were unfamiliar with each other and in a smaller lab population than customary in undergraduate introductory biology labs. There were only four students present in the pilot lab while typical labs have about 25 students. The combination of lack of familiarity with each other, the instructor, and a different lab environment likely contributed to their lack of significant argumentation. Instead, the students would each state their hypotheses and sometimes ask clarifying questions to each other, but ultimately maintain their individual hypotheses with no group consensus. In the transcript starting on line 235, there’s a bit of hesitation while the students communicate what they are drawing because they have not selected a single hypothesis for each mutant as a group. Line 261, Student 2 states: “So we’re both doing the wild type but we’re doing like different hypotheses”. In addition to the lack of familiarity with each other, both students felt their hypothesis – and presumably that of their partner’s – was potentially viable.

**Multiple Hypotheses For A Single Mutant**

On a couple occasions a student would develop multiple hypotheses for a single mutant and maintain the two hypotheses because they could not distinguish between the two with the data they had. This coincides with Lehrer’s desire to have students recognize the utility of differing models to represent the same information. The difference is that there are two models matching the same data for the student and Lehrer was describing one phenomenon being expressed by models that highlight different components of the phenomenon. In lines 192-196, Student 2 explains their hypotheses for Mutant 1: “… something goes wrong in the protein; A protein in either the eyespot or the flagella. So, maybe the eye spot won’t be able to see certain – “see” in quotes – “see” certain wavelengths and umm… that could cause like only a slightly functional phototaxis.” Student 4 follows with: “I was actually thinking maybe the reason is for the chlorophyll… because – I’m not sure but like, I think cause they can like absorb the light and then like the light detecting and then so we know that they can swim” with a clarification from Dr. Bolger: “Okay so somehow the chlorophyll because they’re the thing that needs the light it’s what might be detecting it?” (198-202) Later Student 4 clarifies with: “so like so one mutant like so it can’t function anymore [IA] organelle can’t absorb any light this mean they don’t know there’s light.”(290-292) Also, student 2 discusses in more detail a possible hypothesis for the observation of the lack of movement toward light: “I said there could have been a mutation in one of the proteins in the eye spot that allows them to see certain wavelengths of light. And, like, almost like the lab we did earlier about people being color blind. Like they can only see certain wavelengths so they only see like certain colors.” (280-284)
After a few collaborative discussions, students seemed to gain a bit of confidence with their partner. Through these discussions on some occasions, researchers noticed incidences of generative thinking. As students were discussing what they would draw, Student 2 stated, “Oh, wait, could it have multiple eye spots?” (342) So, as the students were reasoning through their hypothesis in preparation to draw, they began to experience some generative thinking.

Line 283 shows the student’s explicitly referencing the lab from the week prior to the pilot lab: “And, like, almost like the lab we did earlier about people being color blind. Like they can only see certain wavelengths so they only see like certain colors.” The reference was to a lab involving rhodopsin and how those who are colorblind have only one or two varieties of rhodopsin instead of the usual three. In this lab, the mutations were discussed as well; the student references the possible change in the protein here, but does not relate that to a possible gene mutation or deletion. This suggests that for more specific and informed hypothesis generation, it is necessary to have such a lab later in the semester so that students have had fundamental classes on genetics and a few more relatable labs such as those on photosynthesis and light detection.

The multiple hypotheses suggest the problem was sufficiently difficult, but further testing of their explanations would be necessary to attempt to distinguish between hypotheses. In order to implement this lab into future MCB labs, it may be necessary to incorporate another assay of experiment that would allow distinguishment. This may ease students frustrations when they have multiple viable models and also would allow them more cycles of reasoning.

When the time came for students to draw their final model on a poster, the remaining students elected to pursue their own models and depict them instead of coming to a consensus. Figure 4 demonstrates an example of the student posters to explain what is going wrong in the mutant Chlamydomonas. The student lists: “eye spot does not recognize light correctly”, and “multiple eye spots (does not know where to move)”.
Figure 4: The poster drawn by a student at the end of lab to explain two potential hypotheses this student had for Mutant 1. The hypotheses were both different from that of the partner who elected to draw their own model. The student indicates the light source and the Chlamydomonas organism; indicates the eye spot(s) and the two possible hypotheses for Mutant 1.

Lack Of Tests
Among the limitations for the lab was that students were unable to directly test their models for more information. This was due, in part, to resources available; also, to prepare for the lab, it would be necessary to predict what the students would hypothesize and what they would want to test. The greatest contributor to the lack of tests was actually the implementation of the lab, which was quite different from the designed lab. As a result the students had less opportunity for cycles of reasoning than anticipated when designing the pilot. For future implementation, it would be necessary to properly administer the lab to maximize cycles of MBI where students could hypothesize, investigate the hypothesis, and revise their model accordingly.

Lack Of Public Defense Of Model
Another limitation with the small population of the pilot lab was that the groups were unable to defend the model they had devised for the two mutants to the class. This was done to an extent with the group containing students 2 and 4 defending their models to the instructor, however the other group had left at the time. In addition, the pilot was designed so the students would first individually develop a model to assist in explaining the observed phenomena and then sharing their idea with their partner so they could come to a consensus. This did not occur; instead the students each listed their own ideas and asked each other clarifying questions, but elected to each maintain their own explanation. The low attendance also prevented a great variety in the number
of viable hypotheses that was anticipated when planning the pilot. As a result, the amount of defense the students had to do was limited only to the questions of their partner and of the instructor.

Discussion

Research Question 1: How might instructors develop a laboratory experience for undergraduate biology students based on the idea of “Model Based Inquiry”?

The design of the lab did imply that success with MBI would be possible. Students were tasked with an organism, Chlamydomonas, with which they had not prior experience; and they were tasked with a process, phototaxis, that they’d not discussed in class. Even so, they were nearing the end of the semester for MCB and had sufficient preparation with fundamental biological topics to create hypotheses of their observations. The lesson plan developed primarily involved PowerPoint slides and a worksheet to prompt the students through their investigation of the organism and the development of their models. They would then be provided with more information and opportunities to revise or reinvent their models. In addition, students would be working in groups and thus practice argumentation on a small scale before coming to a consensus on a model that explains all their observations to that point. At such a time, students would then justify their model and the reasoning behind it to their peers as a class. The design of the lab was sufficiently challenging for undergraduate biology students in the later part of the semester. It allowed for multiple opportunities to revise their model, allowed students to revise their model, and allowed them to form predictions from said model.

Research Question 2: How well will implementation of a laboratory lesson we design align with aspects of “Model Based Inquiry” that have been previously described for K-12 students?

The implementation of the MBI cycles of reasoning does not appear limited by the age or stage of students. Instead, the challenge lies with instructors to develop a topic and investigational pursuit that is sufficiently challenging to students whatever their level. There is the anticipated limitation of the difference in knowledge and experience among students taking introductory Molecular and Cellular Biology courses at the University of Arizona, however. There was evidence of the elements of MBI that students accomplished including the recognition of patterns – what each population of Chlamydomonas did (sink, move to the light, or remain suspended with no light preference), the organization of data patterns and observations into an explanatory model, the model-data fit discussion for what could be causing the observations in the mutants, and the investigation of models’ coherence through discussion with a peer. The design of MBI using this lesson plan appears viable with the population of undergraduates at the University of Arizona; the success thus depends upon proper implementation, and a larger number of students.

MBI in MCB Laboratories

The utility of Model Based Inquiry is apparent in research done at many levels of education. The success is attributed to the cycles of reasoning that organize the investigative pursuit to explain phenomena. MBI allows students to explore their own ideas and gain confidence in expressing them, as well as provides them with experience in testing the viability of their hypotheses and revising or rejecting and redeveloping hypotheses. These are the skill of scientist that can be broadly applied to most disciplines. As Passmore states, “Requiring students to use their knowledge to construct explanations for natural phenomena is quite different from
asking them to simply repeat the ideas back on a test.” (Passmore et al. 2005) This method also improves the interest level of students in science and reduces the intimidation science often causes as they experience it for themselves. In addition, they achieve an improved understanding because MBI “has a conceptual and explanatory coherence, rather than being a grab bag of unrelated facts to be committed to memory.” (Passmore et al. 2005) Students begin to understand science as a process and an investigative pursuit where there are sometimes multiple viable explanations for hypotheses.

There are certain challenges with the design of Model Based Inquiry for practical purposes in an introductory undergraduate laboratory. Primarily, MBI leaves much of the direction of the lab open to students and the instructor provides only guidance. This results in much variability between each individual lab section because students will vary in their previous knowledge and amount of generative thinking, as well as the models they develop and desire to test. MBI requires cycles to investigate and fortify or redesign models – this requires the preparation of potential test students may desire in advance. In addition, the varying amounts of knowledge will cause the question to be too difficult for some and too easy for others. Stewart et al. state, “What is key is for the problem to be complex enough so that students have experiences that allow them to understand the rigors of scientific modeling.” (2009) Many instructors may also find the design of the lab challenging to implement since it is student led and instructor guided.

The instructor also faces challenges of implementation when conversing with students. The instructor feels pressured to offer students answers and the student wants to be given the answer; so, for successful implementation of MBI in MCB labs, it is necessary to refrain from giving outright answers, and instead guiding students along the right path. This allows some structure for the instructor, and allows the students some freedom of investigation as well.

**Pilot Design Analysis**

The original design of the lab with what was planned is a potentially viable way to have students experience MBI in an introductory biology setting with simple tools. In practice, there would be more students available for the lab – even with so few, it may have been best to simply wait out the time for implementation of the plan. Also, all of the data collection occurred before students drew the organism for the first time, and their observations of the mutants were irrelevant at the time and thus, when we later discussed what could be going wrong in the mutants, students could not remember their observations and those they had written did not pertain to the questions we asked. In addition, the laboratory prep staff cleaned up to prepare for a lab that followed and the students were unable to go back and have a second look at the mutants.

The lab was designed for a classroom of approximately 25 students. As such, the plan was difficult to enact with only 4 and only 2 students remaining in the poster development. The students were encouraged – but not forced – to come up with a mutual model that satisfied both students. As a result, the student each designed their own poster and explained the observations independently. They each considered the others’ as viable, but maintained their own. These students were in an unusual setting with instructors and students they did not know and had a classroom substantially smaller – and thus probably more stressful – than their usual MCB lab. All these contributed to a lab very different that what was planned and – most importantly – one with limited information on the use of MBI in a laboratory setting. However, the request of the students to view the microscopes again after they had developed and discussed their models and
began applying them to what could be going wrong in the mutants may be a slight indication of a cycle of reasoning where they attempted to investigate their model and possibly revise it.

While the implementation of the pilot lab was not according to the lesson plan, students did experience and achieve some of the goals of MBI. As a result, this lab may be viable for use in MCB introductory laboratories with some revision. Revision would include the proper implementation of the original lesson plan and some additional assays or experiments that would allow students to further explore possible hypotheses as they narrow their focus with each additional piece of information. The lab would also reinforce the knowledge gained up to that point in the semester and would best be implemented at a later point when students have discussed photosynthesis, DNA, transcription, translation, and perhaps some discussion of receptors or signaling as well to facilitate thoughtful development of hypotheses during the lab.

“Modeling promotes students’ opportunities to craft their identities as inventors of models, not simply as appliers of models from the textbook. They come to believe in their capability to make contributions that are novel, rather than merely to replicate contributions made earlier by others. Finally students come to understand a little more about the nature of science – in particular, how those conventionally accepted scientific models were built in the first place: via a process much like the one they engaged in.” (Lehrer et al. 2006)

Ultimately, this lab may be viable for undergraduate biology laboratories, but it would require practice in classroom management and a skillful adherence to the planned series of events – although much of the lab is student driven.
References


Appendix

Group 1 Transcript

[00:27] Student 2: Say it's just moving towards the light because it probably enhances like it making its own energy
Student 4: [IA] why they go and then no more
Student 2: Yeah
Student 4: It's kind of weird [IA] more green stuff?
Student 2: Mmhmm
Student 4: what is it called?
Student 2: Clumping? Oh, the organism?
Student 4: Ohh, yes, thank you
Student 2: I'm just saying it's moving towards the light source, because they kind of clumped at the bottom and that's where the light was
Student 4: Oh.
Student 2: Yeah. I'm guessing that might have helped with it photosynthesizing
Student 4: This mean they all like to go toward the light when they- when they- when they take it out
Student 2: When they take it out
Student 4: The light everywhere
Student 2: Yeah, exactly

Recording 2a

Student 1: I think that - Umm she talked a little bit about it having - umm... chloroplasts
Student 3: Mmhmm
Student 1: Which reminds me of like photosynthesis and like that involves light. So I think that the like organisms in there like they understand like -
Student 3: They want the light
Student 1: - yeah they want the light
Student 3: so they go down
Student 1: Yeah so they like will congregate there but then like when we took them out they like we could watch them like immediately say like 'oh, now there's light everywhere now we can go back... to the umm'...
Student 3: Yeah
Student 1: You know... So
Student 3: That makes sense

[2:11] Student 2: Wait is the- is this already on? (yeah) Okay.
I think Sam - i think sam turned it on. You guys feel like you're under the microscope huh?
[laugh] Yeah yeah you can stop it if you're not talking anymore. So I want to hear what you think - uhh why kind of why - how do you explain what you saw including the green kind of band at the end.
Student 2: Uh I said that like [IA] photosynthesis. And then when you took it out it started moving around because there were other sources of light other than [IA]

Dr. B: Dr. Bolger: Did you guys think that? They seemed to be moving to the light somehow.
Okay and yeah, right. So when you have light everywhere they kind of went up. So cause some-
like- 'cause sometimes you see some just kind of clumped at the bottom right settling out, but I don't think - i mean - how would it look different in this assay if it was just falling? would what be different? (IA) It wouldn't swim back up. That's true umm so we actually here's a little bit - [IA] I kind of held back on you a little bit more- what you guys just described is phototaxis. You may have heard of chemotaxis? or moving toward chemicals. Phototaxis is moving toward light.
And this is chlamydomonas under the microscope. It has what we call an eye spot - that red structure that you can see - hopefully, maybe. And it has two flagella. And I'm actually gonna show you what it looks like in the video. Let's watch a little video - YouTube is my favorite tool - of what they look like swimming. And I think one of these is - can you turn the lights - no we just need the lights out 'cause it's an old video. So this should be with a high speed camera so we can actually see the flagellar movement. Do you see that? So they're like - so kind of not your ordinary bacterial flagella which goes like [visual demonstration] these guys do like what I call the swimming thing. But you can't see that without the high speed camera I think and probably they also umm.. did something to slow down the motion like put some gel in there or something. Umm the other one is umm here... let's watch one more. So this one is not as umm... close up as the flagella - it"s a newer microscope so you can actually see the guy moving around. So sometimes he's moving forward and then sometimes he'll just suddenly start to spin and you can see all that green stuff in there like that you could see under the high powered scope. So these guys are kind of interesting I think. And remember they're a unicellular organism doing all this. Umm... let's see. And you can show your friends on YouTube [laugh] the clamymdomonas you learned about in lab. So let's go to umm.. so what I want you guys to do 'cause we're practicing with this idea of drawing models so you kind of all figured out that they're moving to the light - and we call that phototaxis and you know a little about the structures they have - just a little bit. So what I wanted you to do - you can talk to each other but maybe everyone can draw their own - draw a picture - not just a picture of what you saw under the microscope - but a picture to explain your hypotheses. Now, based on a little knowledge at this point; but what's your hypotheses about how chlamydomonas does this whole phototaxis thing - and if you had to draw a picture - like think of a text book. And you know there's all those diagrams in there, and they kind of explain the process, right? So think about a guess as to how you think this might happen and just draw a picture that you thi- and you can help each other if you feel a little unconfident of the draw a picture of something you don't know about [laugh] but you know them now- you've seen them.

Recording 2b

Student 1: [00:56] Yeah. Looks good. I thought that like - or - kind of like what we watched on the video
Student 3: yeah
Student 1: yeah the flagella like - and this just kind of like how we swim like we use our arms
Student 3: Yeah exactly
Student 1: and we're like a multicellular organism and like this is not. So...
Student 3: What's that called? The swivel thing?
Student 1: I thought it was - the... the... [Dr. Bolger: The flagella?] the flagellum. We call them hairs; we can call them flagellum? It doesn't matter?

Dr. B: Yeah, yeah. I mean, we know what you're talking about when you use both words in here [laugh] You might be [IA] Usually [laugh]

[2:50]
Student 3: [IA] the organism 'like' the light so it make the flagella to move or just the flagella 'like' the light

Student 1: I think it's like... it's the actual organism and it'll like -

Student 3: control?

Student 1: control the flagellum

Student 3: Yeah

Student 1: Cause like the flagellum is like specifically for movement, so -

Student 3: yeah

Student 1: and what is gonna 'like' the light is like the actual organism because it has like chloroplasts in it like we talked about umm and it'll need the light to do photosynthesis - umm... to be able to live

Student 3: Thank you

Student 1: Mmhmm

[7:33] Student 2: Okay.

[8:08] Student 4: Am I supposed to draw a [?]

Student 2: What? I'm like. What I'm doing is like I drawing kind of like a smaller one and like a bigger one (oh) yeah.

Student 4: Nevermind I'll draw a bigger one [laugh] [IA]

[9:48] Student 2: So I think what might be happening is like the protons might be hitting the eye spot and somehow that signals the flagella to move (mmhmm) maybe.

[12:55] So who's ever heard of a genetic screen? So this is something scientists do when they want to figure out what's causing a particular phenomenon. They can mutate a lot of organisms and then look at them - especially with microorganisms where you can do this with a lot of them - but they do this with mice and other things too - to try and find changes that affect that phonotypes. So - what we have in our box over here is from Carol Diekman's lab - there are some mutants from some mutagenic screen right? Umm so - how would you guess - for this thing - so these are - these are mutants that cannot perform properly phototaxis so how would you go about finding those? Do you think? So let's say you have a bunch of chlamydomonas with a random different mutations in their genome?
Student: [IA] so you can see which ones move toward the light and which ones linger behind
Dr. Bolger: Does that make sense? So you could like put the different ones in different tubes. And maybe do this really simple assay - in fact she's doing that right now with some more. And so how would you - somebody else - if it was a mutant - what do you predict you would see?
Student: [IA]
Dr. Bolger: It wouldn't move toward the light. Hahaa my screen has worked and I have fo-. And probably most of your - usually with screens - most act normally, you're looking for a needle in a haystack right? But that's gonna help you understand the process 'cause once you have something that doesn't work you can start to figure out why. So before we go and look at what our little guys are doing hopefully. I want you to put it - so you guys have drawn these pictures of how you think maybe phototaxis is happening. So on your worksheet it just says "why might it be that some change in the DNA could cause these guys not to swim to the light" and there's probably lots of different reasons but try and come up with one. One specific thing of what might prevent them using the picture of what you think happens maybe so take a second to think about that

[16:45] And then the next questions ask you about – why is it that a change in DNA cause the thing to not to swim toward the light. So like, in a general sense, how could DNA do this?

[18:35] Who is it that had to leave early? Was it you? Why don't you come over before you finish writing - cause I know you're in suspense right? [laugh] [IA] Alright we'll just take out one set. Oh, you want to come over too? so it changes pretty rapidly as we saw right? So we gotta look at them right when they come out so - why don't you pull out your own tape and just stick them in here and then we'll let them pull out their set. Yeah sure I guess cause they're coming over. So come over guys. So let's organize these. So we've got mutant two - nothing at the bottom. WT - performing as we kind of expected cause we saw that before right? Mutant two - something right? Somebody want to hold it up and see if it dissipates the way we expected the swimming ones to do? And mutant 3 is just - I don't like mutant 3; we're excluding him from the lab. Here's mutant one. Alright so, somebody - here's the [IA] if you guys want to look at them and observe. So anyone that wants to take one... mutant two, mutant one, WT, he's already starting to swim right? (yeah) cause there, that's the other WT. So we can see them moving. So the mutants are not looking the same, or what do you think. The WT, was it to fast to tell or... what did you th- you were the first to look, what did you notice?

[IA]

[23:02] Student 2: [IA] The first time we look at mutant one, is it like...
Student 4: It was moving but not like as quickly as the normal one
Student 2: But the second one was like turning right?
Student 4: Yeah, it was just spinning around
Student 2: But it was only like one or two of them

[IA]

[25:30] So what we want you to - if you don't mind - five more minutes umm... cause we're trying to see how this would work. We would do this as partners, but since there's only two of
you - we'll have you each do one so I want you to do is take this piece of paper and thinking -
your model that you have - draw a picture of what you think might be going wrong in each of the
two mutants based on what you know. So you know what they were doing under the microscope,
and you know what they did in that assay, and you have a picture of what you think's necessary
for phototaxis, so what do you think might be happening. You want to do it together? Okay, sure
Student 2: Can we kind of like go over [IA]
Dr. Bolger: Yeah, yeah. I, and I'm gonna go over the whole thing with you. Why don't you guys
start it here and I'll just listen and talk to you guys as you do it. Here's some markers. But you
probably need to compare your models because you might not have the same one right?

[26:52] Student 2: So let's try using a different color for each of them.
Dr. B: So what have you already got on your pictures for your models?
Student 2: Umm I said that protons may hit the eye spot and the eye spot may 'realize' that
certain wavelengths are hitting it so it somehow signals the flagella to move. And then as a
defect I said maybe there, so like, something goes wrong in the protein. A protein in either the
eye spot or the flagella. So, maybe the eye spot won't be able to see certain - "see" in quotes - see
certain wavelengths and umm.. that could cause like only a slightly functional phototaxis.
Dr. Bolger: Uhhhuh. No that's great, and you had...?
Student 4: I was actually thinking maybe the reason is for the chlorophyll... because - I'm not
sure but like, I think cause they can like absorb the light and then like the light detecting and then
so we know that they can swim
Dr. Bolger: Okay so somehow the chlorophyll because they're the thing that needs the light it's
what might be detecting it? Okay.
Student 4: Mmhmm. And then - like if the signal or something [IA] Swim towards the light
Dr. Bolger: Mmhmm. So show me on your picture
Student 4: I like - So here is like object that detect light, so they swim towards the light and this
is how they
Dr. Bolger: So this is how they're doing that. Okay cool. Umm, so you guys figure out how you
want to draw it. And there's obviously multiple things it could be. So...
Student 2: Yeah. So we can kind of show like the light hitting both the eye spot and the
chlorophyll... okay

[28:55] Iliana: You guys can do a little zoom in window if you want.
Student 2: Chloroplast...
Iliana: You could draw like a bigger thing and then like a circle -
Dr. B: However you want to draw it. Yeah. If you were explaining it - imagine that you knew for
sure how it works and then we're gonna talk a bit more at the end so you won't go away in total
ambiguity. She's gotten green; green is good for green things [laugh]

[29:15]
...
Student 2: The wild type one -
Dr. B: She's got green. Green is good for
Student 2: Well yeah
Student 4: So I'm drawing this?
Student 2: I thought we were gonna draw the same one together for the WT. We'll just draw everything together I guess.

Student 4: Okay.

Student 2: Okay, so... [IA] And then... [drawing]

Student 4: Maybe we should put the light together.

Student 2: Put what together?

Student 4: Yeah the light so we can see [IA] directions.

Student 2: Ohhh... Yeah... That could [IA] [laugh]

Student 4: Is it better? Yeah. We can draw -

Iliana: You guys can use the other paper too - like if you need to.

Student 4: Okay so we can draw the lig- what do you think? We can draw the light in like one positions and so like you can draw from the eye spot and I can draw [IA]

Student 2: Okay.

Student 4: We need to work together.

Student 2: Okay.

Student 4: Does that make sense?

Student 2: Yeah it does. The light's gonna be hitting off the chlorophyll.

Student 4: Actually just draw it here - fine here I'll just put the light.

Student 2: Or we could put it under because like that works too.

Student 4: so we could just put it like here and then here.

Student 2: Okay so how do you want to draw the light?

Student 4: [laugh] uhhhhhh....

Student 2: We can just draw a box [drawing] light...Okay so do you want to agree that these are photons? Okay

[31:30] Student 4: [to Iliana] Is there only one eye spot?

Student 2: I think so.

Iliana: Umm... in the wild type there is.

[32:08] Student 2: So you want to draw the photons hitting the chloroplasts and I'm gonna do the eye spot.

Student 4: Mmmmm.

Student 2: Okay.

Iliana: I might have a red marker if you guys need it.

Student 2: Okay yeah. Thank you.

Dr. B: It's beautiful. So is this for the mutants or is this for the -

Student 2: So we're both doing the wild type but we're doing like different hypotheses.

Dr. B: Gook, okay.

Student 4: So this is for the chloroplasts.

Dr. B: Absorb through the chloroplasts.

Student 2: And this is for the eye spot.

Dr. B: Okay. Cool. And then we got to figure out for mutant one and mutant two. In fact, I'll just -

[33:32] So what was the same about mutant one and mutant two and what was different?

Student 2: They weren't moving towards the light as much, or at all.
Dr. Bolger: So they were phototaxis mutants, so something’s wrong with phototaxis. And was anything different about the two - that you observed?

Student 2: Well, under the microscope, mutant one was moving more than mutant two. So, maybe that one was like more functional but not completely functional

Student 4: It seems like for the mutant one it seemed like they're staying there

Dr. Bolger: But they weren't swimming

Student 2: they were like swirling - swirling in place almost

Dr. Bolger: Mmhmm. And what were the different hypotheses that you had for how a mutation could cause a phototaxis - did you guys - I heard more than one

Student 2: I said there could have been a mutation in one of the proteins in the eye spot that allows them to see certain wavelengths of light

Dr. Bolger: Mmhmm

Student 2: And, like, almost like the lab we did earlier about people being color blind. Like they can only see certain wavelengths so they only see like certain colors.

Dr. Bolger: So its something with their sensing...

[34:35] Student 2: It could be like - like it could affect the tertiary structure and how like -

Dr. Bolger: Yeah, and there's something called photo rhodopsin - and they have the photo - things here. And what was the other one? So it could be how it senses the light. Was there any other hypotheses that you had?

Student 4: [IA] so like so one mutant like so it can't function anymore [IA] organelle can't absorb any light this mean they don't know there's light.

Dr. Bolger: They don't know there's light, so it's like they're blind. And was there any other hypotheses?

Student 2: Yeah. Umm. I said maybe something is wrong with the flagella that doesn't allow the flagella that doesn't allow the flagella to rotate correctly

Dr. Bolger: Okay

Student 2: ... correctly...

Dr. Bolger: Okay, so they're not doing this somehow. So, those sound like two or three different hypotheses. I just challenged you to think from the things you know - what you observed. And you guys are correct. So figure out which one kinda matches which. So which one sounds more like mutant one and which one sounds more like mutant two do you think? Mmhmm so mutant one and mutant two have different things going on

Student 4: Can I see one more time mutant one and mutant two again?

Dr. Bolger: I - over here - I think she just put it away. So yeah, so I think what it was doing was mutant one was kind of the one that was swimming all around and mutant two was slow or not moving or there were some that were just swirling a little bit.

Student 2: [IA] Those ones may not even have been the mutant right? They could have just been collected-

Dr. Bolger: Well it's possible, but I think - let's assume that they're all [IA] the people I got the lab stuff from were cultured correctly. So you guys just draw two pictures and what you think for mutant one and mutant two. And then that'll be the en- and I'll show you kinda pictures so you can see the answers

[36:38] Student 4: mutant one [IA] together

Student 2: I think mutant one is like slightly functioning and then mutant two is not at all

Student 4: [IA]
Student 2: Oh, the flagella?
Student 4: I think the second one the mutant two [IA] because it can turn
Student 2: Yeah, it figures [IA] almost like
Student 4: Circle [laugh] just turn around
Student 2: And then mutant one it might be for the eye spot and the chloroplast
Student 4: Yeah, that's what I think
Student 2: [IA]
Student 4: [laugh] keep reading...
Student 2: Okay so, for mutant one we said, like
Student 4: [IA]
Student 2: Okay yeah
Student 4: For mutant two we could say like - I forgot- how is it again?
Student 2: Flagella?
Student 4: The flagella may be shorten or like...
Student 2: Oh yeah that's true
Student 4: Shorter..... [IA]
Student 2: [IA]

[38:57] Student 2: Do we want to draw it like.... just draw it like... so for this one we're saying
the eye spot is functioning not the flagella?
Student 4: Only this one we're saying
Student 2: Yeah, and then for this one the eye spot's not working correctly so it's not going
towards the light? Okay
[drawing]
oh wait, could it have multiple eye spots? like maybe
Student 4: [laugh] two eye spots
Student 2: [laugh] maybe like [to instructor] Were there multiple eye spots on one of them
Dr. B: Oh, well actually that is a type of mutant that can happen - multiple eye spots - but they're
supposed to have one. Normal - the WT has one. Yeah, so that's another possibility for what can
happen - there's multi eye mutants.
Student 2: Yeah. So if it has [IA] it moves like in random ways
Dr. B: Yeah that's another possibility - one that has multiple eyes
Student 2: [to student 4] I think maybe we should put that [laughs]
[IA]

[41:04] Student 2: so yeah it doesn't recognize the light [IA] Okay
Student 4: So this one has two eye spots?
Student 2: Possibly. Well we came up with two hypotheses. Maybe the eye spot doesn't properly
register the light - or multiple eye spots and it doesn't know what to move towards
Iliana: and then this one?
Student 4: Maybe like - what's it called again? (Flagella) Maybe the flagella are shorten or
maybe not functioning [IA]
Iliana: They weren't made properly or something?
Dr. B: Cool, this looks very diagrammatic. So mu - so are you guys done? (yeah) Okay so tell me
what you drew
Student 2: Okay so for mutant 1 - we came up with two hypotheses but I think it's the first one just cause even if it had multiple eye spots it could probably see the light at the bottom, unless like - like in that specific situation. So we're saying that the eye spot doesn't recognize the light so it doesn't move towards the eye source and it can't perform phototaxis.

Student 4: This one is just a flagella mutant like yea so maybe shorter [IA]

Student 2: Yeah, and we thought that just cause they weren't really moving

Dr. Bolger: Oh okay so that's how you - with my challenging - that's how you determined that that made sense for that one?

Student 2: Yeah

Dr. Bolger: Based on?

Student 2: Based on the low power microscope and how they weren't really moving. They were just swirling

Dr. Bolger: So you think their eye spot works?

Student 2: Yeah

Dr. Bolger: Okay. Yeah so I'm gonna show you some photographs of what they really look like so we'll see if you predictions were good. So - ummm... It's kind of hard to see - actually we can just look on here and see it well. Take a look at - on my screen here. Alright so mutant - this is actually the WT - it's not in color but - oh - right here, so that's the eye spot. So this is actually the mutant that you had

Student 2: So there was no eye spot?

Dr. Bolger: There's no eye spot. It doesn’t' have an eye spot

Student 4: This is the mutant one?

Dr. Bolger: This is the mutant one. Mmhmm. And umm... and so uhh this one - but you had the idea of two eye spots - those actually do exist - they also have ones that can detect one wavelength of light but not another wavelength of light and like some of them only phototax if you don't filter the light so your idea about breaking the proteins for sensing is (not?) another way it can happen - this one doesn't form the eye spot at all cause you notice [IA] This one is a little hard to see

Student 2: that one almost looks like it has two

Dr. Bolger: Yeah, this is the mutant two so if you - you can't really see it, but here's one flagella, but,

Student 4: they only have one

Dr. Bolger: They only have one

Student 2: Ohhh

Dr. Bolger: It's called uniflagellar, so you were right so it has a mutation

Student 4: We were close

Dr. Bolger: You were very close, you guys deduced exactly what was possible to deduce from what I told you. Umm... so let's wat- there's also a little video - there he is [laughter] he so sad.

Student 4: So before it looked like (it was spinning?)

Dr. Bolger: yeah so this guy doesn't appear to be spinning but some of them do exactly that. like they can spin but they can't swim toward the light. And we saw that that they're kind of - you can only move a little bit if you only have one flagella like I guess [IA] [laughter]
Student 2: I think you could miss some mutations if it was like a silent mutation or conservative mutation like even if it changes the amino acid it might be similar enough that it can still function decently.

Dr. Bolger: So some mutations might not cause a phenotype, right? Or Some might mutate something that has nothing to do with phototaxis - and then it might just be dead [laugh]

Student 2: Yeah

Dr. Bolger: But yeah, so, right. And a lot - changing some protein that doesn't change its ability to make the eye spot - or make a flagella - it might

Student 2: What lab would this replace, if you guys did it?

Dr. Bolger: Well we're doing a lot of thinking about this, but, do you have any thoughts? Does this relate to anything you're already learning?

Student 2: I thought it's like really good for like photosynthesis and gene expression. Cause it kind of like gives the ideas to both of them so I think this is like a really good lab

Dr. Bolger: yeah, so I think that we would probably like Emily Dykstra is in charge of all this I'm just helping her but umm it could tie into what you guys are already doing about photosynthesis but also bring home the point of gene expression which is a huge focus of 181 right?

Student 2: Yeah

Dr. Bolger: So you think its interesting to look at the little guys floating around? Well I'm trying to push that it would be nice to have more organisms in the lab

Student 4: Yeah, it would be more fun

Dr. Bolger: Yeah

Student 4: [laugh] apply to wavelengths it's so boring

Dr. Bolger: Its not - well you guys love organisms because that's why you guys chose to be biology majors

---

Group 2 Transcript

Recording 2a

Student 1: I think that - Umm she talked a little bit about it having - umm... chloroplasts

Student 3: Mmm

Student 1: Which reminds me of like photosynthesis and like that involves light. So I think that the like organisms in there like they understand like -

Student 3: They want the light

Student 1: - yeah they want the light

Student 3: so they go down

Student 1: Yeah so they like will congregate there but then like when we took them out they like we could watch them like immediately say like 'oh, now there's light everywhere now we can go back... to the umm'...

Student 3: Yeah

Student 1: You know... So

Student 3: That makes sense
Student 1: [00:56] Yeah. Looks good. I though that like - or - kind of like what we watched on the video

Student 3: yeah

Student 1: yeah the flagella like - and this just kind of like how we swim like we use our arms

Student 3: Yeah exactly

Student 1: and we're like a multicellular organism and like this is not. So...

Student 3: What's that called? The swivel thing?

Student 1: I thought it was - the... the... [Dr. Bolger: The flagella?] the flagellum. We call them hairs; we can call them flagellum? It doesn't matter?

Dr. B: yeah, we know what you're talking about [IA] in here

[2:50]

Student 3: [IA] the organism 'like' the light so it make the flagella to move or just the flagella 'like' the light

Student 1: I think it's like... it's the actual organism and it'll like -

Student 3: control?

Student 1: control the flagellum

Student 3: Yeah

Student 1: Cause like the flagellum is like specifically for movement, so -

Student 3: yeah

Student 1: and what is gonna 'like' the light is like the actual organism because it has like chloroplasts in it like we talked about umm and it'll need the light to do photosynthesis - umm...

to be able to live

Student 3: Thank you

Student 1: Mhm
181 Pilot Lab

Dr. Molly Boiger, MCB
Ilana Rosas, undergraduate researcher, MCB
Samantha Zaepfel, undergraduate researcher, Science Education

Goals for today

- Learn about how changes to genes can lead to changes to phenotype.
- Observe and investigate a photosynthetic microorganism.
- Practice drawing models, making hypotheses and testing your hypotheses through experimentation.
Informed Consent

Chlamydomonas

- Unicellular form of green algae
- Eukaryotic
- Found in stagnant water, damp soil, freshwater or seawater
- Capable of photosynthesis
- Used by Carol Dieckmann lab to study organelle development
Step 1: Investigating Chlamydomonas

• Examine how your tube of Chlamydomonas reacts to light.
  • Place your tube of green Chlamy into the dark box next to the light source.
  • When you return to your bench (after at least 10 min.) observe the tube. Write an possible explanation for what you see.

• View Chlamydomonas under the microscope.
  • Take a look at the live Chlamy that is under one of the lower powered microscopes.
  • Observe the dead Chlamy that is under the high powered microscope. Draw a picture of one Chlamy cell, including the sub-cellular structures that you see.

Why is there a green band?

• Your ideas?
More about Chlamydomonas

• Capable of Phototaxis (movement towards light).
• Has an eyespot and two flagella.
• https://www.youtube.com/watch?v=0xo77Q09Brc
• https://www.youtube.com/watch?v=NkZjzILqwzQ

Step 2: Make a Model

• Draw a picture to explain how you think Chlamydomonas performs phototaxis (swimming towards light).
Genetic mutants that cannot perform phototaxis

- How do you think researchers obtain these mutants?

---

**Step 3: Testing Chlamydomonas mutants**

- Make a prediction.
  - Using your model for phototaxis, predict why a mutant might not be able to perform phototaxis. Explain how a change in the DNA could result in this change to what the organism can do.

- Observe Chlamydomonas mutants.
  - Perform the box assay with wild-type Chlamydomonas and mutants.
  - Observe each live mutant under the low-power microscope.

- Make a poster to share.
  - Draw your model for phototaxis and a picture for what you think may be happening for each mutant.
Step 4: Poster Sharing

- Explain your poster to your classmates

Our Models for Phototaxis in Chlamydomonas

- What differences do we have in our models?
- What are the possible ways that DNA change can alter phototaxis?

https://www.youtube.com/watch?v=ekEih7_jwuw

WILD TYPE  MUTANT 1  MUTANT 2
Mutations Discussion

- What are some ways that mutations can lead to changes in phenotype?
- What makes mutations happen?
- When researchers screened Chlamydomonas for mutations that altered phototaxis, could they “miss” some cells with changes in their DNA?
Welcome to MCB181L Chlamydomonas Pilot lab. Chlamydomonas is a unicellular eukaryote that is photosynthetic.

PART 1: Investigating Chlamydomonas
1. Observe the tube of Chlamydomonas and then place in dark box for at least 10 minutes.
2. Write your initial observation of Chlamydomonas in the test tube and the observation after the test tube was removed from the box.

3. Look at live Chlamydomonas under one of the low powered microscopes. Look at dead Chlamydomonas under the high powered microscope. Draw a picture of one Chlamydomonas cell, including any subcellular structures that you see.

4. What is a possible explanation for what you observed in these investigations? Write your ideas.
PART 2: Drawing a Model for Phototaxis

5. Draw a picture to explain how you think Chlamydomonas performs phototaxis (swimming towards light)
PART 3: Testing Chlamydomonas Mutants

6. In lab today we have some mutant Chlamydomonas that cannot perform chemotaxis. Using your model for phototaxis make a prediction for why a mutant might not be able to perform phototaxis (more than one answer is possible).

7. In your own words, explain how it is possible that a change in DNA could result in a change to what these organisms can do. Remember genes are DNA and they are transcribed to mRNA, then translated to proteins.

8. Observe your tubes of wild-type and mutant Chlamydomonas. Place your wild-type and mutant Chlamydomonas mutants in the dark box for at least 10 minutes. While you wait you may observe the mutant Chlamydomonas under the low-powered microscope.

9. What happened to the mutant VS wild-type Chlamydomonas in the box assay? Write your observations.
10. Using the large sticky notes provided, work with your partner to make a poster that shows your model for phototaxis and pictures to show what you think may be happening for each of the mutants.
Investigating Chlamydomonas

1. Observe the tube of Chlamydomonas and then place in dark box for at least 10 minutes.
2. Write your initial observation of Chlamydomonas in the test tube and the observation after the test tube was removed from the box.

Initial observations: organism clumps together. After shaking, it evens disperses and leaves a transparent green liquid.

After observation: very green, clumped towards bottom, mostly to disperse after held elsewhere.

3. Look at live Chlamydomonas under one of the low powered microscopes. Look at dead Chlamydomonas under the high powered microscope. Draw a picture of one Chlamydomonas cell, including any subcellular structures that you see.

4. What is a possible explanation for what you observed in these investigations? Write your ideas.

The organism moves towards the light source. This may increase the rate of photosynthesis. When taken out, the organism disperses because there are other sources of light (the overhead lights, etc.).
PART 2: Drawing a Model for Phototaxis
5. Draw a picture to explain how you think Chlamydomonas performs phototaxis (swimming towards light)

- Light source hits the eye spot which could signal flagella to move.
PART 3: Testing Chlamydomonas Mutants

6. In lab today we have some mutant Chlamydomonas that cannot perform chemotaxis. Using your model for phototaxis make a prediction for why a mutant might not be able to perform phototaxis (more than one answer is possible).

- a protein in the eye spot may be defective, which would only allow it to “see” certain wavelengths, meaning that it would not react properly w/ phototaxis.

7. In your own words, explain how it is possible that a change in DNA could result in a change to what these organisms can do. Remember genes are DNA and they are transcribed to mRNA, then translated to proteins.

- a change in DNA sequence could change the amino acid sequence of a protein. Depending on the severity of the change, the protein could be non-functional.

8. Observe your tubes of wild-type and mutant Chlamydomonas. Place your wild-type and mutant Chlamydomonas mutants in the dark box for at least 10 minutes. While you wait you may observe the mutant Chlamydomonas under the low-powered microscope.

9. What happened to the mutant VS wild-type Chlamydomonas in the box assay? Write your observations.

- the wild-type accumulated towards the light source. This makes sense as the wildtype was very quick under the microscope and capable of phototaxis.

- the mutants, however, were very slow or didn’t move at all. As they did not congregate towards the light source, this is to be expected. They may not fully be capable of phototaxis.
10. Using the large sticky notes provided, work with your partner to make a poster that shows your model for phototaxis and pictures to show what you think may be happening for each of the mutants.
PART 1: Investigating Chlamydomonas

1. Observe the tube of Chlamydomonas and then place in dark box for at least 10 minutes.
2. Write your initial observation of Chlamydomonas in the test tube and the observation after the test tube was removed from the box.
   For the initial observation, the Chlamydomonas is just a bit green clear light
   After 10 minutes, more green in the test tube, but when it
   started absorb light again, there’s less green organism at the
   bottom.
3. Look at live Chlamydomonas under one of the low powered microscopes. Look at dead
   Chlamydomonas under the high powered microscope. Draw a picture of one
   Chlamydomonas cell, including any subcellular structures that you see.

4. What is a possible explanation for what you observed in these investigations? Write your
   ideas.
   Chlamydomonas would like to stay with the light, since
   only light at the bottom, then they swim towards to the
   light. (movement towards light).
PART 2: Drawing a Model for Phototaxis
5. Draw a picture to explain how you think Chlamydomonas performs phototaxis (swimming towards light)
PART 3: Testing Chlamydomonas Mutants

6. In lab today we have some mutant Chlamydomonas that cannot perform chemotaxis. Using your model for phototaxis make a prediction for why a mutant might not be able to perform phototaxis (more than one answer is possible).

The chlorophyll inside the Chlamydomonas has mutated which means, it might not function. Then it can’t absorb light.

7. In your own words, explain how it is possible that a change in DNA could result in a change to what these organisms can do. Remember genes are DNA and they are transcribed to mRNA, then translated to proteins.

Changing a DNA might change the codon. During the transcription, mRNA would change to different codon then, difference amino acid might bind to it. Different protein has different function.

8. Observe your tubes of wild-type and mutant Chlamydomonas. Place your wild-type and mutant Chlamydomonas mutants in the dark box for at least 10 minutes. While you wait you may observe the mutant Chlamydomonas under the low-powered microscope.

9. What happened to the mutant VS wild-type Chlamydomonas in the box assay? Write your observations.

The mutant Chlamydomonas do not have the phototaxis. That it do not swim towards to the light.

Wild-type still swim towards light.
Pilot Lab MCB181

10. Using the large sticky notes provided, work with your partner to make a poster that shows your model for phototaxis and pictures to show what you think may be happening for each of the mutants.