These directions guide you through reading a scientific research paper. It is important for you to know that reading primary literature is hard and time consuming. It will get easier, but only if you put time and effort into it now. Please make sure to schedule enough time to read the papers required for Biolab. The best way to perform poorly on some assignments is to not fully understand the paper it is based on.

Let's start with the basic outline of a research article and the purpose of each section:

- Title and authors
    - Title is very descriptive (often states the main finding) and is not about being creative and "catchy"!
    - Order of authors is important. What can you tell from it?
- Abstract/summary
    - Brief background of subject
    - Purpose for the study
    - Major findings of the study
    - Relationship between these findings and the field
    - Typically determines if you continue reading making it one of the most important parts of any paper.
- Introduction
    - Presents the background information for a fellow scientist (possibly in another field) to understand why the findings of this paper are significant.
    - Structure is usually:
        - Accepted state of knowledge in the field
        - Focus on a particular aspect of the field, often the set(s) of data that led directly to the work of this paper
        - Hypothesis being tested
        - Conclusions (scientists don't really like surprise endings!)
- Materials and Methods
    - Should be detailed enough for another scientist to replicate the work (volumes, times, company material was purchased from etc.)
    - In reality, often compressed and you may need to look up another paper that is referenced for more detail.
- Results
    - While the introduction poses the questions being asked, the results describe the outcome of the experiments that were done to answer the questions.
    - Results are often simply stated with interpretation of them coming later in the discussion.
    - Figures and tables allow the reader to see the outcomes of the experiments for themselves!
- Discussion
    - Data is analyzed to show what the authors believe the data show. (You don't have to agree with their interpretations!)

    - Findings are related to other findings in the field (contribute to knowledge, correct errors, etc.)– How is this work significant?
- Acknowledgements
    - Thank people who contributed materials.
    - Thank people who contributed technically but maybe not intellectually (would not be authors).
- References
    - Papers cited in the text
    - What parts of the paper cite other papers?
        - Introduction
        - Materials and Methods
        - Discussion
        - (Maybe a few in Results)
- Figures/Tables (throughout the paper)
    - Show essential data in plots or tables that are essential for the reader to understand results.
    - Not all data is typically shown
    - Figures have legends that completely describe the figure without requiring reading of the entire paper.
    - Mostly are found in the Results section, but can be in the Introduction, Materials and Methods, and Discussion

Now that you understand the layout of the paper, how do you read it? Typically when you read a scientific paper, you do NOT want to read it straight through. You actually want to read it in an order that will make it as easy to understand as possible. Everyone has a slightly different method of doing so and you should start to develop your own method. For this class, you will use one technique that assumes you have NOT done a lot of primary literature reading. This method will become less useful as you read more and more papers since you will develop a better understanding of both the experiments and vocabulary. When this happens, you should adjust your reading method appropriately.

First, skim the entire paper. During your skim, you should do the following:

- Look at the major headings
    - Do they follow the “anatomy” we just described?
- How many figures/tables are there, what kinds of figures/tables are they?
    - Are they all representing results or do some help explain introductory material or show a model designed based on the results in the discussion?
- What is the conclusion of the paper?
    - It may not make sense to you at the moment, but note what it is.

Second, go through the paper as a whole simply underlining words and phrases you do not understand. You are not reading the paper for comprehension yet, just trying to make sure you

have understanding of the words so you can comprehend it later. Once you have a list of words and phrases you should look them up. Simply googling them or using a biology textbook is a great option. This is one place in science where wikipedia is a useful tool - just don't trust it completely and never cite it. Look up methods that you are not familiar with. For example, what is/are circular dichroism spectroscopy and/or NMR HSQC and/or NMR residual dipolar couplings?

Third, read for comprehension. Now that you have the appropriate vocabulary, you can read the paper to understand the information within it. Typically you will read the abstract, skim the introduction, look at the figures/read the results, read the discussion, and if needed read the materials and methods for more detail. It is also in your best interest to take notes and make little drawings/sketches as you read. This will help with your compression and allow you to quickly review the paper again in the future. Let's break down what to focus on for each section.

The abstract should essentially tell you what experiment was done and what was found. You can think of this as a map for the rest of the paper. You should be able to understand a vast majority of the abstract after looking up words or techniques with which you were unfamiliar.

The introduction sets up the reader to understand the results and discussion in the context of the field. When you skim the introduction, you should be paying attention to the following:

- What is the accepted state of knowledge?
- What data led directly to the work of this paper?
- What is the hypothesis being tested?
    - Is there a clear hypothesis?
- What are the basic conclusions?
    - Scientists don't really like surprise endings and this is usually stated in the last paragraph.

The results are the experimental results of the paper and should be devoid of any opinion (be careful since this isn't always true). When looking at the results, you often start with the figures/tables as they determine what the text of the results section says. Look at the figure/table and try to come to your own conclusions about what it represents. For example, if the figure is showing wild-type versus mutant protein, is there a difference? You should read the figure legend (the text under the figure) to understand what each part of the figure represents. Once you have studied the figure, then you can read the text of the results section and see if you agree or disagree with the authors. The more papers you read, the easier this will get and the faster it will go. Remember to take notes and doodle pictures as needed. While reading the results, you should be able to answer the following questions for each experiment/figure:

- What is the basic procedure?
- What is the question the experiment sought to answer and the figure shows?

- What is the result?
- What is the conclusion?
- Do you or the authors have any criticisms?

Once you understand the results of the paper, you can move onto the discussion section. Remember in the discussion the results are analyzed to show what the authors believe the data show and this is partially opinion/interpretation! You don't need to agree with the authors especially if you have a different interpretation of the results. Importantly, the findings are related to other findings in the field and results in a statement of the work's significance? When reading the discussion you should answer the following questions:

- What conclusions do the authors draw?
    - Be sure to separate fact from their opinion/interpretation?
- Describe for yourself why these data are significant.
    - Does it contribute to knowledge?
    - Does it correct errors in the field?

Finally, you can read the materials and methods if needed. Typically this is the most dense and difficult to read section of a paper. It is made more difficult if you are not familiar with the techniques being utilized. Often, you can refer back to the materials and methods as you are reading the results section. This will provide more detail as needed. The material and methods sections get easier to read as you learn more and more techniques - like in Biolab!

Fourth, now that you have read the paper, you need to do some reflection on what you have learned. These questions will help you in that process:

- Do you agree with the authors' rationale for setting up the experiments as they did?
- Did they perform the experiments appropriately?
    - Repeated a number of times
    - Used correct controls
    - Used appropriate measurements
    - Other?
- Were there enough experiments to support the one major finding they are claiming?
- Do you see patterns/trends in their data that are problems that were not mentioned?
- Do you agree with the authors' conclusions from these data?
    - Are they over-generalized or too grand?
    - Are there other factors that they neglect that could have accounted for their data?
- What further questions do you have?
- What might you suggest they do next?

As a scientist in training, there are some important paper reading tips you should consider as you move through your undergraduate studies. First, spend a lot of time on each paper NOW looking up every detail of which you are unsure. Time you invest now will pay off in the long run

when you go from taking an hour to read a paper to being able to read one in ten minutes. Discovering the answers for yourself is one of the best ways to learn and have the information be retained. Imagine yourself teaching the paper or figures to classmates - teaching something to others is also another great way to learn. Second, keep a physical notebook or a Google Doc (or something similar) for all the procedures and techniques you lookup. This makes an easy reference for future papers. Third, read papers when you are awake and interested in reading (this is hard when you have to read for class). If you are going to break up a paper and read it over several days be sure to summarize before ending each day.

Adapted from Kelly A. Hogan's "How to Read a Scientific Paper" presentation from UNC Chapel Hill.