Lecture 15: Scientific writing

This lecture addresses how to write a journal-article style manuscript that describes work you already did, when the project is complete. The purpose of the manuscript is share your new knowledge with others. You may submit it for publication, or just for academic credit or even to share the knowledge with other lab members. A journal article typically includes the following components, and this is the style we require for the final project:

1. Title
2. Abstract
3. Background/Introduction
4. Methods
5. Results (description and direct interpretation of data and figures)
6. Discussion (summary, indirect conclusions, comparisons, analysis)

Overall writing advice:

7. **Concise.** Scientific writing should be as concise as possible. To stay focused, always start with an outline of your main points and what you need to include to make them. Later, delete any paragraph, sentence, or phrase that is not needed to understand or believe your main points.
8. **Precise**. Scientific writing should say exactly what you mean. Don't choose wording that sounds more interesting or pretty, if it obfuscates what you want to say.
9. Objective.
10. **Organized for clarity.** Summarize and introduce (almost) every section and paragraph and highlight the important points throughout the document by relating almost everything to your main points.
11. **Interesting**. Organize your information into a story to keep your reader interested. See the specific comments on each section for the types of stories you are trying to build in each section.

<u>Useful Scientific Writing Exercises</u>

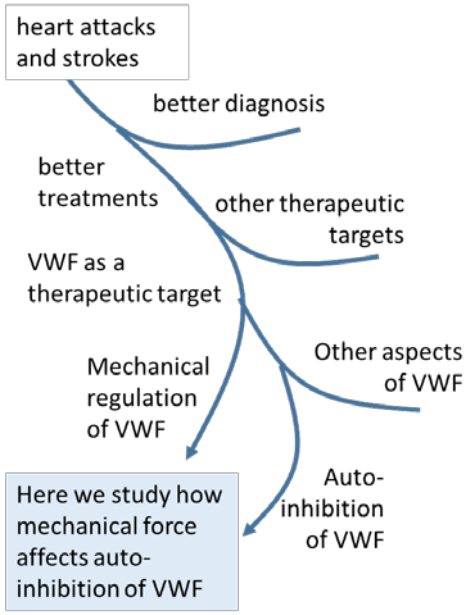
- Critique other's work to see what works and what doesn't.
    - Read an article or a peer's writing, and deconstruct it (outline key points in each section) to make sure you really understand it.
    - Identify stylistic strengths and weaknesses that made the article easier or harder to understand and deconstruct.
    - Only mimic style from work you admire!
- Get a peer review of your writing.
    - Have a colleague do this same exercise – deconstruct, and identify stylistic strengths and weaknesses.
    - Compare their deconstructions (what you did convey) to what you meant to convey, and fix if needed.
    - Fix the stylistic weaknesses they found.

Writing a Background/Introduction Section

This section is where you provide the context for the project. The story for the background should be focused to explain why the knowledge (to be) gained is **novel**, and why this new knowledge is **significant**, rather than on a comprehensive review of the most important literature in your field. Writing an introduction should help you develop your project, so should not be left until you are done with the experiments (simulations).

Significance. You need to **trace a path from the significance of the general topic to the specific work you did**. The first sentence or two should be understandable to anyone with a high school education and should relate to the topic of your journal or assignment. This starts you with a general issue that your readers can already understand and agree is important. Now you trace a path to your specific work by justifying each branch point with information that they may not have already known. I call this making a **branch pathway**. In some cases, two branches may combine to lead to your project, as in the example below (see the two arrows pointing to the blue box describing the topic of the project.) When you make a pathway diagram, try to predict the key branch points where the reader may doubt the significance of your path. These are places you need to provide evidence in the form of citations and/or arguments.

Example: One of the Thomas lab projects might be introduced as follows:



- *What is the obviously important topic*? Heart attacks and strokes are a health issue in the US or world.
- *Why do we need better treatments?* Even when a patient is diagnosed with cardiovascular disease, we cannot always safely prevent heart attacks or strokes, because blood thinners that inhibit thrombosis also inhibit hemostasis, so cause bleeding.
- *Why target VWF as a treatment*? Heart attacks and strokes occur in high flow, and require both a VWF-initiated high flow mechanism of clotting as well as mechanisms common to both high and low flow clotting pathways, which are targeted by existing blood thinners. So inhibition of VWF may provide a more specific target.
- *Why study mechanical regulation of VWF*? VWF is mechanically activated by arterial flow to initiate arterial thrombosis, so understanding the mechanical activation mechanism may show a way to inhibit arterial thrombosis.
- *Why study auto-inhibition* of VWF? VWF can be activated by point mutations or truncation, so has a method to inhibit itself. We hypothesize that mechanical force removes the auto-inhibition. This native auto-inhibition may provide ideas for therapeutic inhibition.

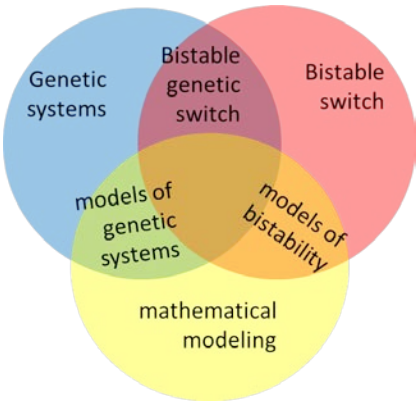
Exercise: write a branch pathway and accompanying outline for your project.

Some helpful notes for converting your pathway diagram or notes into written text:

- **Stay focused**, and only include enough details to justify your choice of paths and to provide background to understand your work. Early branches, which address common concepts, may only take a sentence because the analysis was done already in a review you can cite. Later branches may take a whole paragraph to justify because the point being made is not common knowledge, takes a lot of citations and analyses, and also needs to address novelty – see below.
- **Don't overreach**. In your narrative, you don't need to name or describe the alternative branches, and you definitely don't need to claim they are less important. But if any of those things strengthen your justification, you may include them.
- **Segues** help tell your story by connecting the conclusion of one paragraph to the topic of the next. These provide both interest and clarifying summaries. Examples: one paragraph may end with "Therefore, the disease is only treatable if caught early, so early diagnostic methods are critical," which segues to the next paragraph that starts with "There are three diagnostic technologies for this disease" and proceeds to analyze the insufficiency in each method for the purpose of early diagnosis.
- **Citations** are critical to your arguments. Near the top of your pathway, you will mostly be citing reviews or comprehensive analyses of multiple medical studies, because these documents provide overviews of a topic, and so best support the general points you are making in this part of the introduction.

Novelty. You describe the novelty of your work by describing how it is different from the most related work you could find. Your expert readers will be aware of one or more of these prior works, but not sufficiently familiar to realize how yours is different, so without this clarification, they will think your question has already been answered. This also convinces the nonexperts that you have done your due diligence to make sure it wasn't already done. This analysis is usually incorporated into the more detailed, later parts of the introduction pathway, where you are closest to the proposed work you plan.

Two methods of identifying the key concepts you are combining in your work that make it novel are as follows: 1) A **Venn Diagram** of the key concepts shows you how they may overlap, and works great for three key concepts. 2) A **Novelty sentence** describes your project topic in a sentence that includes all the key concept words, and can be used with more than three concepts. Your project is described by the entire novelty sentence, or the intersection of all the concepts in your Venn Diagram. A search on your topic should result in no or a few publications; otherwise, you need to add or narrow a key concept to better clarify your novelty. The most related work is the few that address your entire topic, and/or the few that address your topic less one concept.



Example: The novelty sentence for the Gardner 2000 paper from lab 3 could be that it described a validated mathematical

model for a bistable switch composed of a genetic system. This could be represented in the Venn diagram to the right. They then address the intersections of the sets of concepts after one is removed. They note the existence of natural *bistable genetic systems* (remove "mathematical models" from the novelty sentence or Venn diagram.) They also note that there are *models of bistablity* for other types of system like enzyme networks (remove "genetic systems".) However, they note the need for a theory with predictive capability for genetic systems, suggesting the lack of prior work on *models of genetic systems* (remove "bistable switch") as well as the models of bistable genetic switch (keep all key concepts). This clearly addressed the novelty of their work.

You might note that they also use additional concepts in their introduction that I have not included as key concepts for my novelty analysis of their work. I could have been more complete by qualifying the concept 'mathematical models' with 'validated', but it wasn't actually necessary to establish novelty, although it does emphasize the value of the work. They also used the word "E. coli" since they built their switch in this organism. This was irrelevant to the novelty of their work, which it was so ground-breaking that their approach had not been done in any organism. Had I chosen models of biochemical systems in E. coli, I would have found many papers on enzyme pathways, which do not correctly address the novelty of their work. So it is important to find the correct key concepts.

Some helpful notes for converting your novelty analysis into written text within the pathway structure described above:

- Don't say things like "little has been published". If there is just one paper that shows exactly what you are proposing, that is very little, but still makes yours unnecessary.
- Make sure you address each of these related papers to say why each is not sufficient to answer the questions you pose. Avoid insulting the work – just explain the difference. If there are a few papers within your full set of key concepts, explain why they don't answer your question.
- Make sure you clarify the significance of answering the novel question you are posing. It doesn't need to be earth-shattering.

The summary "here we" paragraph or sentence. The introduction should end with a summary of what you did and learned. This helps the reader see why your work clearly answers the questions raised in the rest of the introduction.

Notes on Citations and assertions in the introduction.

- For every assertion of knowledge, you should provide a citation to support your statement, unless the knowledge is found in undergraduate text books. The article you cite should contain data or analysis that support your statement.
- Cite the original work(s) if just one or two articles exist that support your statement, but cite a review if the review supports your statement with an analysis of multiple papers.
- For assertions of remaining obstacles/problems/issues, you only need to cite an article if someone else made you realize this or you know someone else already said it.

Writing a methods section

Purpose: The methods section has two functions. First, it helps readers, particularly experts in the field, *evaluate your work to determine whether it is reliable*. Second, it allows someone else to *repeat your work* at a later time to verify your conclusion or to pick up where you left off. This section is the only one that doesn't require a story line because it will be used a reference.

Structure. For each method, provide a subtitle and its own paragraph, to help readers identify the one thing they want when they use it as a reference section. You may list the methods in the order they were used, or any other order you chose. You may want to relate to figures, and/or say "unless noted otherwise" if you use a standard procedure but vary it in occasions. Just follow through to note the exceptions when you describe results.

Level of detail. Methods are not Procedures. You can assume with the method that the reader is knowledgeable about this type of experiment; you don't need to teach the method, just provide the key details someone who uses that method would need to reproduce your work. Keep in mind that there are many possible procedures that could be used for the same method, and that should give the same result. You don't need to include details that should not affect the reproducibility of the work. If you are using a method that was described before, you may choose to cite the original work describing this method, to make your work more concise. Make sure the work you cite describes the method, rather than a citation to a method.

Methods are important during writing. Remember that during the writing process, your methods section tells your co-authors exactly what was done and how, so all contributors should make sure their part of the methods are there and complete. This should be provided along with the results! Co-authors should read the methods written by others to assess the level of certainty based on the methodology, so they can give input as to whether anything should be done differently to meet the goals of your paper. If any of you can't understand what was done, one of the authors should be asked to provide more detail. This will ensure that the methods section provides the same function for the readers after publication.

Writing a Results Section

Purpose: The results should answer a question or series of questions. This means it is organized around the questions to be addressed, rather than a description of experiments. However, the results should address the level of certainty of the answer(s) so needs to describe what is done, and how it is interpreted to exclude alternative explanations of the data to increase the level of certainty. Recall that your reader will not read your results except as a reference, so your description of the data must mention anything about the methods necessary to understand the data (but not to reproduce it, or to evaluate whether they agree with your methodology).

Structure: Results includes: figures showing data, figure captions explaining figure, data too simple to require figures, if any, and text describing the data and figures, with simple analysis. Provide structure and reiteration to emphasize your main points:

- Introduce each data set or figure with an introductory sentence(s) that clarifies the question being asked.
- Summarize the section by clearly stating the main conclusion learned in that section.
- Use segues that connect each conclusion to the question of the next section.
- Organize the figures and sections around the main points you want to make.
- Short subtitles for the sections are optional, but can help your reader find your main points.

What makes an effective figure?

- Figure is structured to most easily communicate the meaning of the data you want to convey.
- Legends should be intuitive – they should indicate the key differences between the data sets being compared in that figure, and be short but understandable. (Caption can identify aspects common to the whole figure.)
- If your data requires a lot of quantitative analysis or processing, use multiple panels to show the processing stages on one example of the original data, then show the final analyzed data for all conditions being compared.
- Include any controls and statistical analysis and describe briefly what error bars represent. Include statements about how many times the entire experiment was repeated or how many tests were averaged (n =3).
- I recommend 9 point Arial minimum.
- When possible, use black and white or color-blind friendly colors. Patterns or colors should group the data conceptually and to be as consistent as possible between multiple panels or figures.

What makes an effective caption?

- Short title states the overall result, question being asked, or topic, in a way that is distinct from the other figures in this paper.
- Allows figure to stand-alone to be understood without reading the main text. Therefore, provides enough information to understand the legends and axis titles (which are usually too short to stand alone)

- Clarifies any details of methods that are not defined in the method section because they are specific to that figure.
- Interpretation of data not required but may be allowed.

What makes an effective text description of a data figure?

- Start your description of each (set of) data with a motivation such as "in order to determine if…"
- Describe the direct observations, referring to the figures.
- Address controls and statistics in your narrative to argue the level of certainty (LOC) of the direct conclusions of the figures.
- At the end of the paragraph(s) describing this data set, summarize the key conclusions and/or suggest (low LOC) an interpretation that will motivate the next figure.

What data do I include vs leave out?

- Good answers:
    - Anything that doesn't directly relate to the story you are telling. You don't want a distraction.
    - If data has methodological problems or the controls failed, so that you don't trust it.
    - Anything that makes the story into two stories.
- Bad answers:
    - Nothing! You should get credit for everything you did.
    - Any data that does not agree with your hypothesis or that is not consistent with your other results.

How much interpretation to put in the results?

- Usually put in the Results:
    - All direct interpretation of the data
    - Enough indirect interpretation of the data to write the story line (you may use sentences like "this suggests…." to avoid extensive analysis)
    - Any discussion that motivates more data, since this cannot wait for the discussion.
- Usually save for the Discussion:
    - In depth analysis – don't invite the readers to argue with you now, or they may question your results.
    - Discussion that requires reference to prior work (citations)
    - Discussion of the indirect conclusions addressing the significance of your data

Example: see slides copied below.

Writing a Discussion

Purpose: describe and justify indirect conclusions of the data that address the significance of the findings. You may include rigorous arguments to draw these conclusions at a high LOC or simply provide speculation to inspire future work. Just use appropriate wording to clarify which you are doing for each topic. Your discussion should also address weaknesses and future work, but in a positive light that is useful to your reader, by posing new possibilities and unanswered questions rather than specific experiments or problems that have not been done yet. Examples of this are indicated by an asterisk* below.

Structure: Limit the number of areas/ideas in the discussion to two to four. While a 2 to 6 paragraph discussion is best, a longer one is OK at times as long as there are not 8 unrelated paragraphs.

Potential topics to discuss include the following:

- Summarize the Results. You may summarize the significant conclusions from the results section in the first paragraph of the discussion. I think this is a good idea in a long or complicated paper but a waste of space in a short straightforward one. The reader should be saying "ah, yes, now I understand/see how it all comes together," not "OK, I know that already, get on with it."
- Conceptual models. You may want to present a model for the results you've shown. You may have hinted at this model in the results, but now you bring all the evidence together, and also address alternative models and discuss whether your data argues against them. You may be able to eliminate some but not all models*, so may suggest two models, or even a likely and an alternative model. Models may also be entirely speculative*, simply intended to provide a level of detail to drive further work to explain your conclusions.
- Significance beyond your topic. Consider how your findings may be *generalized* to a broader question of interest to a wider audience, such as in vivo significance of in vitro data, or translation from an animal model to humans, or might be *applied* to solve a technological or clinical problem. Again, you may provide an argument to increase LOC of this significance, or simply speculate in a way that will suggest further work on this topic. In this analysis, you should address how your new idea is distinct and useful given prior knowledge about this broader or more applied problem.
- Relationship to specific highly related prior knowledge. You may need to relate your observations to those of others (or your own earlier works) to help put it in perspective. If your work is similar to another, clarify how it is still new. If your work appears to contradict another work, address how this might be explained while both are still valid observations, to switch your reader from "I don't believe you" to "wow, that's really interesting."

Scientific Writing

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Clarification for Capstone Papers:

- Department has suggestions of format; these are only suggestions.
- Your advisor may have a suggestion or requirement for format – make sure you know which it is.
- Department has requirements for what must be included. These are NOT suggestions.
- If the department requires content that does not fit in the format required by your advisor, use an appendix to which you refer in the main text.
- This lecture describes a "results" and a "discussion" section because most biomedical journals require these two sections.

Clarification for Proposals

- Writing grant, project, or fellowship proposals is slightly different from writing manuscripts, but much of this can be applied. The background section is very similar.

Title

- Your title should provide just enough detail to clarify how your work is different from other works.
- The title should describe the topic, but doesn't need to give the conclusions. However, it might, if one conclusion is most important and easy to convey.

Abstract

- The purpose of the abstract is to:
  - Help people decide whether to read the article.
  - Help remind people when to cite your paper.
- Your abstract should:
  - Provide 1-2 sentences of background
  - Provide minimal description of methods
  - Describe up to three conclusions
  - Describe the significance of the conclusions in 1-2 sentences.
- When you start writing, you want to list your key conclusions in an outline of the abstract, since the rest of the writing must support these points. However, polish your abstract as the last thing you write.

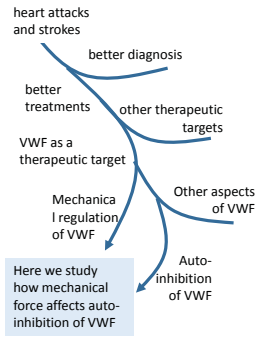
Background Introduction, or Significance and Innovation Section

Introduction/Background

- Purpose: Explains
  - why your work is significant, even the novel part
  - How it is novel (different from related work)
- Structure:
  - Start big picture (understandable with high school education and clearly important to your audience)
  - Follows path to the little thing you are doing
  - Identifies unmet need(s) or unanswered question(s)
  - Usually ends with a "here we" sentence or paragraph that states what was done in a way that clearly addresses those needs or questions.

Tracing Significance with a Branch Pathway.

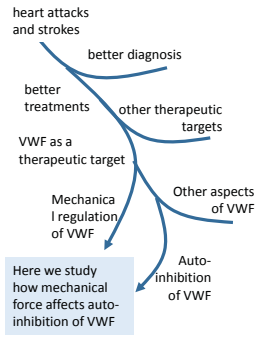
Clarify how you identify each aspect of problem as you narrow the problem to your target (draw the branch pathway diagram), and note the justification (bullet list below):



- *What is the obviously important topic?* Heart attacks & strokes
- *Why do we need better treatments?* Bleeding limits effective treatment
- *Why target VWF as a treatment?* Involved in arterial thrombosis, so more specific target.
- *Why study mechanical regulation of VWF?* That's how VWF is activated.
- *Why study auto-inhibition of VWF?* That's how VWF is regulated.

Converting a Branch Pathway to Writing

- *Stay focused.* Include just enough details to justify the path. This may be one sentence or a whole paragraph for each branch.
- *Don't overreach*. You aren't doing *the most* important work, just an important work, so you don't need to name, describe, or challenge the significance of the alternative branches.
- *Use segues*. These sentences that connect one paragraph to the next provide both interest and clarifying summaries.
- *Use citations*. Near the top of your pathway, you will often cite reviews. Near the bottom, you will cite the most related works.



Exercise: Draw a branch pathway for your project

This exercise leads to an outline of your introduction. For an in-class excercise, just consider steps 1 and 2.

1. Identify the key branches
2. Note the justifications for each.
3. Identify citations you have or need to find to support your justification or to even create a justification.

Clarifying Novelty with Related Work

- Describe the novelty of your work by clarifying how the most related work does not answer the question(s) you have identified as important.
- This helps experts see the distinction between this and work they read or even performed.
- To identify your novelty, list key concepts you combine, in one of the following formats: (see next slide)
  - Novelty sentence (any number of concepts)
  - Venn Diagram (3 concepts)
- If you picked the right key concepts, you will find no or a few publications the cover all key concepts. If you find more, narrow your search!

Key Concepts Novelty Sentence or Venn Diagram

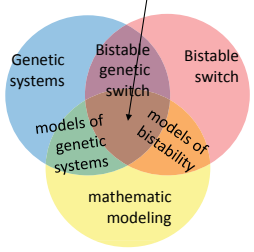
Example using the Gardner 2000 paper on a synthetic biology bistable genetic switch

- Identify the most related work that includes all but one key concept. These don't address your question since they lack the third concept.
- Example: Gardner et al note that …
  - there were validated models of biochemical bistable switches (no genetic systems; orange).
  - naturally occurring genetic bistable switches have been identified. (no validated math models; purple)
  - No validated models on any genetic systems (no bistable; green)
  - And no validated models on genetic bistable switches (3-way intersection)

Novelty Sentence:

A validated mathematic model for a bistable switch composed of a genetic system.

Venn Diagram:



Note on converting to writing

- Don't say things like "little has been published". If there is just one paper that shows exactly what you are proposing, that is very little, but still makes yours unnecessary.
- Make sure you address each of these related papers to say why each is does not answer the questions you pose (e.g. no genetic system).
- Avoid insulting the prior work unless you absolutely can't avoid it.

Results

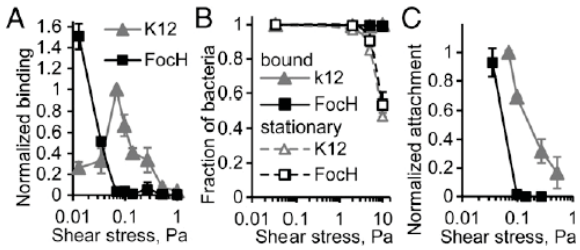
Results Section Overview

- Purpose: Tell a story! Ask and answer a question or series of questions, by explaining the data, including:
  - enough about the methods necessary to *understand the data* (but not reproduce or evaluate the methods)
  - the data itself, including controls and statistics
  - Interpret the data to draw direct conclusions
  - Interpret the data to describe level of certainty of the direct conclusions.
- Structure: Results includes:
  - Figures showing data
  - Figure captions explaining figure
  - Data too simple to require figures, if any
  - Text describing the data and figures, with simple analysis.

What Makes an Effective Figure?

- Figure is structured to most easily communicate the meaning of the data you want to convey.
- Legends should be intuitive – they should indicate the key *differences* between the data sets being compared in that figure, and be short but understandable.
- If your data requires a lot of quantitative analysis or processing, use multiple panels to show the processing stages
- Include controls and error bars as needed
- I recommend 9 point Arial minimum.
- When possible, use black and white or color-blind friendly colors. Patterns or colors should group the data conceptually and to be as consistent as possible between multiple panels or figures.

Figure from Yakovenko et al (2015) PNAS



- Note that symbols and colors (black vs grey) mean same thing in all panels
- Data has error bars. No p-values here because trends are uncontroversial.
- Here panels are different data relating to same question – how shear stress affects number of bacteria bound.

What Makes an Effective Caption?

- Short title states the overall result, question asked, or topic in a way that is distinct from the other figures in this paper.
- Allows figure to stand-alone to be understood without reading the main text.
- Clarifies any details of methods that are not defined in the method section because they are specific to that figure
- Provides enough information to understand the legends and axis titles (which are usually too short to stand alone)
- Does not require interpretation or description of the data shown in the figure, but is allowed to in most journals. This is stylistic preference.

Figure 1: Yakovenko et al (2015) PNAS Vol 112 (32) p 9884

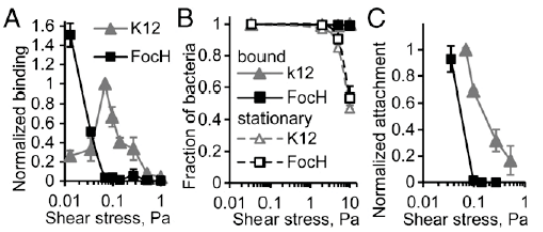


Fig. 1. FimH-mediated *E. coli* binding to man-BSA in flow. (*A*) Number of *E. coli* bound to a man-BSA surface after 5 min injection of free-floating bacteria at the indicated shear stress. (*B*) Percent of *E. coli* that remained bound or stationary on a man-BSA surface after 30 s at the indicated shear stress. (*C*) Initial attachment rate of *E. coli* on a man-BSA surface at the indicated shear stress. In *A* and *C*, data were normalized to the number or attachment rate of K12 at 0.07 Pa. All panels show the mean and SD of two experiments on different days.

- Short title states topic.
- Enough description of the method to understand the figure.
- In this case, no description of the figure conclusions.

What Makes an Effective Text Description?

- First sentence motivates the section/paragraph (the results being described next) by stating the question that was asked.
- A brief description of the methods is necessary so reader can understand the data. (To critique or reproduce the method, they will need to refer to the methods section).
- The figure or data is then described
- The conclusions of the figure are summarized in the last paragraph. This summary may be the direct conclusion or an obvious indirect conclusion with appropriate LOC.
- This summary and the motivation sentence in the next paragraph should provide a logical segue between the two, that draws your reader.

Notes for each results section

- Section may address
  - Theory (equations)
  - Computational data (simulations)
  - Methods (experimental set up, device design)
  - Etc.
- This will change the description of the figure, but still need to use the motivating sentences, and clear structure
- Don't assume they read your methods
- You can assume they read the introduction
- But it doesn't hurt to reiterate/remind the reader of information stated there.

Text describing Figure 1 from Yakovenko et al (2015) PNAS

Bacterial Adhesion in Flow

To determine whether the inactive state of FimH is important for mediating adhesion in flow, we compared two strains of E. coli expressing the activated FocH variant of FimH, versus the wildtype K12 variant that is in the inactive state prior to binding. The two strains had an otherwise identical genetic background, and expressed similar levels of FimH when analyzed by flow cytometry (Table S1). First we performed binding assays, in which we infused bacteria at various shear rates over surfaces coated with man-BSA, and used video microscopy to count the number of bacteria bound to the surface. Man-BSA was used since E. coli adhesion to this glycan is similar to that on mammalian epithelial cells (28). As observed previously (25, 32), bacteria expressing K12 displayed shear-enhanced adhesion (Fig.1A); they bound poorly at low shear (0.013 Pa), well at moderate shear (0.07 Pa), and poorly at high shear (0.14 Pa). In contrast, bacteria expressing FocH bound much better than K12 at low shear, consistent with the idea that the FocH variant is activated. Bacteria expressing FocH displayed shear-inhibited binding, with decreased numbers binding at higher shear rates. Indeed, at moderate to high flow, far more bacteria expressing wildtype K12 bound relative to those expressing the so-called activated FocH. This demonstrates that wildtype FimH provides a functional advantage for adhesion at moderate to high flow.

Section heading indicates topic

Text describing Figure 1 from Yakovenko et al (2015) PNAS

Bacterial Adhesion in Flow

To determine whether the inactive state of FimH is important for mediating adhesion in flow, we compared two strains of E. coli expressing the activated FocH variant of FimH, versus the wildtype K12 variant that is in the inactive state prior to binding. The two strains had an otherwise identical genetic background, and expressed similar levels of FimH when analyzed by flow cytometry (Table S1). First we performed binding assays, in which we infused bacteria at various shear rates over surfaces coated with man-BSA, and used video microscopy to count the number of bacteria bound to the surface. Man-BSA was used since E. coli adhesion to this glycan is similar to that on mammalian epithelial cells (28). As observed previously (25, 32), bacteria expressing K12 displayed shear-enhanced adhesion (Fig.1A); they bound poorly at low shear (0.013 Pa), well at moderate shear (0.07 Pa), and poorly at high shear (0.14 Pa). In contrast, bacteria expressing FocH bound much better than K12 at low shear, consistent with the idea that the FocH variant is activated. Bacteria expressing FocH displayed shear-inhibited binding, with decreased numbers binding at higher shear rates. Indeed, at moderate to high flow, far more bacteria expressing wildtype K12 bound relative to those expressing the so-called activated FocH. This demonstrates that wildtype FimH provides a functional advantage for adhesion at moderate to high flow.

First phrase in section motivates the section

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Motivation is followed by a brief description of methods so that reader understands what was done.

Note that the methods mention design related to level of certainty (isogenic strains and expression data mean that any difference will be due to FimH variant function)

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brief description of methods is followed by description of the first panel of the figure.

Here, statistical tests were not necessary to draw conclusions, so were simply not mentioned.

As observed previously (25, 32), bacteria expressing K12 displayed shear-enhanced adhesion (Fig.1A); they bound poorly at low shear (0.013 Pa), well at moderate shear (0.07 Pa), and poorly at high shear (0.14 Pa). In contrast, bacteria expressing FocH bound much better than K12 at low shear, consistent with the idea that the FocH variant is activated. Bacteria expressing FocH displayed shear-inhibited binding, with decreased numbers binding at higher shear rates. Indeed, at moderate to high flow, far more bacteria expressing wildtype K12 bound relative to those expressing the so-called activated FocH. This demonstrates that wildtype FimH provides a functional advantage for adhesion at moderate to high flow.

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Last sentence of the paragraph summarizes the direct conclusion of the figure (1A) being discussed.

This demonstrates that wildtype FimH provides a functional advantage for adhesion at moderate to high flow.

To determine whether the poor performance of FocH for binding at moderate to high flow was due to an inability of FocH-expressing bacteria to *remain* bound in these conditions,

First sentence of the next paragraph asks the question to be addressed by figure 1B in a way that connects to the previous summary.

What order should the figures be presented?

- Not necessarily chronologically.
- Most important or easiest to understand first - Don't lose your audience!
- Tell a story – each figure should lead to the next. Outline the conclusions and questions, which should act as segues that connect the figures.
- Examples of questions raised by one figure and answered by the next:
  - What is the mechanism for this observation?
  - What can be done with a device or method that works as just demonstrated?
  - This suggests an interesting conclusion. How can we eliminate alternative explanations to increase the level of certainty?

How much Interpretation in the Results?

Usually put in the Results:

1. All direct interpretation of the data
2. Enough indirect interpretation of the data to write the story line (you may use sentences like "this suggests…." to avoid extensive analysis)
3. Any discussion that motivates more data, since this cannot wait for the discussion.

Usually save for the Discussion:

1. In depth analysis – don't invite the readers to argue with you now, or they may question your results.
2. Discussion that requires a citation
3. Discussion of the significance of your data

What data should I leave out?

Good answers:

1. Anything that doesn't directly relate to the story you are telling. You don't want a distraction.
2. If data has methodological problems or the controls failed, so that you don't trust it.
3. Anything that makes the story into two stories.

Bad answers:

1. Nothing! You should get credit for everything you did.
2. Any data that does not agree with your hypothesis or that is not consistent with your other results.

Story line for section 1 of the Yakovenko Paper

Bacterial Adhesion in Flow

- To determine whether the inactive state of FimH is important for mediating adhesion in flow… This demonstrates that wildtype FimH provides a functional advantage for adhesion at moderate to high flow.
- To determine whether the poor performance of FocH for binding at moderate to high flow was due to an inability of FocH-expressing bacteria to remain bound in these conditions…This demonstrates that the inability of the activated FocH variant to mediate binding at moderate to high flow does not reflect an inability to remain attached.
- Since binding of bacteria from solution requires the ability to initiate attachment …Thus, the poor performance of the activated FocH variant at moderate to high flow can be explained by a deficiency in initiating bacterial attachment.

Story line for the whole Yakovenko Paper

Bacterial Adhesion in Flow

- To determine whether the inactive state of FimH is important for mediating adhesion in flow…
- …Thus, the poor performance of the activated FocH variant at moderate to high flow can be explained by a deficiency in initiating bacterial attachment.

Bond kinetics and mechanics

- To further understand the difference in bacterial binding mediated by the two variants, we investigated the difference in association and dissociation of FimH-mannose bonds for the two variants…
- ... This in turn suggests that the active state has a slower association rate that reduces initial attachment in high flow conditions. That is, attachment at high flow may benefit from the inactive state.

Role of conformational state in bacterial binding.

- To verify the importance of the inactive state in initiating adhesion at high flow, …
- …This demonstrates that *E. coli* binding to man-BSA via FimH at high shear stress (e.g. > 0.1 Pa) requires the inactive state of FimH.

Class exercise

1. Engler paper (Matrix Elasticity Directs Stem Cell Lineage Specification)
2. Read/refer to the first results section on page 679, describing figure 1A and 1B. ("Cell Morphology…)
3. Answer the following questions on the Text:
   1. What question(s) are they asking?
   2. what conclusion(s) do they draw?
   3. What makes it easy or hard to understand this?
4. Critique figure 1B regarding understandability of figure and caption.

Discussion

Purpose and Structure

- Purpose: describe and justify indirect conclusions of the data that address the significance of the findings. For each topic, you may speculate to inspire future work, or argue to make your point at a high LOC.
- Structure: identify specific topics to be addressed, trying to keep to 4 or fewer, with no more than 1-2 paragraphs for each.

Discussion Topics to Consider

- Summarize the results. This is not necessary but is very helpful when results are confusing or long.
- Conceptual models. You may want to present a model for the results you've shown, now that you can bring all the evidence together from all your figures and from citations.
- Significance beyond your topic. Consider how your findings may be generalized to a broader question of interest to a wider audience:
  - Physiological significance of in vitro data.
  - Human significance of an animal model.
  - *application* to solve a technological or clinical problem.
- Relationship to specific highly related prior knowledge.
  - If your work is similar to another, clarify how it is still new.
  - If your work appears to contradict another work, address how this might be explained while both are still valid observations, to switch your reader from "I don't believe you" to "wow, that's really interesting."

Useful Scientific Writing Exercises

- Critique style of published work
  - Deconstruct an article you read to make sure you really understand, instead of just think you do:
    - Outline the branch pathway, and novelty sentence in the background
    - Outline the motivation and conclusion of each section.
    - List the issues addressed in the conclusions.
  - Identify stylistic strengths and weaknesses that made the article easier or harder to understand and deconstruct.
- Get a peer review.
  - Have a colleague do this same exercise – deconstruct, and identify stylistic strengths and weaknesses.
  - Compare their deconstructions (what you did convey) to what you meant to convey, and fix if needed.
  - Fix the stylistic weaknesses they found.