The opinions expressed are solely my own and are not necessarily shared by the Department of Physics or the University of Illinois. But they should be.

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Too often, scientists think of doing research and writing as discrete tasks that have little to do with one another. Today, I’d like you to think of them as a feedback loop, where progress in one informs and drives progress in the other.

From Peter Woodford: “Somehow the discipline of crystallizing a thought into a grammatical sentence with a beginning, a middle, and an end clarifies, sharpens, and delimits the thought.

Learning to write in the style described here will not only make you a better writer, it will also make you a better scientist. It will force you to see holes in your thinking, areas where you’ve made assumptions, places where you should add references, or data, or further analysis.
The idea of creating separate holding pens for various parts of a technical document was first articulated, as far as I know, by F. Peter Woodford in *Scientific Writing for Graduate Students: A CBE Manual* (Rockefeller University Press, New York, 1968). Although targeted to graduate students in the life sciences and dated in language (not *all* scientists are men!), the fundamentals of Woodford’s approach remain sound.
Fill your reservoirs thoughtfully
Is the item really necessary?
To what reservoir does it logically belong?
Content for reservoirs:
- Facts, observations, data
- Figures and captions
- Tables
- Analogies
- Ideas and speculations
- Unanswered questions
- Key words
- Felicitous phrases

At this stage, don’t worry too much about niceties of language—concentrate on getting things sorted into the right categories.

Vernon Booth, a major god in my pantheon (Communicating in Science: Writing a scientific paper and speaking at scientific meetings, 2nd ed. [Cambridge University Press, Cambridge, 1993]), also recommends the use of writing reservoirs.
Now you’re ready to start building a coherent narrative

In the next steps, we’ll take the **content** of our reservoirs and make a **plan** to guide the building of our paper.
It’s a truism that in order to get someplace, you’ve got to know where you’re going.

Before you start writing, decide where you want the reader to end up.
An outline is a tool that enables you to look systematically at how a paper or presentation is organized. Learning to write from an outline is one of the easiest ways to (1) get started and (2) improve the content and coherence of your scientific writing.

Today, we’ll look at how to use outlines to get started on any writing project.

Many of the ideas about full-sentence outlining are taken from a course given by Ohio Eminent Scholar and Professor of Physics at The Ohio State University, John W. Wilkins (who is also a Physics Illinois alumnus). His trenchant thinking and incisive writing on communicating in physics are gratefully acknowledged.

For more of Professor Wilkins’ excellent advice on technical writing, see his “Brief Guide to Writing and Speaking”:
Some beginning authors think that if they spent 90 percent of their time on some aspect of the experiment, they should devote 90 percent of the paper to that topic, or they should present a history of the experiment.

Readers don’t want to know all the things that went wrong, all the components that failed, all the adjustments that had to be made to get the data. They want to know what worked, how it worked, what the results are, and what you think they mean.

Remember, a journal is an archive of your results and how you got them so others can reproduce them, not a cemetery where you bury all your mistakes.
Formal physics papers are *always* presented in this order, but they’re not written in this order.

No experienced scientist that I know of starts with the title and writes a paper sequentially. Nobody.

Most scientists usually write papers in the following order:
1. Methods
2. Results
3. Discussion
4. Conclusions
5. Background and Introduction
6. Acknowledgments
7. References
8. Abstract & Final Title

You *must* have an outline to keep a coherent narrative flow as you write the separate sections of a paper.
Writers use two kinds of outlines—“topic” and “sentence”

Topic outlines use short phrases
- CO₂ underground storage—motivation
- Advantages of deep saline formations
- Convection could provide “stirring”
- Boycott effect

A topic outline is a good way to get started, but it may not be detailed enough for science writing

A topic outline consists of short phrases. Here’s an example of a topic outline for a paper on carbon sequestration in deep saline formations.

A topic outline may be best for organizing a number of issues or ideas that could be presented in a several different ways, where the order of presentation is not important. Unfortunately, that is not typically the case for science papers.

While they might not be detailed enough, topic outlines are fast and easy to write. You might find it helpful to sketch out a topic outline first, and then expand it into a full-sentence outline.
Writers use two kinds of outlines—“topic” and “sentence”

Topic outlines use short phrases
  - CO₂ underground storage—motivation
  - Advantages of deep saline formations
  - Convection could provide “stirring”
  - Boycott effect

Sentence outlines use full sentences (duh!)
  - Deep saline aquifers (DSAs) are underground salt-water reservoirs capped by impermeable rocks.
  - DSAs offer large storage capacity for carbon capture and sequestration.
  - Sequestered CO₂ would rise and form a separate layer that restricts dissolution.

Today we’ll look at the sentence outline, which is better suited for papers (and talks) that require complex information to be presented in strict logical order.
Practice full-sentence outlining
Improved clarity
Improved logical argument
Improved cohesiveness; better transitions
Improved conciseness
Improved control of length
Improved writing efficiency
Improved reader experience

This slide is an example of a “topic” outline—the order that the points are presented in doesn’t really matter

Writing a sentence outline will help you as a writer in a variety of ways:

• Your writing will be clearer and more direct. It’s unlikely that you’ll write a cogent paragraph until you can write a sentence that plainly articulates the point of that paragraph.

• Your arguments will be stronger. A sentence outline shows you the narrative flow of the paper. Are your ideas arranged in the most logical, persuasive way to lead the reader to the conclusions you want him or her to reach? It’s much easier to move sentences around as you are planning a paper than it is whole paragraphs.

• Your paper will be more cohesive, because you’ll be more aware of where transitions are needed to move the reader from one idea to the next.

• Your writing will be more concise. A sentence outline will help you spot superfluous material that stands in the way of a straightforward narrative.

• You will get a better idea of the size and scope of your final paper. The length of proposals, journal articles, and conference papers is usually strictly limited. A sentence outline makes it easier to estimate what the final length of your document will be and allows you to make any needed adjustments earlier in the writing process. It’s agonizing to make major cuts after you’ve already gotten something written, and you’ll avoid the temptation of leaving digressions in your paper because of pride of authorship.

• You will ultimately save time. The investment in planning and getting organized now will pay off in an easier-to-write, coherent, clear final document.

• Your colleagues will eagerly look forward to hearing your next talk or reading your next paper. Your reviewers will expedite your publications. Funders will shower you with $$$ (Okay, maybe not #3...).
Tips for writing a sentence outline

Make your sentences as specific and quantitative as possible.

If you have two closely related sentences, combine, differentiate, or eliminate one.

Make a logic map of your sentences; can you show a linear progression of your ideas?

Devise a method that makes it easier to move sentences around and “see” the overall structure of the paper.

This slide is an example of a “sentence” outline—use it for writing projects (papers, proposals, talks) where it’s important to show a logical progression of your ideas.

Make your sentences as specific as possible. The purpose of the sentence outline is to help you spot missing or superfluous material. If your sentences are vague and generalized, you’ll lose the main advantage of sentence outlining.

If you have two sentences that say about the same thing, eliminate one of them, combine them, or differentiate them.

Ideally in science writing, the narrative should flow logically and incrementally from Point A to Point B to Point C to the conclusions. If your outline does not reveal a logical progression of ideas, move things around until it does.

If you’re not sure what a logic map is and want to read an astonishingly badly written explanation of the concept, see
http://static1.squarespace.com/static/5665d05625981deffce6a3c88/t/568976be4bf118b4ed5cd5e1/1451849406364/creatinglogmap.pdf.

A word processing document that displays only part of your outline at a time may not be the best way to get an overall look at your paper. Experiment with other methods—index cards dealt out on a big table, Post-It notes stuck on a wall—use your imagination.

Some scientists I know start out with a visual “outline”; they decide first on the figures they want to present and build from there.
Start by writing down the main points you want to make

- The NASA Solar Dynamics Observatory (SDO) was launched in 2010 to study the solar corona.
- One component of SDO is the Atmospheric Imaging Assembly (AIA), a suite of four telescopes.
- Mirrors image Sun at all seven EUV wavelengths.
- The Sun is the source of all space weather, but its physical processes are poorly understood.
- The AIA is composed of highly reflective multi-layer mirrors.

TIP: Write a complete sentence for each point, in any order now—we’ll arrange the points logically in the next step

At this stage of your writing project, think about what you want to convey to your audience. What are the important points that you want them to understand and remember? And where do you want them to end up? (Hint: at your predefined conclusions!)
As you’re deciding about these points, keep three questions in mind

- What is the main point I want to convey? What do I want to convince the readers of?
- Who is my audience? What do they already know, and what am I going to have to explain? What is their motivation for reading?
- What are my space and time constraints?

TIP: Your answer to these questions will determine the intellectual content of your paper.
Next, arrange the points so they provide a logical narrative.

- The NASA Solar Dynamics Observatory (SDO) was launched in 2010 to study the solar corona.
- One component of SDO is the Atmospheric Imaging Assembly (AIA), a suite of four telescopes.
- Mirrors image Sun at all seven EUV wavelengths.
- The Sun is the source of all space weather, but its physical processes are poorly understood.
- The AIA is composed of highly reflective multi-layer mirrors.

Next, arrange the points in a logical order so they provide a coherent storyline.

Think of this step as creating a map to guide your reader through your talk, paper, or proposal to the conclusions that you want him or her to reach.

Each one of these points is going to be a signpost along the journey.
Check to see if you’ve left anything out...

- The Sun is the source of all space weather, but its physical processes are poorly understood.
- The NASA Solar Dynamics Observatory (SDO) was launched in 2010 to study the solar corona.
- One component of SDO is the Atmospheric Imaging Assembly (AIA), a suite of four telescopes.
- The AIA is composed of highly reflective multi-layer mirrors.
- Mirrors image Sun at all seven EUV wavelengths.

... or if you’ve included superfluous material that will derail the logical flow of your story

Check to see if you’ve left anything out, or if you have superfluous statements that lead the reader off the trail that you’d laid out for him or her to follow.

Make adjustments (additions or deletions) now. It’s much easier to write from a coherent outline than to go back after you’ve already written a wet mess and try to impose some sort of logical structure on it.

Note how the sentences are arranged in a logical order and “zoom in” from general to very specific—a standard paradigm for science writing.

One of the key advantages of this method is its scalability—you can use it for short papers, theses, talks, posters—for any audience.

Suppose you’re writing a maximum-4-page paper for Physical Review Letters and you have 21 sentences and three figures. You know right NOW, before you write another word, that you’ve got too much material for one PRL. Make your adjustments now—it’s much less painful than trying to cut later.
Number your sentences...

1. The Sun is the source of all space weather, but its physical processes are poorly understood.
2. The NASA Solar Dynamics Observatory (SDO) was launched in 2010 to study the solar corona.
3. One component of SDO is the Atmospheric Imaging Assembly (AIA), a suite of four telescopes.
4. The AIA is composed of highly reflective multi-layer mirrors.
5. Mirrors image Sun at all seven EUV wavelengths.

Now you’re ready to start writing...

It seems silly, but numbering actually helps to keep you on track. Writing is an evolutionary process, and if you have a numbered list of points and check them off as you write, you’ll stick to your plan.

You can also start writing “in the middle” if you want to; as long as you’ve got a check-off list, you won’t forget important points.
Each sentence in your outline becomes the “topic” sentence for a paragraph in your paper

The Sun is the source of all space weather, but its physical processes are poorly understood.

<We put a paragraph here>

The Solar Dynamics Observatory was launched by NASA in 2010 to study the solar corona.

Your main points—your topic sentences—provide a framework for your narrative.

The purpose of every additional word that you put in a paragraph should be to support and explain the topic statement and move the reader logically and incrementally to the next topic statement.
Celia’s foolproof, four-step SEES* method to crank out science writing:

1. Put the topic sentence first
2. Explain it
3. Give an example or present evidence
4. Summarize it in a way that leads logically to the next topic sentence

*State ➔ Explain ➔ Exemplify ➔ Summarize

Tip: Use the same construction paradigm for paragraphs, subsections, and sections of your paper

Use the formula to create logical, coherent paragraphs.
In science writing, the topic sentence is almost always the first sentence of the paragraph. While literary writing might put the topic sentence last, to build suspense, or in the middle, to redirect a reader’s attention, put the topic sentence first in your paragraphs to emphasize your important points and reinforce the logical structure of your arguments.

Readers pay the most attention at the beginning of chunks of text. Exploit this natural human tendency by putting your topic sentences in the places where people are most likely to recognize and remember them—as the first sentence of each new paragraph.
2. Explain it

The Sun is the source of all “space weather,” but its physical processes are poorly understood. **Space weather refers to conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere of the Earth that affect the performance and reliability of space and terrestrial systems and that can endanger life and health.**

The Solar Dynamics Observatory was launched by NASA in 2010 to study the solar corona.

In the second sentence(s), explain or expand on the ideas conveyed in the topic sentence.
Your explanation will often include illustrative examples or evidence for your claims. Put them next.

I particularly like this example, because the author used an example from terrestrial weather as an analogy to explain space “weather.”
4. Summarize and transition

The Sun is the source of all “space weather,” but its physical processes are poorly understood. Space weather refers to conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere of the Earth that affect the performance and reliability of space and terrestrial systems and that can endanger life and health. For example, a coronal mass ejection, the solar equivalent of a hurricane, can disrupt telecommunications systems on Earth. Solar research is needed to understand solar processes and predict space weather.

The Solar Dynamics Observatory was launched by NASA in 2010 to study the solar corona...

Finally, add a transitional sentence that sums up this paragraph and leads the reader logically to the next topic sentence.

In this example, the fourth sentence repeats the ideas of “space weather” and “not currently understood” that are introduced in the topic sentence and sets the stage for the next paragraph, which explains what the SDO is and what kind of research it is designed to do. Thus the two paragraphs are linked structurally by the evolution of the ideas and explanations that they present.
You can use the same method for talks, too!

Put your topic sentence at the top of the slide

Use the rest of the slide for

- illustrative figures
- data
- examples
- clarifying details

Take advantage of the way people’s attention naturally ebbs and flows. People typically pay attention at the beginning, drift off in the middle, and then snap back to attention when something changes (the indentation of a new paragraph or the change of a slide).

Use that natural human tendency to position your important points where your reader or your audience is paying the most attention—at the beginning of a paragraph or the top of a slide.
Instead of a few-word, contentless “title,” put a topic sentence at the top of the slide, which the audience will read first, that explains and unifies the rest of the information presented on that slide.

When you’ve nearly finished your presentation, copy the title statements of each slide into a separate document and read them as a narrative. Does your “story” hang together? Are there obvious gaps? Is any part of the story hard to follow?
Think of the section headings of your poster as your topic sentences. Use the rest of the space to explain, exemplify, and summarize.
Tip: Start filling your reservoirs and crafting your outline early

Start writing while you’re still taking data

Conventional approach is finish the project and then write it up—bad idea

Making the outline will make you see where the holes are and where more (different) data are needed

Much easier to fill in those holes while the project is on-going

Commit to writing incrementally; writing should be an integral part of your research work—think “feedback loop.”
To recap...

1. Heed Aristotle—logic before language.
2. Start filling your reservoirs while the project is still underway.
3. Write from an outline. Always! And use a full-sentence outline for best results.
4. Use the SEES paragraph method to create a tightly written, coherent logical narrative.

NOTES: