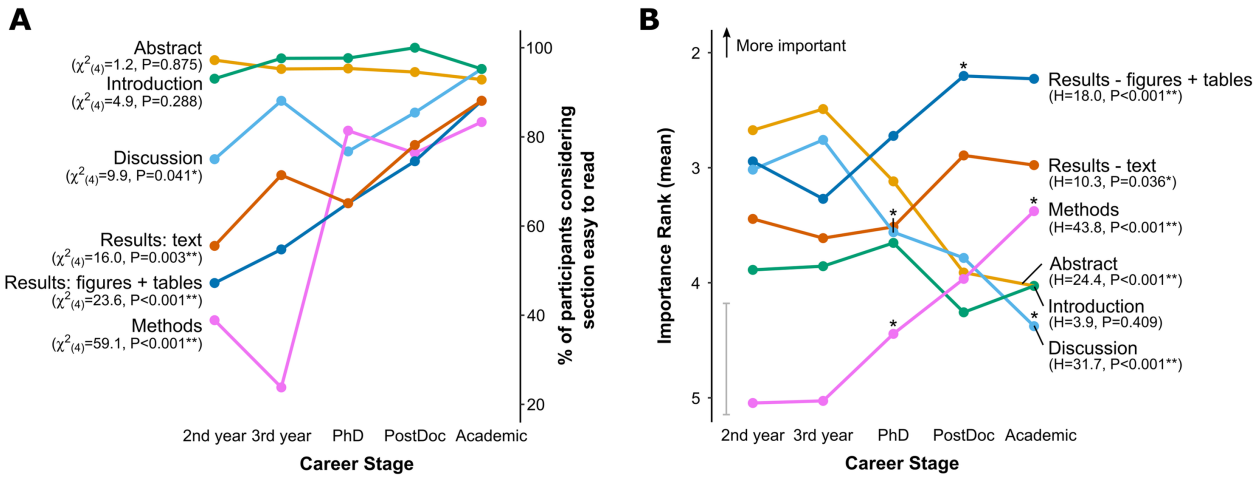
HIXON WRITING CENTER

LEARN TO READ SCIENTIFIC JOURNAL ARTICLES LIKE A PRO

EXPERTS READ SCIENCE PAPERS DIFFERENTLY

Studies on students and professionals in STEM suggest that the way people interact with scientific papers changes dramatically as they move from undergraduate studies to professional roles. Students become more comfortable with reading and prioritize different sections of papers as they move from learning about a subject to being an active participant in research. Often, the most challenging parts of scientific papers, such as the information-dense methods and results sections, are the most valuable for research professionals.



A) In this study of biology students and professionals, the sections of academic articles that are challenging for undergraduates in their 2nd or 3rd year become easier to read with more experience. **B)** What matters to undergraduates in a paper is different than what matters to professionals. Academic professionals tend to care most about results and methods – the sections that are most difficult to read as a student. Source: Hubbard, Katharine E., Dunbar, Sonja D. "Perceptions of scientific research literature and strategies for reading papers depend on academic career stage." *PLOS ONE* 2017.

Learning to read scientific writing is a long-term process, just like any other research skill. However, there are still things you can do today to become a better reader. In the following sections, we will explore how professionals interact with the scientific literature and important considerations and tips for reading more effectively. Practicing these strategies to critically analyze a writer's claims, extract useful information from texts and figures, and build a strong knowledge base will accelerate your STEM journey and make future papers easier to understand.

FIRST: CHOOSING A PAPER TO READ

Types of Papers, Journals, and Publication Processes

When reading scientific journals, you will likely encounter **research articles** about specific projects written with the traditional introduction-methods-results-discussion structure or **review articles** that summarize and reflect on existing literature on a particular topic. Some scientific journals also publish other paper types, sometimes referred to as **communications** or **letters**, that may contain "mini" research stories that aren't appropriate for a full-size research article, responses to recently published papers, or other expert commentary. Some journals are also dedicated to **methods papers** in which researchers share newly developed techniques and protocols. While in some fields publication in a journal is most common, in others, researchers most often submit their work as **conference papers**.

Similarly, not all scientific journals are the same. Some journals have a broad focus (such as *Nature* or *Science*), while others may focus on a narrow topic area. Some are associated with specific scientific societies that support research in a specific subject and/or geographical area (for example, the *Journal of Biological Chemistry* is published by the American Society for Biochemistry and Molecular Biology). Some may even have separate publication routes for specific contributors (for example, *PNAS* has a different process for National Academy of Sciences members than for external contributors). Every journal has its own requirements for paper length, style, and content, which shape the kinds of research stories that they publish. The exact criteria by which papers are chosen differ from journal to journal, with some having stricter standards than others, but in most cases, a paper must be chosen by an editor and pass through peer review to be accepted for publication. It is also important to be aware that predatory journals that publish articles with limited quality control or falsified materials do exist and are not always easy to spot without careful research and knowledge of the field.

Unlike most research journals, **preprint servers** like Arxiv or Bioarxiv host research papers that have not yet been peer reviewed. This does not necessarily mean these papers are of low quality. In some fields, it is common to release an article as a preprint before seeking formal peer-reviewed publication. In other cases, researchers share data through preprints to enhance collaboration on high-stakes projects that would be hampered by waiting for peer review. For example, starting in 2020, many virology researchers began publishing through preprint servers to facilitate rapid discussion of results pertaining to the pandemic. Another reason researchers release preprints is to stake a claim in a competitive field – when researchers have reason to be concerned another group may be trying to publish similar results before them ("scooping" them), they may post a preprint before submitting to a journal to ensure that their work is the first online and visible to the broader community.

What's important to remember about preprints is that they are not curated and have not gone through the standard quality control steps of a traditional publication. While many of these papers may be of high quality, some of them are not. It is up to you, the reader, to determine the expertise of the authors, evaluate the quality of the work, and remember that preprints may represent "drafts'' with unpolished writing or incomplete stories.

Finding a Paper to Read

There are many strategies for finding scientific articles to read. **Keyword searches** through Google Scholar or more field-specialized databases, such as those provided through the Caltech Library are commonly used, though to get specific, relevant results, you may need to experiment with search terms and settings. **Review articles** are also great starting points – these articles synthesize information from a variety of sources to create an accessible summary of the state of the field. A good review article will point you toward many relevant papers in its reference list. **Paper discovery or citation mapping tools** designed to help you find articles related to ones you have read can help you uncover relationships between papers and authors through their visualization features. Some examples include ResearchRabbit, Inciteful, Citation Gecko, and Litmaps. Similarly, some **citation managers,** such as Readcube Papers**,** have recommendation tools for finding papers related to those in your library. Finally, **AI search tools** such as Semantic Scholar enhance your keyword searches with short paper summaries and additional contextual information.

No paper discovery tool is perfect; depending on the search strategies the tool employs and how you use them, the resulting recommendations may miss highly relevant papers. For example, some tools prioritize papers that are more recent or more highly cited, meaning you will be shown fewer older foundational papers or papers too new to have been cited in other work. It is also important to use AI-based search tools with care. While generated paper summaries can provide quick insights to help you identify relevant results, they may contain inaccuracies or poorly capture the authors' intentions. Before drawing conclusions about a paper, make sure to look at the abstract to evaluate the paper through the authors' own words. Remember that all search tools are starting points for research, not replacements for reading and evaluating papers yourself.

What Questions Do Experts Ask When Evaluating Papers?

STEM professionals often ask additional questions to understand the context of a paper they are interested in reading:

- *Who are the authors? Have I seen their names before? Where do they work? Have they written about this subject before, or are they exploring a new research area? Are they an interdisciplinary team?* These questions reveal the kinds of perspectives, experiences, and intended audiences the writers bring into their work. Science can be a very small world. While working on a research project, STEM professionals may get to know many of the people in the field. They may pay attention to which groups have a specific expertise or promote a particular method or perspective and get to know other researchers and their scientific approaches through collaborations, seminars, or conferences. This information shapes professionals' expectations of papers they read. For example, a reader might expect an established expert who pioneered a particular method to produce reliably meaningful results in the narrow area of their expertise, while an interdisciplinary team might bring a new perspective to the field.

  New to the field? Keep track of authors whose names appear frequently in your reading, talk to colleagues and mentors about other groups whose work intersects with yours, and take advantage of any opportunity to network with other researchers in the field. Be

curious about others' academic journeys and ask questions of people whose work excites you – What did they study? Who did they work with? How did they get into the research they do now? You will likely discover that researchers' current perspectives and interests are shaped by those of people they've worked with in the past.

- *What journal was this published in? Is it a journal with a narrow focus or broad? What do people in my field think of this journal? Was the paper peer reviewed? If so, does the journal make the peer review files available?* These questions provide insight into the intended audience and impact of the work, as well as "quality control" steps involved in the publication process. As described above, journals and the papers they publish are highly variable. STEM professionals incorporate information about a journal into their evaluation of a paper. They may read about the journal's publication process, skim recent article titles to get a feel for what gets published, or look up journal metrics such as **impact factor,** which reflects how often articles in the journal get cited by other papers. They pay attention to where influential researchers in the field publish, and where they find the papers most useful to their work.

  While publication metrics or the perceived quality of a journal in a field help set expectations for the quality of published papers, plenty of fantastic research is published (often intentionally) in small journals, and even the most highly esteemed journals may occasionally publish flawed research. In addition, one interdisciplinary journal can be highly regarded for one field, while mostly ignored in another. Knowing something about the journal that published a paper you are reading can help you understand a paper's context and infer the authors' intended audience, but it is important to read widely and curiously rather than limiting yourself to one or two journals.

  New to the field? Start keeping track of where the articles you read are published and pay attention to trends – which journals appear again and again? Read about the journal's focus and policies on their website and learn about the interests of the editors (that is, the people making decisions about which articles get published). Talk to mentors and colleagues about which journals they like to publish in and why.

- *When did this paper get published? What do we know now that we didn't know then? What work inspired this paper?* STEM professionals make a point to stay on top of news in the field, actively seeking out new articles in areas of their interests. However, they don't just stop at articles from the last month or year – they often return to older papers that provide useful context for their work, reveal the history of the field, or explain highly influential ideas that are still applicable today. They make a point to understand not just what they're doing *now*, but the history of research that allowed their project to come to be.

  New to the field? Let your reading inspire future literature searches: if the paper is older than the last year or two, look and see if other articles on the topic have been published since then. If the paper is newer, look at the citations for interesting papers that will take you "back in time" to earlier discoveries that laid the groundwork for the newer work. Find a system that works for you to quickly identify new articles on your topic of interest. For example, set keyword alerts through Google Scholar to be notified when relevant papers are released. Making a point to check for new work will help you become more fluent in the current conversations in the field.

JUST THE GIST: FINDING THE RESEARCH STORY

With the abundance of research available, it is important to be discerning about which papers you invest time into reading. So, how do you choose the right articles to focus on in your limited time? Many STEM professionals report that they read papers selectively and out of order, first reading the sections that give them a clear idea of the research story and only reading the paper in full once they have determined its relevance.

Starting your reading with the abstract, which functions as a succinct summary of the whole paper, allows you to quickly glean the research story. Depending on your field, the abstract may contain some or all of the key story components described below. You may also skim the introduction if you need more context for the research question or skip to the discussion or conclusion to see what claims the writers are making about their work. Note that while these conclusions will give you a sense of where a paper is going and its relevance to your own work, it is important not to take these conclusions at face value without reviewing the results more closely. As you read, look for these components of story:

- What was the **context**? What prior knowledge were the researchers starting with? What perspective do they have?
- What was the **problem** or **question**? What question or problem did the researchers set out to solve? What were their goals?
- What was the **significance** of the question? Why study this subject at all? How did this subject contribute to a broader understanding of the field? What aspects of the work were timely, novel, or broadly applicable?
- What was the **approach**? What methods were important for addressing the question?
- What were the **major findings**? What did the researchers discover, and how did it relate to the research question?

Another way to think about story in scientific papers is to look for or write **ABT statements** (see our Storytelling handout). These statements include an AND (context), BUT (problem) and THEREFORE (solution) component. ABT components are often easily identified in abstracts and introductions by their signal words. Some examples of these signal words include:

AND (CONTEXT)	BUT (PROBLEM)	THEREFORE (solution)
And/also	But	Therefore
In addition	Yet	So
Currently	However	As a solution to this problem we
We know	Despite	As a result
Recent work suggests	Although	To answer this question
Interestingly, importantly	is still not understood	Here we show

EVALUATING SCIENTIFIC ARGUMENTS

While researchers aspire to communicate their work accurately and clearly, it is important to remember that scientific writing is always influenced by the nature of doing science and the personal biases, needs, and perspectives of the people doing it. Researchers are often under pressure to publish as rapidly and frequently as they can. A strong publication record can be the determining factor in finding collaborators, securing funding, keeping a job, or earning promotions and recognition in the field. The process of finding answers to scientific questions is also rarely straightforward, and researchers sometimes put forward competing models, pursue leads to dead ends, argue over interpretations of data, or debate best approaches. As a result, scientific papers represent ongoing conversations in the field shaped by individual interests, experiences, and expertise, rather than transmissions of irrefutable, perfectly objective information. Overall, scientific writing is functionally persuasive writing where researchers try to frame their accomplishments in the best light and build compelling arguments for their interpretations of data.

To make matters more difficult, scientific writing is just as prone to human error and misconduct as anything else. Even with the best intentions and years of expertise, researchers sometimes make errors in data analysis or overlook crucial details that change the way their work is interpreted. Ideally, the peer review system should catch these mistakes, but that system sometimes fails. There are also more malicious cases of fabricated or otherwise misrepresented data, which can be even more difficult for reviewers to detect (to learn more about these issues, see the work of Elizabeth Bik, a microbiologist who works to identify and raise awareness of integrity issues in published research).

With all these complications, it's up to you, the reader, to evaluate the strength of the arguments writers make and draw your own conclusions about the papers you read. This process starts with being aware of how and why STEM professionals make arguments in their writing. When you can identify the strategies writers use to make arguments about the meaning and significance of their work, you can evaluate whether their evidence adequately supports their claims. As you read, look for examples of:

- **Stating motives and objectives:** Scientific articles generally provide clear explanations for why projects were done and what researchers hoped to achieve in the introduction. Successful articles often weave connections to their motivation and objectives throughout the paper to create logical connections between each step in the research process and relate the research project to compelling but reasonably achievable goals. Effective writing should make you the reader understand the research process and feel confident in the importance of the authors' work. If the goals of a paper are unclear, you may feel unsure of the relevance of specific pieces of data or struggle to grasp the importance of the research project for the field. In contrast, writing that overstates the significance of the work or supplies unrealistically ambitious goals may cause you to doubt the writers' expertise or the validity of their findings.

- **Referencing prior work:** Researchers not only cite other papers to provide sources for background information, but also to situate their work in the field. For example, they may discuss prior work to show how the field has developed two competing hypotheses, which may be supported or refuted by the results in the paper, or cite an article that introduced a model useful for interpreting new data. When reading, stay alert to how

writers use others' work. Thoughtful citations reveal how well-read the writers are, suggest who influenced their work, and provide additional evidence for claims that go beyond the researchers' own data. If writers only cite a narrow set of sources closely related to their own research group or fail to acknowledge competing ideas in the field, they may appear less objective and less convincing for critical readers.

- **Justifying methodology:** Effective scientific writing should make it clear why the researchers chose a particular method and that these methods are appropriate for answering the research question. Researchers should include relevant details that allow you to evaluate the strength of their approach and reconstruct their protocols. They may cite related studies that developed the method or provide evidence of the method's suitability for their particular use case. As a reader, ask yourself: were the researchers' choices the best choices? Do I understand why they used the methods they did? If I had the appropriate resources and expertise, could I replicate on these experiments?

- **Validating results through statistical tests:** Researchers often provide additional information that demonstrates the validity of their results and helps readers understand their relevance. This information may address:
    - Generalizability: Did they run their tests multiple times or with multiple samples? Did they use sufficiently large sample sizes to reasonably represent the phenomenon being investigated?
    - Significance: What statistical tests did they run? What were the results? Are the results significant enough to make a difference for the problem the researchers are trying to address?
    - Awareness of the limitations of their methods: Did they confirm their results in another way? Do they mention common pitfalls that might impact your interpretation of their results?

  Many areas of research have specific, standardized protocols for data analysis and data presentation that writers adhere to for easy comparison between papers. Keep an eye out for figures, tests, statistics tables, or other features that appear again and again in papers in your field.

- **Relating results to broader claims:** The discussion section is often where researchers expand on their work by introducing new models, extrapolating their results to new contexts, speculating on applications, or suggesting future directions for research. Even as they move beyond the data, writers often bolster their claims by tying them back to specific pieces of data they have obtained or connecting their ideas to other "knowns" in the field. While the degree to which researchers promote the broader relevance of their own work in their writing varies from field to field, as the reader you should feel supported in interpreting the paper and have a clear idea what the authors consider important conclusions. In addition, be alert for sweeping claims without adequate evidence from the results or other work – this may be a sign that the writers are trying to make meaning from their data that isn't actually there.

- **Addressing counterclaims and limitations:** Writers may also bring up alternative interpretations of their data and explain why their preferred interpretation makes more sense. They may also explicitly mark the limits of the work they were able to do, and they indicate a path for future work. Including alternative explanations or acknowledgement of limitations makes writers appear more trustworthy and reveals

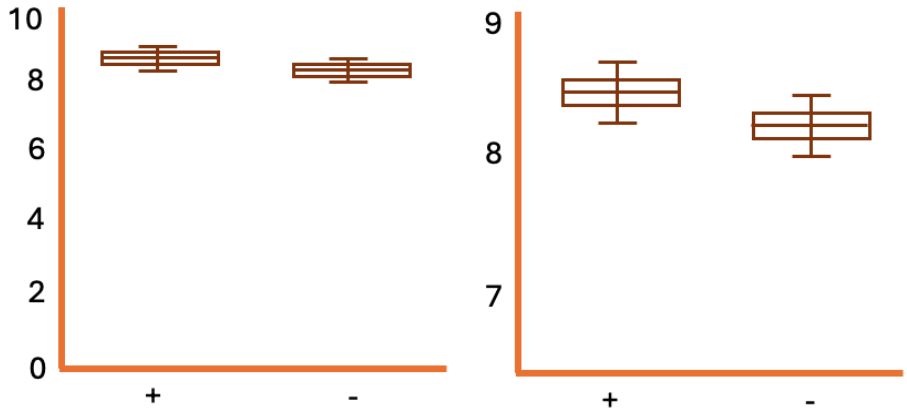
questions for further research to push the field forward. On the other hand, writing that lacks these features may feel uncritical or of uncertain significance.

As you read, put yourself in the shoes of a critical reviewer and ask yourself questions: are these arguments convincing? What alternative conclusions might you draw based on the data? What is missing to make the story stronger? If you run into methods with which you are unfamiliar, or statistical analysis that you haven't seen before, take a moment to look it up – not only might you learn a new tool you can use yourself, but you will be able to evaluate the paper more accurately with this knowledge. For more insight, find a journal that publishes peer review files alongside a final paper. Some *Nature* papers, for instance, include these files (take a look at an example here and here). Read the reviewer's comments to see how readers entrusted with evaluation of a manuscript ask critical questions about the text. What concerns come up most often in this feedback? How many do you think could be addressed through clearer and more convincing writing, and how many can only be addressed through additional experimentation?

A Closer Look at Figures

Figures can make complicated data clearer with visual elements, but they also require extra care to avoid misinterpretation. As you look at figures, ask yourself: can you explain the experimental strategy behind the data shown, and why it was chosen? Do you know what is represented on the plot, and why this visualization strategy was chosen?

Be aware that design choices can influence the way you interpret a figure. For example, items that are close together appear more related than those far apart, and choices of scale or axis labels can make data appear more or less noisy. To see how this works, glance quickly at the figure following this paragraph. At first look, the samples on the left plot might appear more similar to each other than those on the right. A closer inspection reveals that the y-axes of the plots start at different values. The right plot appears to zoom in on the region of interest, revealing differences that were obscured in the plot on the left.



As a reader, be careful to avoid these first-glance assumptions and take the time you need to fully inspect the features of a figure and what data is being shown. Be critical about the choices

writers make in their figures and ask yourself: are the trends I'm seeing real and backed with statistical analysis? Would I interpret the figure differently with another layout?

Finally, in most papers, the figures will not only have a descriptive caption, but will also be referred to and explained in the main text of the article. It can be helpful to read this associated text while looking at the figures. Is there any discrepancy between how the authors describe the data in the text and what is represented in the figure? What might be alternative explanations for the data besides what the authors suggest? How does the figure support (or not) the main message of the paper?

READ TO LEARN: BUILD YOUR KNOWLEDGE BASE

Reading scientific papers can feel especially challenging when you are new to the field. However, this practice is part of many STEM professionals' workflow. Researchers make a point to keep up with the literature in their field to further their knowledge and discover new ideas they can incorporate into their work. They keep track of what they read and return to important papers again and again as they conduct their experiments and discuss what they read with collaborators to share new insights to enhance their projects.

If you are feeling overwhelmed by information while you read, try one of these strategies to test your understanding and keep track of what you discover:

Mini Summaries

For each paper you read, try to distill its significance to one sentence. What is the question being answered? What strategy did the authors employ? What was the outcome? For a slightly less condensed summary, try writing a ~3-sentence **ABT statement** (as described in our Storytelling handout) containing the same components. Keeping a log of each paper you read, or saving these summaries with your papers in a citation manager, can help you keep track of what you are learning and quickly find important information again.

Recall, Summarize, Question, Connect, Comment (RSQC2)

For a more detailed test of your understanding, try the "RSQC2." First, after reading, try to recall the main concepts and terms from the paper from memory. Then, assemble these key ideas of the paper into a summary in your own words. Write down questions about the work – what remains to be explored? What are you curious about? What wasn't explained completely by the paper? What don't you understand? Next, draw connections between this paper and other papers you've read. How does this work relate to the knowledge you already have? Finally, write an evaluative comment about the paper. After all this reflection, what do you think about the paper? Is it helpful/not helpful? What are its strengths and weaknesses?

Annotate for Comprehension

As you read, develop an annotation strategy to help you organize your thoughts and extract key information. For example: underline important concepts and topic sentences, or circle key terminology or interesting phrasing that catches your eye. Mark transition/topic changes and

note the relationship between the topics. Jot down notes in the margins whenever you have thoughts about what you are reading.

Question Breaks

As you reach the end of a paragraph or section in a paper you are reading, pause and ask yourself questions. What was the meaning of the passage? What do you still not understand? Did any information in this section remind you of other work you've encountered? What is the connection between the points being made in this section, or between this section and the rest of the paper? Clarify anything you aren't sure of before moving on to the next section.

Mind Mapping

Mind mapping isn't just useful for brainstorming writing topics – it can be helpful for organizing information as well and keeping track of connections between ideas in different papers you read. As you identify important or interesting concepts, conclusions, or pieces of data, add them to your map and look for new connections.

One-Slide Weekly Reviews

If you are trying to get up to speed on a new subject and need to read many papers, try building this reading into your routine. One strategy is to do a "weekly review" of new papers. One day a week, take some time to check major journals in your field for new papers on your subject, or spend time on your to-read list of interesting articles found through a literature search. Skim the paper briefly and make a one-slide summary consisting of the one figure you find most informative + a few brief sentences describing the paper + a link to the paper. The resulting presentation will give you a quick visual guide to your reading that week. For extra accountability, do this with friends or people you work with in your research and share your discoveries with each other.

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