THIRTEEN

"THE DATA SUGGEST"

Writing in the Sciences

CHRISTOPHER GILLEN

CHARLES DARWIN DESCRIBED *On the Origin of Species* as "one long argument." In *Dialogue Concerning the Two Chief World Systems*, Galileo Galilei cast his argument for a sun-centered solar system as a series of conversations. As these historical examples show, scientific writing is fundamentally argumentative. Like all academic writers, scientists make and defend claims. They address disagreements and explore unanswered questions. They propose novel mechanisms and new theories. And they advance certain explanations and reject others. Though their vocabulary may be more technical and their emphasis more numerical, science writers use the same rhetorical moves as other academic writers. Consider the following example from a 2006 book about the laws of physics.

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> The common refrain that is heard in elementary discussions of quantum mechanics is that a physical object is in some sense both a wave and a particle, with its wave nature apparent when you measure a wave property such as wavelength, and its particle nature apparent when you measure a particle property such as position. But this is, at best, misleading and, at worst, wrong.
>
> V. J. STENGER, *The Comprehensible Cosmos*, 2006

The "they say / I say" structure of this passage is unmistakable: They say that objects have properties of both waves and particles; I say they are wrong. This example is not a lonely argumentative passage cherry-picked from an otherwise nonargumentative text. Rather, Stenger's entire book makes the argument that is foreshadowed by its title, *The Comprehensible Cosmos*: that although some might see the universe as hopelessly complex, it is essentially understandable.

Here's another argumentative passage, this one from a 2001 research article about the role of lactic acid in muscle fatigue:

> In contrast to the often suggested role for acidosis as a cause of muscle fatigue, it is shown that in muscles where force was depressed by high $[K^+]_o$, acidification by lactic acid produced a pronounced recovery of force.
>
> O. B. NIELSEN, F. DE PAOLI, AND K. OVERGAARD, "Protective Effects of Lactic Acid on Force Production in Rat Skeletal Muscle," *The Journal of Physiology*, 2001

In other words: Many scientists think that lactic acid causes muscle fatigue, but our evidence shows that it actually promotes recovery. Notice that the authors frame their claim with a version of the "they say / I say" formula: Although previous work suggests ____, our data argue ____. This basic move and its many variations are widespread in scientific writing. The essential argumentative moves taught in this book transcend disciplines, and the sciences are no exception. The examples in this chaper were written by professional scientists, but they show moves that are appropriate in any writing that addresses scientific issues.

Despite the importance of argument in scientific writing, newcomers to the genre often see it solely as a means for communicating uncontroversial, objective facts. It's easy to see how this view arises. The objective tone of scientific writing can obscure its argumentative nature, and many textbooks reinforce a nonargumentative vision of science when they focus on accepted conclusions and ignore ongoing controversies. And because science writers base their arguments on empirical data, a good portion of many scientific texts *does* serve the purpose of delivering uncontested facts.

However, scientific writing often does more than just report facts. Data are crucial to scientific argumentation, but they are by no means the end of the story. Given important new data, scientists assess their quality, draw conclusions from them, and ponder their implications. They synthesize the new data with existing information, propose novel theories, and design the next experiments. In short, scientific progress depends on the insight and creativity that scientists bring to their data. The thrill of doing science, and writing about it, comes from the ongoing struggle to use data to better understand our world.

START WITH THE DATA

Data are the fundamental currency of scientific argument. Scientists develop hypotheses from existing data and then test

those by comparing their predictions to new experimental data. Summarizing data is therefore a basic move in science writing. Because data can often be interpreted in different ways, describing the data opens the door to critical analysis, creating opportunities to critique previous interpretations and develop new ones.

Describing data requires more than simply reporting numbers and conclusions. Rather than jumping straight to the punch line—to what X concluded—it is important first to describe the hypotheses, methods, and results that led to the conclusion: "To test the hypothesis that ____, X measured ____ and found that ____. Therefore, X concluded ____." In the following sections, we explore the three key rhetorical moves for describing the data that underpin a scientific argument: presenting the prevailing theories, explaining methodologies, and summarizing findings.

See how a physicist begins with data on pp. 206–13.

Present the Prevailing Theories

Readers must understand the prevailing theories that a study responds to before they can fully appreciate the details. So before diving into specifics, place the work in context by describing the prevailing theories and hypotheses. In the following passage from a 2004 journal article about insect respiration, the authors discuss an explanation for discontinuous gas exchange (DGC), a phenomenon where insects periodically close valves on their breathing tubes.

> Lighton (1996, 1998; see also Lighton and Berrigan, 1995) noted the prevalence of DGC in fossorial insects, which inhabit microclimates where CO_2 levels may be relatively high. Consequently, Lighton proposed the chthonic hypothesis, which suggests that

> DGC originated as a mechanism to improve gas exchange while at the same time minimizing respiratory water loss.
>
> A. G. Gibbs and R. A. Johnson, "The Role of Discontinuous Gas Exchange in Insects: The Chthonic Hypothesis Does Not Hold Water," *The Journal of Experimental Biology*, 2004

Notice that Gibbs and Johnson not only describe Lighton's hypothesis but also recap the evidence that supports it. By presenting this evidence, Gibbs and Johnson set the stage for engaging with Lighton's ideas. For example, they might question the chthonic hypothesis by pointing out shortcomings of the data or flaws in its interpretation. Or they might suggest new approaches that could verify the hypothesis. The point is that by incorporating a discussion of experimental findings into their summary of Lighton's hypothesis, Gibbs and Johnson open the door to a conversation with Lighton.

Here are some templates for presenting the data that underpin prevailing explanations:

- Experiments showing ______ and ______ have led scientists to propose ______.
- Although most scientists attribute ______ to ______, X's result ______ leads to the possibility that ______.

Explain the Methods

Even as we've argued that scientific arguments hinge on data, it's important to note that the quality of data varies depending on how they were collected. Data obtained with sloppy techniques or poorly designed experiments could lead to faulty conclusions. Therefore, it's crucial to explain the methods used to collect data. In order for readers to evaluate a method, you'll need to indicate

its purpose, as the following passage from a journal article about the evolution of bird digestive systems demonstrates:

> To test the hypothesis that flowerpiercers have converged with hummingbirds in digestive traits, we compared the activity of intestinal enzymes and the gut nominal area of cinnamon-bellied flowerpiercers (Diglossa baritula) with those of eleven hummingbird species.
>
> J. E. Schondube and C. Martinez del Rio, *Journal of Comparative Physiology*, 2004

You need to indicate purpose whether describing your own work or that of others. Here are a couple of templates for doing so:

- Smith and colleagues evaluated ______ to determine whether ______.
- Because ______ does not account for ______, we instead used ______.

Summarize the Findings

Scientific data often come in the form of numbers. Your task when presenting numerical data is to provide the context readers need to understand the numbers—by giving supporting information and making comparisons. In the following passage from a book about the interaction between organisms and their environments, Turner uses numerical data to support an argument about the role of the sun's energy on Earth.

> The potential rate of energy transfer from the Sun to Earth is prodigious—about 600 W m^{-2}, averaged throughout the year. Of this, only a relatively small fraction, on the order of 1–2 percent, is captured by green plants. The rest, if it is not reflected back into space, is available to do other things. The excess can be considerable: although some natural surfaces reflect as much as 95% of the

> incoming solar beam, many natural surfaces reflect much less (Table 3.2), on average about 15–20 percent. The remaining absorbed energy is then capable of doing work, like heating up surfaces, moving water and air masses around to drive weather and climate, evaporating water, and so forth.
>
> J. S. TURNER, *The Extended Organism*, 2000

Turner supports his point that a huge amount of the sun's energy is directly converted to work on Earth by quoting an actual value (600) with units of measurement (W m^{-2}, watts per square meter). Readers need the units to evaluate the value; 600 watts per square inch is very different from 600 W m^{-2}. Turner then makes comparisons using percent values, saying that only 1 to 2 percent of the total energy that reaches Earth is trapped by plants. Finally, Turner describes the data's variability by reporting comparisons as ranges—1 to 2 percent and 15 to 20 percent—rather than single values.

Supporting information—such as units of measurement, sample size (n), and amount of variability—helps readers assess the data. In general, the reliability of data improves as its sample size increases and its variability decreases. Supporting information can be concisely presented as:

- ________ ± ________ (*mean ± variability*) ________ (*units*), n = ________ (*sample size*).

For example: Before training, resting heart rate of the subjects was 56 ± 7 beats per minute, n = 12. Here's another way to give supporting information:

- We measured ________ (*sample size*) subjects, and the average response was ________ (*mean with units*) with a range of ________ (*lower value*) to ________ (*upper value*).

To help readers understand the data, make comparisons with values from the same study or from other similar work.

Here are some templates for making comparisons:

- Before training, average running speed was ________ ± ________ kilometers per hour, ________ kilometers per hour slower than running speed after training.
- We found athletes' heart rates to be ________ ± ________% lower than nonathletes'.
- The subjects in X's study completed the maze in ________ ± ________ seconds, ________ seconds slower than those in Y's study.

You will sometimes need to present qualitative data, such as that found in some images and photographs, that cannot be reduced to numbers. Qualitative data must be described precisely with words. In the passage below from a review article about connections between cellular protein localization and cell growth, the author describes the exact locations of three proteins: Scrib, Dlg, and Lgl.

> Epithelial cells accumulate different proteins on their apical (top) and basolateral (bottom) surfaces. . . . Scrib and Dlg are localized at the septate junctions along the lateral cell surface, whereas Lgl coats vesicles that are found both in the cytoplasm and "docked" at the lateral surface of the cell.
>
> M. PEIFER, "Travel Bulletin—Traffic Jams Cause Tumors," *Science*, 2000

EXPLAIN WHAT THE DATA MEAN

Once you summarize experiments and results, you need to say what the data mean. Consider the following passage from a study in which scientists fertilized plots of tropical rainforest with nitrogen (N) and/or phosphorus (P).

> Although our data suggest that the mechanisms driving the observed respiratory responses to increased N and P may be different, the large CO_2 losses stimulated by N and P fertilization suggest that knowledge of such patterns and their effects on soil CO_2 efflux is critical for understanding the role of tropical forests in a rapidly changing global C [carbon] cycle.
>
> C. C. CLEVELAND AND A. R. TOWNSEND, “Nutrient Additions to a Tropical Rain Forest Drive Substantial Soil Carbon Dioxide Losses to the Atmosphere,” *Proceedings of the National Academy of Sciences*, 2006

Notice that in discussing the implications of their data, Cleveland and Townsend use language—including the verbs “suggest” and “may be”—that denotes their level of confidence.

Whether you are summarizing what others say about their data or offering your own interpretation, pay attention to the verbs that connect data to interpretations.

To signify a moderate level of confidence:

- The data *suggest/hint/imply* ________.

To express a greater degree of certainty:

- Our results *show/demonstrate* ________.

Almost never will you use the verb “prove” in reference to a single study, because even very powerful evidence generally falls short of proof unless other studies support the same conclusion.

Scientific consensus arises when multiple studies point toward the same conclusion; conversely, contradictions among studies often signal research questions that need further work. For these reasons, you may need to compare one study’s findings to those of another study. Here, too, you’ll need to choose your verbs carefully.

- Our data *support/confirm/verify* the work of X by showing that ________.
- By demonstrating ________, X’s work *extends* the findings of Y.
- The results of X *contradict/refute* Y’s conclusion that ________.
- X’s findings *call into question* the widely accepted theory that ________.
- Our data *are consistent with* X’s hypothesis that ________.

MAKE YOUR OWN ARGUMENTS

Now we turn toward the part of scientific writing where you express your own opinions. One challenge is that the statements of other scientists about their methods and results usually must be accepted. You probably can’t argue, for example, that “X and Y claim to have studied 6 elephants, but I think they actually only studied 4.” However, it might be fair to say, “X and Y studied only 6 elephants, and this small sample size casts doubts on their conclusions.” The second statement doesn’t question what the scientists did or found but instead examines how the findings are interpreted.

When developing your own arguments—the "I say"—you will often start by assessing the interpretations of other scientists. Consider the following example from a review article about the beneficial acclimation hypothesis (BAH), the idea that organisms exposed to a particular environment become better suited to that environment than unexposed animals.

> To the surprise of most physiologists, all empirical examinations of the BAH have rejected its generality. However, we suggest that these examinations are neither direct nor complete tests of the functional benefit of acclimation.
>
> R. S. WILSON AND C. E. FRANKLIN, "Testing the Beneficial Acclimation Hypothesis," *Trends in Ecology & Evolution*, 2002

For more on the "twist it" move, see p. 60.

Wilson and Franklin use a version of the "twist it" move: They acknowledge the data collected by other physiologists but question how those data have been interpreted, creating an opportunity to offer their own interpretation.

You might ask whether we should question how other scientists interpret their own work. Having conducted a study, aren't they in the best position to evaluate it? Perhaps, but as the above example demonstrates, other scientists might see the work from a different perspective or through more objective eyes. And in fact the culture of science depends on vigorous debate in which scientists defend their own findings and challenge those of others—a give and take that helps improve science's reliability. So expressing a critical view about someone else's work is an integral part of the scientific process. Let's examine some of the basic moves for entering scientific conversations: agreeing, with a difference; disagreeing and explaining why; simultaneously agreeing and disagreeing; anticipating objections; and saying why it matters.

Agree, but with a Difference

Scientific research passes through several levels of critical analysis before being published. Scientists get feedback when they discuss work with colleagues, present findings at conferences, and receive reviews of their manuscripts. So the juiciest debates may have been resolved before publication, and you may find little to disagree with in the published literature of a research field. Yet even if you agree with what you've read, there are still ways to join the conversation—and reasons to do so.

One approach is to suggest that further work should be done:

- Now that ________ has been established, scientists will likely turn their attention toward ________.
- X's work leads to the question of ________. Therefore, we investigated ________.
- To see whether these findings apply to ________, we propose to ________.

Another way to agree and at the same time jump into the conversation is to concur with a finding and then propose a mechanism that explains it. In the following sentence from a review article about dietary deficiencies, the author agrees with a previous finding and offers a probable explanation.

> Inadequate dietary intakes of vitamins and minerals are widespread, most likely due to excessive consumption of energy-rich, micronutrient-poor, refined food.
>
> B. AMES, "Low Micronutrient Intake May Accelerate the Degenerative Diseases of Aging through Allocation of Scarce Micronutrients by Triage," *Proceedings of the National Academy of Sciences*, 2006

Here are some templates for explaining an experimental result.

- One explanation for X's finding of ______ is that ______. An alternative explanation is ______.
- The difference between ______ and ______ is probably due to ______.

Disagree—and Explain Why

Although scientific consensus is common, healthy disagreement is not unusual. While measurements conducted by different teams of scientists under the same conditions should produce the same result, scientists often disagree about which techniques are most appropriate, how well an experimental design tests a hypothesis, and how results should be interpreted. To illustrate such disagreement, let's return to the debate about whether or not lactic acid is beneficial during exercise. In the following passage, Lamb and Stephenson are responding to work by Kristensen and colleagues, which argues that lactic acid might be beneficial to resting muscle but not to active muscle.

> The argument put forward by Kristensen and colleagues (12) . . . is not valid because it is based on observations made with isolated whole soleus muscles that were stimulated at such a high rate that >60% of the preparation would have rapidly become completely anoxic (4). . . . Furthermore, there is no reason to expect that adding more H+ to that already being generated by the muscle activity should in any way be advantageous. It is a bit like opening up the carburetor on a car to let in too much air or throwing gasoline over the engine and then concluding that air and gasoline are deleterious to engine performance.
>
> G. D. Lamb and D. G. Stephenson,
> "Point: Lactic Acid Accumulation Is an Advantage during Muscle Activity," *Journal of Applied Physiology*, 2006

Lamb and Stephenson bring experimental detail to bear on their disagreement with Kristensen and colleagues. First, they criticize methodology, arguing that the high muscle stimulation rate used by Kristensen and colleagues created very low oxygen levels (anoxia). They also criticize the logic of the experimental design, arguing that adding more acid (H^+) to a muscle that is already producing it isn't informative. It's also worth noting how they drive home their point, likening Kristensen and colleagues' methodology to flooding an engine with air or gasoline. Even in technical scientific writing, you don't need to set aside your own voice completely.

In considering the work of others, look for instances where the experimental design and methodology fail to adequately test a hypothesis.

- The work of Y and Z appears to show that ______, but their experimental design does not control for ______.

Also, consider the possibility that results do not lead to the stated conclusions.

- While X and Y claim that ______, their finding of ______ actually shows that ______.

Okay, but . . .

Science tends to progress incrementally. New work may refine or extend previous work but doesn't often completely overturn it. For this reason, science writers frequently agree up to a point and then express some disagreement. In the following example from a commentary about methods for assessing how proteins interact, the authors acknowledge the value of the two-hybrid studies, but they also point out their shortcomings.

> The two-hybrid studies that produced the protein interaction map for *D. melanogaster* (12) provide a valuable genome-wide view of protein interactions but have a number of shortcomings (13). Even if the protein-protein interactions were determined with high accuracy, the resulting network would still require careful interpretation to extract its underlying biological meaning. Specifically, the map is a representation of all possible interactions, but one would only expect some fraction to be operating at any given time.
>
> J. J. Rice, A. Kershenbaum, and G. Stolovitzky, "Lasting Impressions: Motifs in Protein-Protein Maps May Provide Footprints of Evolutionary Events." *Proceedings of the National Academy of Sciences*, 2005

Delineating the boundaries or limitations of a study is a good way to agree up to a point. Here are some templates for doing so.

- While X's work clearly demonstrates ______, ______ will be required before we can determine whether ______.
- Although Y and Z present firm evidence for ______, their data can not be used to argue that ______.
- In summary, our studies show that ______, but the issue of ______ remains unresolved.

Anticipate Objections

Skepticism is a key ingredient in the scientific process. Before an explanation is accepted, scientists demand convincing evidence and assess whether alternative explanations have been thoroughly explored, so it's essential that scientists consider possible objections to their ideas before presenting them. In the following example from a book about the origin of the universe, Tyson and Goldsmith first admit that some might doubt the existence of the poorly understood "dark matter" that physicists have proposed, and then they go on to respond to the skeptics.

> Unrelenting skeptics might compare the dark matter of today with the hypothetical, now defunct "ether," proposed centuries ago as the weightless, transparent medium through which light moved. . . . But dark matter ignorance differs fundamentally from ether ignorance. While ether amounted to a placeholder for our incomplete understanding, the existence of dark matter derives from not from mere presumption but from the observed effects of its gravity on visible matter.
>
> N. D. Tyson and D. Goldsmith, *Origins: Fourteen Billion Years of Cosmic Evolution*, 2004

Anticipating objections in your own writing will help you clarify and address potential criticisms. Consider objections to your overall approach, as well as to specific aspects of your interpretations. Here are some templates for doing so.

- Scientists who take a ______ (*reductionist/integrative/biochemical/computational/statistical*) approach might view our results differently.

- This interpretation of the data might be criticized by X, who has argued that ______.
- Some may argue that this experimental design fails to account for ______.

Say Why It Matters

Though individual studies can be narrowly focused, science ultimately seeks to answer big questions and produce useful technologies. So it's essential when you enter a scientific conversation to say why the work—and your arguments about it—matter. The following passage from a commentary on a research article notes two implications of work that evaluated the shape of electron orbitals.

> The classic textbook shape of electron orbitals has now been directly observed. As well as confirming the established theory, this work may be a first step to understanding high-temperature superconductivity.
>
> C. J. HUMPHREYS, "Electrons Seen in Orbit," *Nature*, 1999

Humphreys argues that the study confirms an established theory and that it may lead to better understanding in another area. When thinking about the broad significance of a study, consider both the practical applications and the impact on future scientific work.

- These results open the door to studies that ______.
- The methodologies developed by X will be useful for ______.

- Our findings are the first step toward ______.
- Further work in this area may lead to the development of ______.

READING AS A WAY OF ENTERING THE SCIENTIFIC CONVERSATION

In science, as in other disciplines, you'll often start with work done by others, and therefore you will need to critically evaluate their work. To that end, you'll need to probe how well their data support their interpretations. Doing so will lead you toward your own interpretations—your ticket into an ongoing scientific conversation. Here are some questions that will help you read and respond to scientific research.

How well do the methods test the hypothesis?

- Is the sample size adequate?
- Is the experimental design valid?
  Were the proper controls performed?
- What are the limitations of the methodology?
- Are other techniques available?

How fairly have the results been interpreted?

- How well do the results support the stated conclusion?
- Has the data's variability been adequately considered?
- Do other findings verify (or contradict) the conclusion?
- What other experiments could test the conclusion?

What are the broader implications of the work?
Why does it matter?

- Can the results be generalized beyond the system that was studied?
- What are the work's practical implications?
- What questions arise from the work?
- Which experiments should be done next?

The examples in this chapter show that scientists do more than simply collect facts; they also interpret those facts and make arguments about their meaning. On the frontiers of science, where we are probing questions that are just beyond our capacity to answer, the data are inevitably incomplete and controversy is to be expected. Writing about science presents the opportunity to add your own arguments to the ongoing discussion.

FOURTEEN

"ANALYZE THIS"

Writing in the Social Sciences

ERIN ACKERMAN

SOCIAL SCIENCE is the study of people—how they behave and relate to one another, and the organizations and institutions that facilitate these interactions. People are complicated, so any study of human behavior is at best partial, taking into account some elements of what people do and why, but not always explaining those actions definitively. As a result, it is the subject of constant conversation and argument.

Consider some of the topics studied in the social sciences: minimum wage laws, violence against women, tobacco regulation, the 2000 election, employment discrimination. Got an opinion on any of these topics? You aren't alone. But in the writing you do as a student of the social sciences, you need to

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