Contents

In fond memory of Stanley Leonard Miller.
He taught for 25 years at Stephenville High School,
enriching thousands of lives—including mine.

Introduction: Two Regrettable Forgeries

In 2005 I began working as an editor for ExploreLearning.com. We provide schools across North America with interactive educational simulations, called *Gizmos*™, designed to enhance standard science and math lessons. Because Gizmos are supplementary, we tailor them to align with the content regularly found in major textbooks. A surprising problem repeatedly arises during the creation of science Gizmos: the textbooks we review falsify the topic under consideration.

It can be said that textbooks are guilty of two regrettable *forgeries*, one matching each of the term's common meanings. In some cases textbooks forge counterfeit explanations, passing off myths as genuine accounts for natural phenomena. In other cases textbooks present factual information in misleading ways. If the human mind is a smithy wherein observation and experience shape one's beliefs about the natural world, then blights of this second type end up forging misconceptions when students (quite understandably) draw false conclusions from the tendered exposition.

Science textbooks perpetuate these myths and misconceptions because they are *efficient, effective,* and *expedient*. Claiming a candle burns out when placed under a jar because it has consumed all the available oxygen is effective for reminding students that oxygen plays a role in combustion. Claiming tides on Earth's far side (the half farthest from the Moon) are due to "centrifugal force" is an efficient method of explaining away a phenomenon whose legitimate treatment requires some challenging visualization. Claiming scientists approach problems using "the scientific method" is an expedient to help students develop certain cognitive skills pertaining to science.

Each of these three claims turns out to be doubly wrong. A candle consumes only a small portion of the oxygen in a jar, and it would go out even if oxygen were continually pumped into the vessel. Centrifugal force is purely illusory, so it should not be presented as the impetus behind any phenomenon—particularly not for tides since they would occur even if there were no circular motion in the Earth-Moon-Sun system. Lastly, "the scientific method" represents neither how scientists engage individual research problems, nor the long-term route by which science advances as a whole.

Emergency medical workers must triage incoming patients into categories: those who can be saved but require urgent care, those who can be saved without immediate aid, and those whose chance of survival is so small as to not warrant attention more productively spent on others. A similar demarcation has occurred in science education among those truths that are considered important and graspable, those that are elective, and those that will not appear on standardized testing. Textbooks often sacrifice honesty regarding members of this third group in their efforts to convey those deemed more important.

The problem is not that textbooks (or the education standards they address) treat a limited set of topics. American science education already suffers from "one inch deep and a mile wide" syndrome: I certainly do not advocate widening that trench. The problem is that publishers, in their zeal to hammer home lesson objectives, are willing to make untrue claims and present counterfeit accounts. Myths hamper comprehension of the key ideas they are intended to demystify and muddle students' conceptions of related, lower-priority topics. But they help pupils pick the right answer on standardized tests, so they persist.

Children are not the only victims of such information fraud. Teachers rely on textbooks to provide accurate accounts on a raft of topics. It would be absurd to expect teachers to personally verify their textbooks' presentations, nor are there convenient means to do so. As a former teacher, I can assure you the last thing frontline educators need is another demand on their time.

For both of these victims—teachers who have been betrayed by textbooks and former students who were deceived by them—I've written these three volumes on common science myths and misconceptions. The work comprises[1] topics generally falling into one of four categories:

- Everyday observations explained by myths tied to a more important topic (e.g., describing the blood in veins as blue because it has no oxygen; misapplying Bernoulli's principle to explain flight)

- Fallacious portrayals of natural processes (e.g., claiming clouds form because cold air holds less water than hot; likening the warming effect of a planet's atmosphere to the operation of a greenhouse)

- Factual errors likely to cause larger misconceptions (e.g., misrepresenting the nature of science; providing the wrong definition for "producer")

---

[1]I am hopeful readers interested in this kind of book are also the type who will not mind a few remarks on *comprise* and *compose,* words I will frequently have need of in these volumes. Since the 1960s, "comprise" has increasingly been used as a synonym for "compose." It is becoming more and more common to read "oxygen and hydrogen comprise water" (or, put in passive voice, "water *is comprised of* oxygen and hydrogen"). The prevalence of this usage by careful writers is particularly odd, for it is forbidden by the *Chicago Manual of Style*, the *de facto* guide to American English. (Though I must admit that *Chicago* also frowns on long footnotes . . .)

The traditional meaning for "comprise" is "to include." (It comes from the same root as *comprehensive.*) Hence "comprise" and "compose" have historically been used as *antonyms*, their meanings converse to one another. That is to say "oxygen and hydrogen atoms compose a water molecule," and "a water molecule comprises oxygen and hydrogen atoms." This was the dominant use of "comprise" from the mid-18th century to the mid-20th century and its *only* use for over three centuries prior to that. Words are not static; their usage changes over time, but I do not know of any *verb* in English to have its meaning utterly reversed so that a pair of antonyms become synonyms.

- Factual errors so flagrant they are worth pointing out for their own sake (e.g., presenting simple machines as multiplying force; claiming that a substance stays at a constant temperature when it changes state)

In other words, I have tried to select serious issues rather than mere nitpicks. Most cause students to construct incorrect mental models of nature, cognitive frameworks that can hamper later studies and persist for a lifetime.

Beyond forging the aforementioned counterfeits and misconceptions, the emphasis on knowledge (rather than comprehension) encourages educators to *persuade* students of a claim rather than provide a sound reason for it. As an example, consider the Coriolis effect, which refers to the influence of Earth's rotation on the apparent motion of objects. In particular, an arrow moving straight (as seen from space) will seem to follow a curved path to observers anchored to Earth. Students are often asked to accept this phenomenon with reasoning similar to:

> Other than the North and South Poles, all points on Earth rotate to the east. Points on the equator have the farthest to go in each 24-hour period, so they rotate the fastest. In general, the closer to the equator you are, the faster you rotate. This means than an arrow shot toward the equator flies over terrain rotating faster and faster eastward. To an observer standing on Earth's surface (rotating with it), such an arrow appears to curve because it travels over terrain moving eastward faster than it is.

This kind of reasoning may persuade someone that Earth's rotation causes flying objects to appear to curve, but the account is hardly robust. A student reading carefully has to wonder *what about an arrow shot due east?* Paths going eastward at all points are just lines of latitude on a globe. All points on such a path are rotating east at the same speed. According to the discussion given here, an arrow going due east should not curve at all, yet the Coriolis effect is equally potent in all directions. It is impossible to understand how the Coriolis effect can generate hurricanes if you believe it only influences the motion of objects moving north or south, which are the only objects textbooks cite when illustrating the topic.

Related to these efforts at persuasion are simple glosses of the form "Because A is true, B is true as well," where A and B are related, but not in the kind of logically tight way suggested by the sentence. For example, when explaining why you can rub a balloon against someone's hair and stick it to the wall, it is rather deceptive to say "because the balloon is negatively charged, it sticks to the wall." It is true that the balloon's negative charge leads to the attraction observed, but not in the straightforward manner described. The wall is neutral; it has no net charge. Negatively charged items generally have zero attraction to neutral ones.[2] A facile explanation like "because the balloon is negatively charged, it sticks to the wall" only encourages people to formulate erroneous beliefs about electrostatics. For example, a student could not be blamed for deducing that protons (positively charged particles) and neutrons (neutral particles) are held together in the nucleus of an atom for the same reason.

I believe I avoid falsely presenting such persuasions and glosses as genuine explanations in these chapters, though proper treatment of some topics demanded longer discussions than I would have liked. I have given suitable disclaimers in the rare instances that a satisfactory account was truly beyond the scope of secondary science education.

[2] In this case, the negatively charged balloon has the capability of causing the wall's distribution of charge to change, so that the surface of the wall is no longer neutral. See the *Circuits* chapter in volume 2 for more details.

My goal was to present accounts granular enough to allow complete understanding of the topic involved, and I provide notes, useful vocabulary, and sources for further study in an appendix. It is my hope that these volumes will find their way into the hands of many teachers. The detailed discussions should empower them to decide for themselves how to sculpt the material to match the needs of their students. Chapters on the simpler phenomena have been written in an informal tone in case educators wish to assign them as enrichment for students. The whole book should be readable by a precocious high schooler.

Should a reader find himself stumped by any of the descriptions given herein, I welcome requests for clarification as well as any other comments or suggestions. I am also looking for more examples of myths perpetuated by standard textbooks. Please send your personal favorites to `david@zukertort.com`.