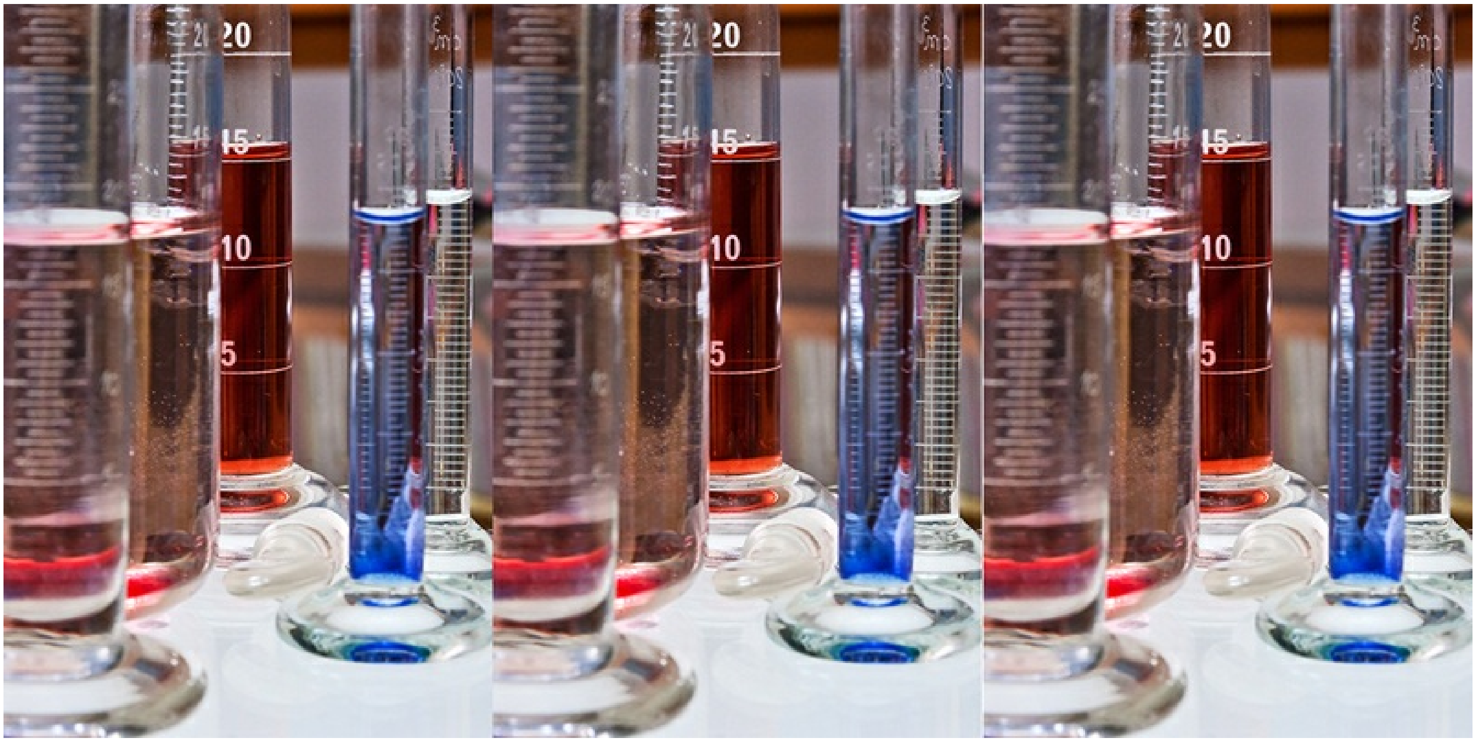
Bad Reactions to Bad Reactions



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By Mercedes Taylor

The student pulled her test tube out of the ice bucket for the 10th time, and then slumped in despair at the sight of the clear liquid.

She shoved the sample back into the ice and put her head in her hands. Nestled in the ice next to her own, her classmates' test tubes were full of fluffy white crystals, the result of a four-hour lab on recrystallization. Clearly, at some point in the afternoon, this student had done something different from her peers, and now not a speck was visible in her test tube.

The recrystallization lab is like most of the experiments we do in my "Chemistry 3A" section: There is a single desired outcome, intended to teach a chemical concept or a laboratory technique. But of course experiments can go awry in myriad ways, as anyone who has spent any time in a laboratory knows.

Detachment and resilience in the face of undesired results become increasingly crucial as students progress further into scientific research and careers. In my own field of chemistry, graduate training entails a few semesters of courses and exams, followed by years of full-time lab work. My fellow doctoral students and I experience so much "failure" in the lab that to consider it as such would make getting up each morning impossible.

At times, many of us do struggle to maintain our motivation. During my second year, I asked a more-experienced graduate student to check in with me every morning in lab — to make sure I showed up. I told her my friends didn't understand why I was so discouraged. (My boyfriend referred to my lab as "Doom and Gloom.")

That older student became an informal mentor of sorts. She told me that sometimes nonscientists didn't get what our work could be like. "Nobody else's job is an uninterrupted series of little failures," she laughed. But she also was one of the first people who told me I had to stop seeing each unexpected result that way.

At the time, I was trying to synthesize a new material — a crystalline, purple powder — that I expected to behave a certain way in the presence of natural gas. It was similar to materials I had synthesized before, but this time I replaced a single hydrogen atom with a fluorine atom. I completed the long synthesis and ended up with the desired purple solid.

But when I dosed it with natural gas, I saw data I didn't expect — data that I thought indicated my material was impure. So like a diligent scientist, I resynthesized the whole thing, from scratch. And I saw the same result. The whole process took about a month, but I repeated it twice more, using ultra-pure starting materials and taking meticulous care not to expose the precious purple powders to air — only to get the same frustrating response.

With slumped shoulders, I presented the results of those four attempts to my Ph.D. adviser, who said something exceedingly obvious: "Maybe what you're seeing is an inherent property of the material."

Because I had hoped for and expected a certain behavior, I viewed my results as indicative of sloppiness or error on my part, not as valid information.

Learning from unexpected results, rather than being discouraged by them, hasn't come naturally to me. Working on a new project this year, I became despondent over my inability to reproduce a promising result. I wrote a long email to my adviser about the situation, and this time he responded even more pithily: "Science often does not go as planned." A bit curt, but I doubt it's the first time he's had to say that to a graduate student.

Unfortunately, once we fortify ourselves with the conviction that all results are merely new information — not "good" or "bad" per se — we realize that the rest of the scientific community is against us, too: Negative results are less sexy, less sought-after, and less publishable. A negative result — "We rigorously tested this compound, and it turns out it doesn't cure cancer" — is still good science and can help guide the development of future medicines. But it's less likely to make it into a top-tier journal. In such a climate, it takes extra mental toughness to accept undesired data without responding emotionally.

Nevertheless, detaching yourself from the notion of "good" and "bad" results not only helps your mental health and ability to learn, it can also prevent confirmation bias. That very human instinct to confirm a pre-existing vision can lead scientists to misinterpret ambiguous data or cherry-pick results. World-class scientists have had their careers ended because of such practices.

Better to break the habit in Chemistry 3A.

While I don't grade students on the outcomes of an experiment, they suffer other negative consequences when they get the "wrong" result. Sometimes all they remember is the incorrect version. I explain what went wrong and what was meant to happen, but that is not nearly as memorable to them as what they witnessed occurring in their own flask. Frustration with perceived failure leads them to adopt a dismissive, negative attitude toward that particular concept, which can prevent them from making the mental effort necessary to retain it.

So what can we do to prevent undergraduates from reacting emotionally to "bad" results and help them learn the intended concept? I've adopted a couple of strategies.

First, I use my tone and body language to convey positivity and curiosity: "Really? Cool! Nobody else's reaction turned that color!" By engaging warmly with them, I lessen their frustration and stir their curiosity about the result.

In reassuring a distraught student, I do not say, "Don't worry, you won't be graded on the outcome of your experiment" (though in my labs, that is true). For many students, saying "it's not graded" means "it doesn't matter." I want to alleviate their stress about the result so they will learn the scientific concept, without causing them to check out.

Second, I question them from a scientific standpoint about what happened and why, and lead them firmly toward an explanation that reinforces the concept at hand. For example, recrystallization depends on a compound's solubility in a particular solvent; a successful recrystallization teaches students how to manipulate slight differences in solubility. Rather than letting a failed recrystallization confuse matters, I reason with students about how volume, temperature, or solvent might have prevented their recrystallization, invoking the same principles of solubility that would have explained a positive result.

Finally, I keep in mind that failed experiments are an opportunity to teach the philosophy of science and the nature of academic research. As a doctoral student in chemistry, I have plenty of stories I can share about how often my own research experiments fail and how my adviser is trying to get me to view failure as a part of the process. I reinforce that attitude when grading. Next to their gloomy descriptions of unexpected data, I might jot "good observations" or "interesting result."

In grading my students' lab write-ups, I assess the extent to which they understood the possible reasons for their undesired result. Without intervention on my part, a surprisingly high number of them make no attempt at an explanation — instead they write comments like "Didn't work. I don't know why," or "No crystals?" (insert sad-face emoji), or "For some reason my partner's reaction worked, but mine didn't."

I want students to omit words like "failed," "wrong" or "didn't work" and instead to simply describe the result and offer an explanation. For example, after conversing with my frustrated undergrad in the recrystallization lab, I would expect her to write something like, "My recrystallization failed, but I think it's because I used too much solvent," or even better, "My test tube didn't yield any crystals because I used a lot of solvent."

As I teach my students to neutrally observe the outcome of an experiment without passing judgment on it, I continue to try to develop that same mind-set myself. Maybe by the time I finish my doctorate, I'll be telling them coolly, "Science often does not go as planned."

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