An Allegory for Teaching scientific Method

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The practice of science has been characterized as the systematic application of common sense (McComas, 1996). This view, frequently held by scientists themselves, holds that the same qualities that allow pre-industrial societies, pioneers, cast-aways, and common folk everywhere to cope with their environment and prosper also make for good scientists. Admirable human features such as hard-headed pragmamticism, tenacity, shrewdness, and perceptivity produce not only successful Robinson Crusoes, but in a more rigorous guise, the foundation for all our awesome knowledge of the physical universe.

Many students (especially those with poor scientific backgrounds) do not share this view. They believe scientific endeavors are of some impossibly higher order, out of reach for them; they assume science requires knowledge of arcane jargon, complex instrumentation, and heroic mathematics. Worse, they suspect that science does not exercise any creative ability, but consists merely of following procedures (Tobias, 1990). These students generally lack an understanding of how science achieves and justifies its results, why scientists can have confidence in those results, and how science avoids errors (an excellent appraisal of scientific critical thinking skills is available in Lett, 1990).

A goal of any science curriculum should be to educate students about the process of science as well as its contents (American Association for the Advancement of Science, 1993; National Research Council, 1994). A lack of facility with the way science works can lead to grave misunderstanding and ultimately to dissatisfaction with science itself, leading students to avoid other...
science courses (even those designed for nonmajors) and scientific careers (Tobias, 1990). If students could be helped to see that, for all of its daunting complexity, scientific research actually rests on relatively simple principles — essentially the same faculties most of us use every day to solve problems and to learn — they would undoubtedly enjoy science more. They might also acquire a greater ability to be critical about topical issues such as genetic engineering, creationism, and global warming, and would likely feel empowered to study and participate in science in school and beyond (Micikas, 1996).

One of the most difficult but crucial aspects of science education, for both teachers and students, concerns the problem of certainty. Much (perhaps all) of our scientific knowledge is provisional. Yet, if we attempt to give students a sense of the inadequacy of our current understanding, we may fail to inspire them. We risk giving them the impression that science is ineffective and unstable. On the other hand, the common fiction that the ideas we present are well settled truths is not honest or satisfying.

In my experience, the assumptions implicit in scientific analysis and questions of certainty frequently trouble students, and are rarely addressed by teachers. Students are rarely taught, for example, that they must actively adopt a stance of logical reasoning to think scientifically (and, at least temporarily, reject other ways of knowing), and that in doing so they lose the possibility of absolute certainty. They may never learn why crediting natural processes (the "rules of nature") as being primary in the universe is vital to scientific progress, even in the face of phenomena which are difficult to understand and perhaps laden with emotional, ethical, and religious connotations. Nor do they learn that the techniques we have created for studying these rules are, paradoxically, certain to give us only uncertain (but useful) answers to our questions. If students (who generally do not lack credulity) are never taught these basic concepts, they will be inclined to embrace whichever explanations are most appealingly offered to them (Lett, 1990).

I present here a simple but effective allegory that teachers can use to help high school or lower division college students understand the value and application of science. I use this allegory with students majoring in science, but have also found it useful for introducing science to nonscience majors, since it does not refer to science specifically, requires no scientific background, and addresses some of the key issues students must grapple with when asked to think scientifically. I present the allegory using the Socratic method: I give the students a piece of information or a bit of the scenario and then I probe them for explanations, reasons, courses of action, etc. The bold faced questions in the allegory are the typical questions I will ask as we go through the allegory in class.

The Allegory

Imagine:

You are home alone, sleeping on the second floor of your house. The hour is late. Suddenly you are ripped from a dream by what you think was a door slamming on the first floor. Since you believe you are alone in the house, you become somewhat concerned. **What caused the door to slam?** Several possible explanations immediately occur to you, including:

- Someone has broken into the house.
- There is a ghost or spirit of some kind in the house.
- You were dreaming and merely imagined the door slamming.

There are, in fact, innumerable possible explanations for the noise. You listen intently, hoping for some clue, but no further noise ensues.

**What is your initial response?** For most people, fear would likely be prominent. Your heart would be racing, your eyes and ears straining. **What should you do next?** At this point you have two alternative ways to respond. You can investigate the noise or you can decide not to investigate the noise. The latter response may be preferable to you for many different reasons. You may believe it is too dangerous to go downstairs, you may be paralyzed with fear, you may be too tired to care, you may have decided that the noise was a ghost and there is nothing you can do but remain under the covers and hope it goes away.

If you choose to investigate, you may still hold any of the possible reasons for the door slamming; but whatever you suspect, for some reason you are motivated to find out what really happened. You may want either to confirm a preconceived notion or you may seek to discover which of the many reasons actually was responsible. So you gather your courage and proceed down the stairs.

Upon arriving you find that, in fact, the door to the living room is closed, and you are quite sure it had been open when you went upstairs. Now that you have confirmed that a door did slam, you can rule out your imagination as responsible for the noise, but you cannot yet rule out any of the other explanations. You open the door and walk into the room. Nothing is amiss. You search the room thoroughly and cannot find anything wrong. You may provisionally rule out the thief explanation. **So what caused the door to slam shut?** Two
sorts of explanations occur to you. Either there was some sort of inexplicable, eerie, supernatural event (i.e., there is no logical explanation for the event), or there is a reasonable natural explanation. Many people will become increasingly panicked if their initial search does not quickly turn up a reasonable natural explanation.

Further investigation reveals an open window with drapes that are rustling gently. Is it possible that the wind slammed the door shut? Now you have a plausible explanation for the slamming door, and you may decide to simply accept it and go back to bed. You may also decide that the event was too weird, that it fit in some uncanny way into the dream you were having; besides, there is no breeze coming through the window now that would be strong enough to move the door. You may have seen horror movies like this; your intuition may be screaming that a supernatural force must have been involved. The hairs on the back of your neck may be erect. Is there any way you can tell which explanation is correct? How can you know the truth?

The answer is complicated. In fact, you will never be able to know for sure what happened, in a strict sense, since you were not present. But you can try to find the most likely explanation. How can you assess what is most likely? One obvious method is observation. You could sit, and watch, and see what happens. What would you be watching for? A strong breeze periodically blowing through the window would support your theory.

You could also manipulate the situation to see what happens. What experiment could you do to determine the most likely cause of the door slamming? What if you reopened the door, sat down and watched? If the curtains fluttered suddenly as a breeze blew through the window, and subsequently you observed the door slamming, you might have evidence in favor of the natural explanation. However, you did not actually see the original slam happen, so you will never know for sure if the slam that occurred while you were watching had the same cause as the one that woke you up. And what if your experiment failed and the door did not slam in your presence? What if you never again hear a door slam by itself in your house? This would seem to eliminate a natural cause but you would have no proof one way or the other. The rarity of the event does not disprove a natural explanation in favor of a supernatural one, but it makes investigating the cause difficult or impossible. (It is worth pointing out to students that disproving one explanation does not support another competing explanation, which is a common logical error people make. For example, falsifying the theory of evolution by natural selection would not suggest that the theory of special creation is, therefore, correct.)

What if your experiment succeeds and you observe the door slamming after a wind blows through the window? You might still wonder if a spirit had caused the wind in the first place. Or worse, what if a mischievous phantom was hiding in the room and every time the curtains fluttered the phantom caused the door to slam. You would be tricked into thinking there was a direct cause and effect relationship between the breeze entering the room and the door slamming when, in fact, there was not. Ultimately, is there any way to rule out the action of mischievous spirits?

The explanation you choose for the slamming door depends on whether you decide, a priori, to look for natural explanations or supernatural. No amount of physical evidence will dissuade you if you are not willing to suspend your belief in the participation of spirits. Similarly, any event, no matter how strange or unusual, can be explained by reference to some natural phenomenon, if you so tend. Even a clear sight of a ghost slamming the door with a twisted look of mayhem on its vaporous maw could be ascribed to hallucination or some peculiar confluence of atmospheric conditions and poor lighting.

Two Ways of Thinking

While thinking scientifically is not beyond the ability of most people, as this example suggests, many people choose nonrational (i.e., faith based) worldviews, and reject science. In essence, these two divergent explanations for events are equally valid (in the sense of fitting the facts) and there is no obvious way to decide between them. While a science teacher could not possibly resolve this issue during class, a key point for students to understand is that ultimate uncertainty does not preclude immediately valid and valuable knowledge of physical events (such as the slamming of a door in the night).

Supernatural explanations require us to accept that the causes of events involve agents beyond our understanding, control, or ability to predict. Assessment of these sorts of explanations is solely a matter of belief, and is typically based on appeals to authority, not fact. Naturalistic explanations proceed to a very different end: All events are considered potentially explainable by commonly accepted mechanisms. The most straightforward explanation that accounts for all the facts is preferred. Scientists insist on remaining eternally skeptical of everything and everyone, constantly questioning if a simpler, and therefore, better explanation for our observations exists. To be fair to the requirements of logic, scientists must tolerate a fair dollop of uncertainty, and must admit we can never exactly prove any hypothesis; at best we can hope to rule out some potential explanations.
Table 1. The symbolic events of the allegory and what they represent.

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<thead>
<tr>
<th>EVENT</th>
<th>MEANING</th>
<th>DISCUSSION POINTS</th>
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<tr>
<td>The door slam.</td>
<td>Any physical event or phenomenon.</td>
<td>This could be anything: a volcanic eruption, cancer, evolution, a falling star.</td>
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<td>Fear followed by decision to investigate.</td>
<td>Fear is a normal human response to the unknown. Curiosity is necessary for science. (Note that curiosity is not the same as investigating merely to support a preconceived notion of causality.)</td>
<td>Many aspects of nature inspire awe in people, and are explained by supernatural forces. People often choose to avoid these places or events altogether (superstitions) because of their belief. Only through curiosity can we come to know the truth.</td>
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<td>Looking for a natural explanation.</td>
<td>Individual predilection. Each person, based on their culture and education is more or less disposed to credit supernatural explanations. Students should think about where they fall on this continuum.</td>
<td>Humans, especially when confronted with scary events, will either look for natural explanations or supernatural explanations. Often a natural explanation is sought first, and if one does not turn up, supernatural explanations are assumed, the only proof being a lack of a natural explanation.</td>
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<td>Finding open window and going back to bed.</td>
<td>Failure of curiosity and tenacity.</td>
<td>Scientists constantly work on their knowledge and rarely accept any question as fully settled until it has been thoroughly tested and supported with divergent lines of evidence.</td>
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<td>Observing window.</td>
<td>Observation.</td>
<td>Obviously observation is important in science, but often is not sufficient to support a theory.</td>
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<td>Reopening door and observing.</td>
<td>Experimentation.</td>
<td>Much, but by no means all, scientific knowledge is amenable to experiment.</td>
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<td>Decision to credit only natural explanations.</td>
<td>Fundamental assumption of science.</td>
<td>While supernatural phenomena may or may not exist, in attempting to understand any physical event, we must consider only natural explanations. Otherwise, we will achieve no understanding of how the event works. For example if we burn our rice and ascribe the event to Spirits, we will never figure out that turning the flame down will prevent overcooking.</td>
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<td>Decision that of all the possible natural explanations, the wind through the open window is the best.</td>
<td>The scientific principle of parsimony.</td>
<td>When there are competing explanations for a phenomenon that are all valid and logical, we accept the simplest provisionally, thereby avoiding all unnecessary complexity. It is interesting to point this out to students who often believe that science is gratuitously complicated.</td>
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Significantly though, even in the absence of absolute proof, our provisional explanations have great value because they are predictive— the better the explanation the more consistently predictive it will be. For example, in our allegory, if we were to reopen the door and go back upstairs to bed, we may soon be awoken by another slam. Using naturalistic explanations, it might not take us long to figure out that if we close the window, we could sleep undisturbed. We could conduct experiments in which we leave the door open night after night, and look for patterns in prevailing weather conditions on nights with slams. Then we could predict on which nights we would be likely to have a slam and which would be safe. If some explanation other than weather ultimately proved to be correct, then we were fooled, but only about the mechanism, not the result. We would have slept well even without the true explanation.

Conclusion

I end the allegory class by reviewing the symbolic events of the allegory and relating them explicitly to science (Table 1). A formal recitation allows students to articulate specific insights they might have achieved.

I have had some very lively discussions using this allegory as a stimulus. I believe, by asking students to imagine themselves in the situation described by the allegory (without telling them we are really discussing scientific method), they can come to understand that the essential way science works is not foreign to their daily lives. The allegory serves as a bridge between the world of science and the everyday world, and fully reveals some of the essential mental prerequisites for scientific thinking, including curiosity, adherence to natural explanations, hypothesis generation and testing, toleration of uncertainty, open-mindedness, and skepticism.

After the allegory discussion, I present specific scientific problems and have the students go through the same process they used in the allegory. I find that spending time on the allegory before broaching scientific issues provides a sufficient foundation in scientific reasoning, and saves me time and frustration later in the term. Students tell me that the allegory discussion impresses them, and they often refer to it throughout the course and sometimes even years later.

References


