How would Socrates teach science?

Adapting an ancient pedagogy to build deeper understanding and inclusive learning communities

By Ann Riedl & Mike Klymkowsky

> **"The soul, since it is immortal and has been born many times, and has seen all things ... has learned everything that is ... so that when a man has recalled a single piece of knowledge — learned it, in ordinary language — there is no reason why he should not find out all the rest ... for seeking and learning are in fact nothing but recollection."**
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> — "Meno," The Collected Dialogues of Plato, Bollingen Series

The Socratic method is personal, typically involving conversation in a small group. Because it is interactive, it takes time: time spent listening to ideas and composing and posing questions that should lead students to reflect and reconsider their underlying assumptions, the relevance and implications of these ideas, and whether other ideas need to be considered. Responses to questions become the focus of new questions, a process that continues until the group reaches clarity and consensus. The process is not unlike the preparation, review, response and revision of a scientific manuscript.

> **As I was leaving the classroom recently, I overheard one of my students complaining that I always answer his questions with another question. "I hate that. I just want to know the answer." What I thought of as good teaching practice was annoying my student. The Socratic method dates back well over 2000 years, but does it have a place in today's science classrooms?**
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> **— Ann Riedl**

The goal of the Socratic method is to strip away illogical, inconsistent, irrelevant and unsupported claims and ideas, thereby revealing truth. People who hold illogical or empirically unsupported beliefs can find a Socratic discourse discomforting. Some view the Socratic approach as antagonistic and unwelcoming, particularly to students who are already uncomfortable within the academic community. When we asked students, "Why was Socrates annoying?" many said he was arrogant, certain that he knew the answers to the questions he asked and unwilling to accept alternatives. Some said Socratic questioning leads to competitive and potentially embarrassing situations — a form of jousting to establish who belongs in a class and who does not.

Children start noticing, and caring about, their audience's response as early as age six, according to published research. Children may hesitate to ask questions because they fear being judged or appearing stupid. A Socratic approach can cause a student who already has concerns about their place in a class or a discipline to feel like an imposter, and such feelings are a primary reason why students leave science degree programs and careers.

Yet, in our experience, working scientists often float silly ideas and ask questions (occasionally over beer and popcorn) to clarify their understanding. They would rather resolve confusions from the start than build projects (or answer test questions) based on incorrect or irrelevant assumptions. Building the confidence to test ideas in public and to understand what determines whether they work is key to the scientific thought process.

Can the Socratic approach be applied in a way that minimizes its possible negative aspects, helps students arrive at mechanistic explanations and reflects how scientists actually talk to each other? Can it build up rather than erode students' confidence and help them to see themselves as part of the process that identifies relevant principles and resolves uncertainties? Can it be used to transform education into a creative and constructive process rather than a system that requires students to remember and regurgitate facts?

How does the Socratic method mirror the scientific process?

The sciences differ from philosophy and religion in a number of ways. Rather than Truth with a big T, the sciences aim to develop working and testable mechanistic models for natural phenomena. Robert T. Pennock, a philosopher and professor, wrote, “Science never guarantees absolute truth, but it aims to seek better ways to assess empirical claims and to attain higher degrees of certainty and trust in scientific conclusions.”

Model building and testing is a creative and social process that involves playing with ideas, considering the evidence that supports the model and whether simpler or more accurate models are possible. These models presume an observer-independent physical world. They also provide science with a direction — over time, explanatory models get more accurate and explain more; the types of plausible models decrease as scientific understanding improves.

While wrong ideas do emerge, the scientific community rarely stays distracted for long by unsupported speculation or incorrect ideas.

The goal of a Socratic approach is to help students work productively with disciplinary ideas and their application, discarding those for which there is no or contradictory evidence. We believe that such an understanding is particularly useful in the biological sciences, where closely related organisms (such as mice, Neanderthals and modern humans) can display significant mechanistic differences as a result of their evolutionary histories. Without an understanding of basic principles, a student can only memorize the required answer.

How can we build an inclusive Socratic community in a science course?

Given the realities of many modern college classrooms (and Zoom sessions), generating a Socratic environment can be challenging, due in part to students’ previous experiences with science education. In an age of Googling, memorization is much less important than making sense of and testing plausible models for various phenomena. To get Socratic, we have to reconsider the challenges we pose to students, the problems we ask them to solve, the phenomena we ask them to explain and the ideas we expect them to apply.

All too often, particularly in the biological sciences, students are faced with problems that can be solved only by memorizing the correct answer. Unlike physics and chemistry, the behavior of a biological system cannot, even in theory, be predicted from first principles (a point made explicitly by Ernst Mayr, who noted the role of historic, and often unknowable, stochastic and environmental events that influence evolutionary processes). At the same time, physics and chemistry constrain the underlying molecular and cellular processes. By focusing on these common processes, we can help students analyze novel situations and propose and critically consider plausible mechanisms that may produce them. We recognize and value the creative process that reflects what scientists do. We can focus on the importance of understanding the mechanisms of reaction coupling rather than memorizing the steps in the Krebs cycle.

> **It is all too common to find that even advanced students answer complex questions with a single word or phrase; it is almost as if they have never had to make an argument based on assumptions and mechanisms but have been trained to recognize the repeat stock phrases.**
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> **— Mike Klymkowsky**

We must grapple with significant practical considerations. Socratic interactions traditionally involve small groups of people. How can we adapt them to an introductory science class, which is typically anything but intimate? Strategies exist that can be used in large classes and smaller recitationlike sections, provided instructors are trained in how to create scenarios that encourage student responses, and in how to respond in turn. This means avoiding the almost reflexive approach of correcting the student and providing the answer. We want to ask students to articulate their assumptions; these are skills that must be developed by both instructors and students. We need to emphasize that we do not expect a perfect response from students but rather a plausible one. This is no trivial challenge, particularly since it may mean students need to recall and return to ideas and ways of thinking that they were exposed to weeks or months earlier. Time for recursive reconsideration of underlying ideas must be built into course design.

This probably will lead to a decrease in content, so we need to consider carefully what we present and what we expect students to do with it. Are we asking for memorization or for the application of general principles and

discipline-specific concepts? Have we trained the students to build and evaluate models and explanations? Are we presenting them with tasks complex enough to allow for multiple solutions that can be the focus for Socratic feedback, leading students to reconsider and revise their responses? Do our questions require students, working alone or in a group, in class or asynchronously, to articulate their assumptions? In such a context, we can exploit asynchronous interactions mediated by software systems that allow for extended conversations within groups of students together with instructors' Socratic feedback.

> In a recent developmental biology class, I was struck by students' inability to consider how the anterior–posterior axis of a gastruloid could be revealed, even though Hox gene expression, a classic marker of this process, had been considered in depth earlier in the semester.
>
> — Mike Klymkowsky

Whether the group is large or small, a Socratic exchange requires that those running the conversation be trained in encouraging students to consider the implications of their assumptions and to reflect upon what they might be overlooking. Departments could hold short workshops and encourage classroom observations to teach instructors how to do this. The instructor's role is not to judge the correctness of the final response but to catalyze the discussion. In the best case, the instructor's role will be usurped by other students in the class.

The goal is to show that scientific progress does not depend on otherworldly geniuses but is the result of a social and collaborative process, a process in which all who are willing to engage can contribute.

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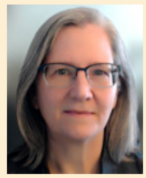

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