One Bottleneck at a Time

Addressing common learning issues encountered by students

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Teachers can easily identify what subjects their students have trouble with, whether it is transcription and translation, glycolysis and fermentation, balancing chemical equations, or vector analysis of forces acting on an object. Every year, we try to make these complex issues more accessible to our students. New editions of textbooks provide improved graphics and more lucid descriptions. Yet, students still find these topics troublesome. This article describes a method by which teachers can analyze and find solutions for these kinds of "student-learning bottlenecks," and at the same time incorporate more inquiry into the classroom. The method is based on a summer workshop in which teachers collaborate with their colleagues to remedy learning bottlenecks that they have identified in their courses.

The importance of inquiry

For some time, a school of thought has suggested that science teaching too often focuses on the conclusions that have been reached through science, rather than science itself. Science is a process of investigation; scientists investigate the natural world and try to find out how it works. However, science teaching often devolves into a mere listing of "facts." This contradiction occurs because, in order to make new discoveries, it is necessary to understand a great deal about what is already known. Consequently, science teaching easily adopts the form of presenting already known information. Further, for some teachers, the demands of covering the National Science Education Standards and preparing students for high-stakes testing can lead to an emphasis on science content over inquiry (NRC 1996). Unfortunately, teaching the "dry, yeast-less facts" (Martel 2001) removes much of what makes science interesting to students and teachers. The process of discovery must be reincorporated into science teaching.

Inquiry-based teaching—teaching that incorporates discovery—is challenging. It takes longer than a straightforward lecture, and it can require a greater depth of knowledge on the part of the teacher, especially if students come up with novel questions that the teacher is unable to answer right away. Perhaps the biggest difficulty is finding that special balance between allowing enough time for students to discover information, and covering all of the material specified in state or national standards. Reworking class material to make it more inquiry-based can be a daunting task; therefore, many of us teachers do not make this transition to inquiry.

Learning bottlenecks

We have used the method outlined in Figure 1 at Indiana University (IU) in a summer professional development workshop called the Summer Research Institute (SRI) to help secondary teachers address learning bottlenecks encountered in inquiry-based activities. During this two-week workshop, mornings are dedicated to group discussion among the participating teachers. Most of this article will focus on the morning aspect of the workshop. Afternoons are given over to research in the laboratories of investigators at IU. During the afternoon laboratory work, participants gain a direct, if brief, experience with the process of science by working side by side with university scientists in their laboratories.

The approach used during the morning sessions of the SRI workshop follows the paradigm described by Middendorf and Pace (2002). Each participant first identifies a student-learning bottleneck. Then, group discussion centers on analysis (supported by readings from the educational literature) of the different bottlenecks using the seven-step plan illustrated in Figure 1 (every Step referred to in this article is found in Figure 1). After a week of discussion and analysis, each participant prepares and delivers a short lesson that seeks to remedy their particular student-learning bottleneck. During each presentation, the other participants act as students and provide feedback concerning how the lesson felt "on the other side" of the teacher/student relationship. Every participant gains insight into their own particular learning bottleneck *and* those of the other participants, providing them a wealth of information to draw from in subsequent teaching.

Thinking like an expert

After identifying the specific bottleneck to be addressed (Step 1), teachers (the experts) define how they handle this topic that students find so difficult (Step 2). This is the most challenging and important step in the process. It is invaluable to work through this in a one-on-one discussion with a colleague, preferably one who teaches in a different field and does not carry the same assumptions or consider the same things to be obvious. For example, two biologists may have difficulty identifying the underlying assumptions that they both have when thinking about mitosis. By contrast, an English or history teacher would be unlikely to make the same assumptions and would be better able to help break the concept down into its essential components.

Even though Step 2 is difficult, it is vital to the process of eliminating student-learning bottlenecks. Teachers already know what they are trying to describe and know many other aspects of science that relate to the particular topic. Teachers also know what the diagrams are intended to illustrate. To students, however, the information may be entirely new. Worse, students may have internalized erroneous preconceptions, or they may have struggled unsuccessfully with the information previously and developed a mental block. By devoting significant discussion time to the issue of articulating how experts process the information when working with the

FIGURE 1

The seven-step plan for addressing a learning bottleneck.

Step 1: Define a bottleneck

Identify a particular moment in your classes when students repeatedly fail to grasp what you are trying to help them learn, yet success requires that they *do* grasp it. Define, as carefully as you can, how students' reasoning goes astray.

Step 2: Define the basic learning tasks

When you approach the same information as students are expected to learn, how do you approach it? What, in general, do experts in the field do as they address this material? Think deeply about what thought processes you use, recognizing that they may be so fundamental to you that you do not even recognize that you do them. Hint: Write down a step in your thinking. Then ask, "*How* do I do that?" This will lead to another statement. Again ask, "*How* do I do that?" Continue until everything is explicitly stated.

Step 3: Model these tasks explicitly

To help your students grasp what you want them to grasp, you need to show them the kind of thinking that is required. If a particular thought process is needed, but they have no notion that such a thought process is even possible, is it realistic to expect them to stumble onto it by themselves? ***Show*** them what you do. ***Illustrate*** how you think about the problem yourself. *Think out loud.*

Step 4: Motivate the students

Develop a learning situation in which your students will *want* to struggle with the information. Help them discover how the information is meaningful to them, not "just something you do in school."

Step 5: Create occasions for students to practice these steps and receive feedback

In order to learn, students must actually carry out an appropriate thinking process. Give them an opportunity to do so. At the same time, give them feedback about how they are doing.

Step 6: Assess student learning

It is essential to determine whether your methods have worked, and the students are learning what you are trying to help them learn. Find out immediately and often, not only at the end of the unit or semester.

Step 7: Share what you have learned about student learning

If your students face a learning bottleneck at some point, it is virtually guaranteed that students of other teachers do as well. If you've found a way to solve the bottleneck, share what you have learned with your colleagues.

topic, teachers can discover thought patterns they use that students do not (Bransford, Brown, and Cocking 2000).

For example, teachers typically use "simple tools" (e.g., Punnett squares, vector diagrams, and the periodic table) to illustrate concepts or to make predictions about processes. We describe these tools easily to students, but students often remain mystified. What we see and think when describing and using these tools is, apparently, different from what our students experience. One workshop participant said, "Today's activity where we had to explain our bottleneck to a partner was helpful in that it allowed me to see all the assumptions that I make when teaching the content. This really allowed me to see that there are many places where students might be getting off track. Identifying these problems could very well be key in solving these bottlenecks."

A group discussion of "thinking like an expert" can provide insights that might be difficult for teachers to realize otherwise. For example, many natural processes are dynamic, but are invisible because they occur over too slow a time scale (movement of tectonic plates) or are too small to see (transcription and translation). We often visualize these processes as a "mental movie." Describing these "mental movies" to students, however, requires the use of diagrams and animations, most of which are carefully designed to illustrate only the "important" features. When teachers see the diagrams, they know what is left out, and what the illustration is intended to symbolize. However, students may not. Even something as simple as reading a diagram has inherent assumptions and conventions, of which teachers are aware, but students may not be.

It is therefore essential to give students a boost. If you as the teacher think about a process in a particular way that students are unlikely to discover quickly, why not show them what this thinking process is like? You may not be able to show them your "movie," but you can certainly tell them that you do play movies in your mind. If students have difficulty solving a particular type of problem (e.g., balancing chemical equations), put a problem on the board and think out loud as you solve it—including any false starts. That is, *model your thinking* for students (Step 3). This is not the same as providing students with an algorithm for solving this kind of problem, or going quickly through a process previously practiced. Rather, teachers should be willing to put up a new problem and walk slowly through the steps to solve it. And what would be so bad about having students occasionally observe you struggling through a problem, much as they do? They would see that struggling is part of the process and recognize that it is okay.

How does modeling differ from lecturing? There is a significant difference. Modeling is thinking aloud and illustrating a thought process. Lecturing is a simple telling of information.

Creating the hook

The classic stand-up lecture is more likely to be soporific than edifying. Students simply listen, for few have learned the art of thinking actively about the material being presented (Bonwell and Eison 1991). With the limited time available to cover standards, it is inevitable that some form of information-presentation will be necessary. Furthermore, some learning bottlenecks may be sufficiently complex that it would be unrealistic to imagine that students could discover all the information for themselves. Again, some sort of information-presentation may be necessary. But, should the first step be to present our students with information?

A major benefit of inquiry-based teaching and working with a real problem is that it increases students' interest and engagement with the material. A well-crafted hook that lures students into learning is indispensable; an investigation, even if only a short one, often does so effectively. Furthermore, inquiry-based experiences provide students with opportunities to practice the kind of thinking upon which science is based. That is, inquiry-based learning achieves Steps 4 (motivate) and 5 (practice) of the seven-step plan.

A short inquiry-based scenario can easily introduce a topic and provide the hook that engages students. For example, a chemistry teacher in the SRI workshop turned a standard lesson on balancing chemical equations into an inquiry lesson. She engaged students by having them act as consultants for a chemical company that wanted to use the minimum amount of reactant X to make a certain amount of product Y. Students had to work together in groups to try to solve the problem given their knowledge of chemical equations. After working with the problem for 10 minutes, students were more receptive to a description of how to solve the problem (see also, Bonner 2004).

As we have worked with teachers in the SRI workshops, we have learned a number of valuable approaches to addressing learning bottlenecks. Among them is the necessity for the subject matter to relate to students' lives. We all learn by incorporating new information into our existing knowledge base. Learning something that is so different that we don't know how to relate to the information is exceptionally hard. Because of this, carefully chosen inquiries (or short scenarios that give students a brief exploration before the main lesson) can be invaluable.

For example, teachers can merely describe freshwater invertebrates in a lecture-based "Walk Through the Phyla," or teachers can involve students in a local Riverwatch program (*www.riverwatch.org*) so that they can obtain useful data on the health of streams and rivers, using freshwater invertebrates as indicators of water quality. With the lecture-only approach, students will learn something about freshwater invertebrates, but with the problem-based Riverwatch approach, students learn the same information in a context in which they have a stake in the outcome. The more personal context and involvement of the second approach lead to easier and longer-lasting learning. Similarly, teachers can simply describe the processes of glycolysis and fermentation to students or can enlist students' help in figuring out why one loaf of homemade bread came out flat and heavy, while the other loaf came out light and fluffy (Bonner 2004).

Share the wealth

As with any learning outcome, it is important to determine whether students are learning what we hope they will learn (Step 6). With learning bottlenecks, and the introduction of new pedagogical approaches, it is particularly important to determine the effectiveness of new instructional strategies. Because each component of an instructional unit is an essential step in reaching the overall learning goal, assessment should be embedded in instruction as frequently as practical, not merely left to the end of a unit or term. In the first attempt to overcome a bottleneck, end-of-unit assessment may show little improvement in student performance. While this information by itself would be discouraging, assessment of the separate components of the lesson may show that some of the innovations were actually very successful, with students stumbling on only one or two issues that can be addressed the next time around.

It is almost certain that other students in other classrooms also experience the learning bottlenecks experienced by your students. When you find a creative solution, be sure to share those ideas with colleagues (Step 7). In return, your colleagues may have some insights that can refine your solution to make it even better.

Lessons from the labs

The analysis of student-learning bottlenecks takes up the mornings of the SRI workshop. Of course, teachers may follow the same analytical method independently with each student-learning bottleneck that they identify in their classrooms. It is more difficult for teachers to recreate, on their own, the afternoon component of the workshop: Research in the laboratories of IU faculty. Nonetheless, an important and rather unexpected principle emerges from the SRI participants' experiences.

Initially, we imagined that the afternoon research component would provide a research experience for teachers whose training may not have incorporated one—and thus extend the "inquiry experience." However, it has proven to have a much more subtle, and perhaps more important role as well. Entering a laboratory for the first time and receiving the "standard introduction" to the research problems is overwhelming. There is too much information to assimilate. The research protocols seem like complex recipes, which must be followed almost blindly, without knowing where they came from or why they work. Even though this is real research, anyone who is new to a lab seems to have little choice but to treat it like a "cookbook lab" until they learn enough to understand the science more fully. This feeling of disorientation is true of incoming graduate students, postdoctoral fellows, and faculty on sabbaticals; it is also true of the workshop participants.

Invariably, the workshop participants draw the parallel between themselves in the research lab and their students in the classroom. This comparison provides a valuable insight into students' experiences in classrooms, and changes the atmosphere in our classes. This insight is best expressed by one workshop participant who said, "Never again will I become impatient with a student who cannot figure out how to follow the protocol. Today, I was that student."

In summary, we have found that the overall paradigm described by Middendorf and Pace (2002) for college faculty is effective in initiating the transition to inquiry-based teaching for secondary teachers. Whether in summer workshops, staff meetings, or informal teacher partnerships, working cooperatively with other teachers to solve student-learning bottlenecks allows teachers to pool their experience and insight and redefine the way they teach. By collaborating with other teachers to test a new approach to teaching a particularly troublesome concept, it is possible to become sufficiently familiar with the new methods that one is not only willing but eager to use them in the classroom. Having overcome one bottleneck successfully in a cooperative atmosphere with collaborating teachers, you can easily approach other bottlenecks to student learning in the same way, thereby improving student learning, one bottleneck at a time. ■

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