Biology Today

Problems in Beloit

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I've just returned from Beloit, Wisconsin, where I spent a problem-filled week. It was wonderful! The source of my problems was BioQUEST, a project for the improvement of undergraduate biology education. BioQUEST's aim is to promote a research approach to learning, to foster an understanding of how biologists perceive the world. To accomplish this, the developers of BioQUEST, including John Jungck (Beloit College) who hosted the workshop, are focusing on what they call the "3 P's"—problem posing, problem solving and persuasion (Peterson & Jungck 1988). The BioQUEST project has been going on for several years with development of software to give students experience with the 3 P's. The workshop I attended brought together 20 biologists to work on curriculum in areas where BioQUEST was thought to be weak: botany, cell physiology, developmental biology and noncomputer applications.

I have rarely had such an enjoyable week, and I have never had such a rewarding professional experience. To talk about biology morning, noon and night for eight days was terrific. The organizers, along with John Jungck, were Jim Stewart and Patti Soderberg of the University of Wisconsin-Madison. The three of them did a great job of bringing together a wonderful group of people. I won't mention everyone for fear of turning this into a litany, but I learned something from each participant and from every session we had. I'll describe some of the seminars which were presented and some of the discussions we had in an effort to give you the flavor of what went on at Beloit College. It was too good an experience to keep to myself, and perhaps some of the ideas that I found so exciting will also be helpful to others.

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The Three P's

The workshop began with a Sunday evening session during which John Jungck described the 3 P's. Though many of the participants had been involved in BioQUEST projects in the past, there were some like myself for whom the 3 P's were little more than a slogan. While problem-solving has become a pedagogical buzzword, the other 2 P's—problem posing and persuasion—are less publicized, though they turn out to be just as important (Jungck 1991). It makes sense that you can't solve a problem until you know what the problem is. Framing a problem is often difficult for students, yet they must have some experience in doing so in order to understand how biological inquiry proceeds as well as to solve problems. It is almost a truism in science that the most important aspect of discovery is to ask the right question. This is often difficult to do. Allowing students to confront this difficulty is one way to give them an insight into how science is done.

The 3 P's give problem solving a new twist by also calling it problem probing, which implies a more open-ended process. Problem solving implies an end point, a solution to be "found," but for many of the complex problems of science the very form of the solution is unknown. Such uncertainty is difficult for students to deal with. They want the answer; as John noted, they often ask, "How do you know when you're finished?" Problem probing is less threatening to students than problem solving. They no longer feel that there's some correct solution, but rather they are free to explore different approaches and see where these may lead. John said that this creates a "positive attitude toward error." I like this phrase. It means seeing error as a guide. You tried something and it didn't work; that's not failure because you've learned something about the problem through the probing. Error is a guide that redirects your search for a solution.

Students are so afraid of getting the wrong answer on a test that they fear all error. As long as multiple choice tests exist, that fear will not disappear. But in biology class and particularly in biology lab, students' experiences of error should be broadened through problem probing so they can come to appreciate the positive aspects of error, and also to see why error is so much a part of scientific inquiry. It's hard to find the right answer when you are in the dark. Scientists spend a great deal of time exploring research paths that lead nowhere. In *Discovering*, Robert Root-Bernstein (1989) quotes Osborne Reynolds's description of his mentor, the physicist J.J. Thomson; it is a beautiful depiction of problem probing in science:

> He would often begin with an idea which, after he had worked at it for some time, turned out to be wrong; he would start off on some other idea which had occurred to him while working on the previous one, and if this turned out to be wrong, he would start another, and so on until he found one which satisfied him, and this was pretty sure to be right. He often started out in the wrong direction but he got to the goal in the end.

It is one thing for a student to read about such problem probing, and quite another to actually experience it, to feel the frustration and helplessness of error and the elation of shedding light on a problem. The 3 P's approach provides such experiences.

But in BioQUEST, finding the solution isn't enough. There is one more P to go: persuasion. Science, as John Ziman (1968) writes, is "public knowledge." The solution must be presented to the scientific community whose members must become convinced of the solution's validity if it is to become a part of the body of scientific knowledge. Students must learn to present their findings in a convincing way, to draw on the techniques of persuasion to make their case. They have to be able to integrate their findings with those of others and synthesize a convincing model of what is going on in the problem they are exploring. Only in this way will they see that there is more to doing science than just making discoveries; these are meaningless until they are reported, corroborated and then fit into the existing body of knowledge.

I found John's presentation interesting, but I was not yet convinced of the value of the 3 P's. I will admit to having a prejudice against the literature on problem solving. What little of it I've looked at seems complicated and rather uninteresting. Though I use some problem solving techniques in the classroom, it seems a big enough job to teach biology without teaching how to problem solve as well. As the week progressed, there were talks on each of the 3 P's and on how they could be utilized in biology teaching. Slowly, I came to appreciate how problem solving, when combined with problem probing and persuasion, could be a powerful approach in the classroom. I came to see problem solving not as a skill to inculcate as separate from biological knowledge, but rather as a way to give students some understanding of biological inquiry. Problem solving is a skill that may be useful to students in the future, but the main reason for introducing it into biology class is because it gives students a glimpse of how science is done. Biological inquiry *is* problem posing, problem solving and persuasion; so if we are to teach biology as more than a body of information, the 3 P's approach makes sense.

Genetics Construction Kit

As the week progressed, I became more and more convinced (persuaded!) of the value of the 3 P's. Monday morning, we worked with a computer program developed by BioQuest participants. It's called Genetics Construction Kit (GCK), and in it, students are given a number of "field collected" organisms with particular traits—drosophila traits were used. In the simplest simulation (which is, naturally, the one I opted to do), one trait such as eye color is involved. By doing crosses, students can figure out inheritance patterns: Is it a case of simple dominance or codominance, is there sex linkage, etc. This is a BioQUEST simulation, so no problems are posed, no answers given. Students must decide both what questions to ask and when a solution has been reached. Then, in writing up their work, they must persuade others that their solution is reasonable by selecting the most telling crosses.

This was the first time I'd used GCK and looking back now I can say that I enjoyed the experience. But while I was trying to figure out what was going on, what crosses to do and what the results of the crosses meant, I was working hard and feeling tense. I thought to myself that this must have been how Mendel felt as he tried to find some pattern in a sea of data. Science as a journey into the unknown became very real to me. The difficulty and frustration students might experience when using GCK are very real parts of doing science, and students need to appreciate this. But they also need guidance and encouragement in dealing with the uncertainty that is built into GCK, so the problems they confront do not create terribly negative feelings toward science. As with all instruction, the teacher has a large role to play in guiding students in their use of GCK and other simulations.

Persuasion

Over the next couple of days, we had lectures on each of the 3 P's, starting backwards with persuasion, presented by Betty Smocovitis (Stanford University). Like so many of the workshop participants, Betty has a varied background. She is a biologist-turned-historian of science, and she has also been involved in writing-across-the-curriculum projects. She began by saying that biology is a relatively young discipline. The first real university departments of biology were not established until the 1920s. Before that time, botany, zoology, genetics, etc. were seen as separate disciplines rather than as aspects of one science. Betty looks at this from a constructivist viewpoint: The category "biology"' was actively constructed by individuals who persuaded others of the validity of this category. She went on to say that all of us, as biology teachers, daily continue the process of constructing biology when we decide what to teach and in our approaches to teaching.

This is quite a different way of looking at biology and stirred a great deal of discussion. But the part of Betty's talk that I found most interesting involved how a scientific paper is constructed. She quoted from the works of Charles Bazerman (1988) and Greg Myers (1990) who have done critical analyses of the language used in research reports and journal articles. They argue that scientific knowledge is constructed through written arguments, that the language is chosen to give the impression of strict objectivity and to persuade the reader of the validity of the findings. I had read Bazerman's book some time ago, and it made me a little angry and uneasy because it seemed to make scientists and their work seem less objective and more like a power play. But listening to Betty in the light of my introduction to the 3 P's, the use of language to persuade seemed more of a necessity. Science is a social process, there is a community of scientists who must be convinced to accept new knowledge and language is the primary form of persuasion among humans.

Problem Solving

The next P, problem solving, was discussed in a talk by Jim Stewart. He began by showing us a bleach container that looked like a half-gallon milk carton, but only poured when turned upside down and only released a measured amount of bleach on each pouring. Jim asked us to figure out what device inside the container was responsible for the phenomena we'd observed. Working in groups, we tried to develop a "model" and solve the problem. After 10 minutes we hadn't come up with any brilliant explanations, but Jim used this exercise as an entry into the whole issue of how we solve problems: what kinds of models we build, how the models change as we consider more pieces of information, how the members of a group interact in model building. Jim's presentation was a good lesson in how to present problem solving in the classroom. And to emphasize the open-endedness of the 3 P's he admitted in closing that he had no idea how the bleach container worked! He was confronting the unknown along with his students.

Problem Posing

On Wednesday, Chuck Dyke (Temple University) discussed problem posing. Chuck is a philosopher by training; his fields of expertise are social and political philosophy. On the face of it, he wouldn't seem to be a likely participant in a biology curriculum workshop, but he was probably the most valuable person there. I suppose you would call Chuck an amateur entomologist, but his classification skills are at least the equal of any of the biologists at the workshop. He is also an amateur farmer, so his botanical knowledge is pretty impressive too. Finally, he's well-versed in the philosophy of biology, in evolutionary theory and self-organization theory. With this rich background, he brought a unique perspective to the group. Chuck is a thinker, and all week he made comments that made us all think a little harder about what biology is and what it is to teach biology. In his talk, he gave us a number of insights into what it means to pose a problem. He said that students aren't going to be interested in asking questions, in posing problems, unless the problems are within their "cognitive space," their intellectual and linguistic space.

At first I was turned off. I loathe jargon. Since the education field is loaded with it, it is difficult to avoid it all, but I try. Cognitive space seemed to be one piece of jargon I could live without, but I changed my mind as Chuck discussed the concept. He talked about the different ways of studying insects. For example, you can study the insects in a field of goldenrod in terms of a phylogenetic tree: What are the lineages of the insects present, what are the nearest relatives? Genetics and taxonomy are important in answering these questions. But you can take the same insects in a field of goldenrod and look at them in terms of a trophic web. Then you are in a different cognitive space, and you will ask different questions: Who eats what, what is the active trophic stage. Ecology and biogeography are important in answering these questions.

Chuck went on to show how scientists in different intellectual and linguistic spaces have difficulty communicating with each, and how the same is true of teachers and students. If we want our students to appreciate what we are talking about we have to draw them into our cognitive space; or rather, we have to create a space that includes their knowledge and interests so that the questions we pose make sense to them, and so they too can pose questions that are meaningful to them and also make sense in terms of biology.

Chuck got me thinking about ways I can take students into the space called biology that I find such a pleasant and rewarding place to be. I have often thought that I would like to be able to pour my knowledge and appreciation of biology into the brains of my students. I have now replaced this obviously impossible goal with another equally impossible one: sharing my cognitive space with them. The difference is that the former is totally unrealistic, while the latter is something I can move toward. I can at least (I hope) get to the point where our cognitive spaces have considerable overlap.

Interspersed between these lectures were other morning, afternoon and evening sessions given by workshop participants. They were an interesting group of people with a host of assets to bring to BioQUEST. They came from 20 different institutions in 12 states; all areas of the country were represented as were many areas of biology and science education. From the very first session on, I got ideas that I can't wait to try out when classes begin again (I'm writing this in July). For example, Bob Blystone (Trinity University-San Antonio) showed us a microscope-computer interface using the *Image* program developed by Wayne Rausband of the National Institutes of Health. This allows students to make measurements of cells and of subcellular structures, use artificial color enhancement to make some structures more obvious and reconstruct three-dimensional views of embryos from cross sections. At another session, Betty Odum (Santa Fe Community College-Gainesville, Florida) showed us the BioQUEST computer program, *Environmental Decision Making*, which she developed with her husband, H.T. Odum. And John Kruper (University of Chicago) presented the predator-prey computer simulation, *Biota*, which he helped to develop for BioQUEST. Also, Angelo Collins (Florida State University) described her work on "authentic" assessment methods, ways to assess student achievement that go beyond the usual "reductionist" forms of assessment such as multiple choice testing.

Authentic assessment means such things as student portfolios, an idea I had toyed with but didn't quite know how to implement. From Angelo, I learned enough about portfolios to be ready to try using them in class. A portfolio provides a way to follow a student's growth in knowledge and change in attitudes over a period of time; it allows students to show off in areas where they are particularly strong, and it gives them a feeling of ownership of the course material. A portfolio is not merely a collection of all the student's work for a semester; students have some leeway in choosing what to include. The portfolio might also include copies of articles, newspaper clippings, art work, poetry, etc., that is, anything relevant to the course's theme and subject matter. I teach a biology course for communications majors in which I try to get them to explore how biology topics are portrayed in the media, both in words and pictures. I can see their portfolios including not only their own essays and art work, but newspaper and magazine articles and perhaps even a videotape of a TV program. The very act of deciding what to include in the portfolio is a great problem for students to grapple with and involves the question of how to persuade the teacher of the value of their portfolio and of its theme.

Projects

On Tuesday afternoon, we had to break up into groups and start working on curriculum projects which we would continue to develop over the next year and which would eventually become part of the Bioquest package. Several groups fell out quickly as people with similar interests got together. One group of science educators decided to work on a program to introduce the 3 P's to in-service and student teachers. The botanists chose to create a computer simulation of how climate change would affect plant growth. The developmental biologists wanted to put together a curriculum to give students a better understanding of embryogenesis; it would utilize existing software on pattern development. The cell biologists planned to build scale models of subcellular structures and then write up directions on how these could be made by students.

That left five people, including myself, who had no idea what to do. John Jungck put us together in one group so we wouldn't feel lonely. He instructed us to talk and come up with some ideas and then split into two smaller groups. As we outcasts began to talk, Bob Hafner (Western Michigan University) said he was interested in what a problem is, what makes a problem a problem. This struck me as a rather nebulous and uninteresting issue, but we talked—for hours, for days. It was a wonderful experience of tossing ideas around. We discovered that the five of us liked each other, worked well together and each had something to contribute, so we agreed that we wouldn't let John Jungck split us up! We decided to develop activities based on the question: What is a problem?

Contrary to my original impression, this turned out to be an interesting and important question. It's hard to pose and solve problems if you don't know what a problem is. We used as a basis for our work an article by Thomas Nickles (1981) which Bob had brought along. Nickles has developed a constraint-inclusion model of what a problem is. In his view, constraints define the problem and characterize the solution. There are practical constraints such as those of time and money, that narrow the problems a biologist can tackle; the constraints of the biologist's expertise and mind set also come into play as do several other types of constraints: sociocultural, theoretical, etc.

Though we've only just begun exploring the possibilities, we think that our project will be an important addition to BioQUEST. Each of us has made a contribution to the project; our group is a wonderful example of communal research. Besides Bob and me, the other members of our group are John Kruper, who brought an interest in student model-building experiences; Anne Dehring, (University of Wisconsin-Madison), who provided a wealth of experience on how students problem solve in labs; and Ann Kindfeld, (University of California-Berkeley), who has an interest in mental models and a passion for meiosis. Ann's doctoral dissertation was on the concepts and misconceptions that students develop about meiosis, and Ann now thinks of all problems in biology in terms of meiosis. It is fascinating how she can relate any aspect of problem-solving to her central problem. We kidded Ann about it, but we learned a lot from her about meiosis and about how students think.

That's how I'll remember my Beloit experience, as a great mixture of learning and fun. We worked very hard, often from 8:30 a.m. to 10 p.m. (NSF got its money's worth), but we enjoyed every minute of it. Ethel Stanley (Millikin University) was the most effervescent participant and the wittiest; she was always in a good mood. Patti Soderberg was in charge of arrangements and was definitely the most energetic. Patti and Ethel kept us going, while John, Jim and Chuck kept us thinking. I can't recall another week in my life when I learned so much or was so intellectually stimulated.

The profound exhilaration I experienced made me realize how much I love biology and biology teaching, and how much I love to talk about them and to share ideas. By the time I left Beloit with my BioQUEST T-shirt (decorated with three peas in a pod, of course), I was on a BioQUEST high. I suffered several nights of insomnia before I came back to earth and started making plans to use all the ideas I'd collected. I've just finished 20 years of teaching and a week in Beloit has gotten me ready for the next 20. *(For more information on BioQUEST, please contact John Jungck, Beloit College, 700 College St., Beloit, WI 53511.)*

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