Lecture-Free Teaching

A Learning Partnership Between Science Educators and Their Students

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EDUCATION

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Chapter 1

Introduction

My passion for teaching reform took root in 1998, more than two decades after earning my PhD in medical sciences. Before that, I did what most post-secondary educators do – I taught as I had been taught.

During my first decade of teaching at the University of Maine at Presque Isle, I accumulated a large collection of transparencies and annotated my lecture notes so that I would project the transparencies at the appropriate moments. I punctuated my lectures with humorous statements I had conceived over the years and updated my notes to reflect current research. At each class meeting I moved smoothly and energetically through the scheduled topics while my students furiously scribbled notes. I knew they were attentive because they asked probing questions such as “Could you repeat that, please?” or “Will this be on the test?” My goal at that time was to perfect my lectures.

Although they wrote flattering evaluations at the end of each semester, I began to realise that neither the weaker nor the stronger students could reliably apply what they had learned – an important skill for both science majors and non-majors. After more than a year of considering possible solutions to this problem, I submitted a proposal titled “Incorporation of Active Learning Methods Into General Biology and Sciences Courses” and was awarded sabbatical leave for the spring 2000 semester. That semester awoke more creative energy than I had ever experienced while performing the traditional laboratory research for which I had trained.

My stated intention was to improve two of my general education curriculum courses by engaging in some kind of active learning exercise during every class meeting. I initially adapted ideas gleaned from books and journals.

As I became more comfortable with my new teaching style, I designed my own activities. Within a couple of years I had abandoned lectures and replaced them with what I called *Lecture-Free Teaching*. Improving introductory science courses is still my focus, but my new methods have spilled over into all of my upper-level courses.

My next phase of reform was to increase the time allotted for each class meeting. After I incorporated activities into my classes, students began to complain that 50-minute class periods were too short. Both my students and I felt rushed and the topics lacked coherence when activities ended abruptly or had to be completed at home or during the next class. I changed class meetings from 50 minutes, three times a week, to 75 minutes, twice a week.

Ultimately, I erased the arbitrary boundary between lecture and laboratory. In contrast with the traditional weekly schedule of three 50-minute lectures plus a three-hour laboratory at a different time of the week, sometimes with an instructor other than me, my classes now meet with me alone in the laboratory twice a week for approximately three-hour sessions. I gradually replaced instructor demonstrations and cookbook-style laboratory exercises with inquiry-based activities. In cooperative learning groups, students apply the scientific process to develop hypotheses and then design and perform experiments. To complete the circle of reform, I investigated methods of formative and summative assessment and created classroom assessments to complement and reinforce my active-learning and inquiry-based approaches.

The steps to Lecture-Free Teaching discussed in Part I represent the entire process of course design and delineate a never-ending feedback loop that provides information to both the students and the instructor. For one semester the students and their instructor are members of a partnership that contributes to their mutual goal of significant learning that remains meaningful beyond the final exam.

The first step in this process is to consider unchangeable factors so that subsequent course design will complement these elements. Next, the instructor determines specific learning goals for the course, followed by a third step of creating assessments, a crucial part of the feedback loop. Assessments should provide significant information to both the students and the teacher about their mutual progress towards accomplishing the learning goals. Formative assessments are most effective when the opportunity remains for students and educator to make changes that will contribute to success. The fourth step is to choose a teaching strategy that both achieves learning goals and responds flexibly to feedback from the assessments. The teaching strategy must be much more than a collection of active learning methods selected by the educator. Instead, it must provide coherence within each class meeting and from one week to the next. Next comes the fun of developing in-class activities and homework assignments that satisfy the original learning goals and support the teaching strategy while providing cohesiveness to the course.

The remaining steps described in Part I fall into place easily: choosing a marking system based on both formative and summative assessments, assembling a topic schedule and preparing outlines of important terms and

WHAT LECTURE-FREE TEACHING CAN ACCOMPLISH FOR SCIENCE

There is an urgent need for science educators and researchers to replace retiring professionals and to meet the requirements of a society increasingly more dependent on science and technology. Equally important is the need for a more scientifically literate citizenry able to function in a technologically complex world, not only by understanding scientific concepts and new discoveries but also by making informed decisions in their personal lives and in the voting booth. I believe that fundamental reform of science teaching methods can simultaneously address these issues.

The scientific community benefited during the post-Sputnik period from an increase in both material resources and citizen support. But concomitant reforms of science education consisted mainly of altering course materials and adding teaching enhancements; these are not factors that contribute to students' deciding for or against science careers.

My interest in pedagogical reform was stimulated in part by my previous research on gender equity in maths and science education (Wood 1997; Wood and Brown 1997). Through reading, observing secondary school students in single-sex maths classes, interviewing secondary school girls who participated in both mixed-sex and all-female maths classes and personally experiencing science classes as an undergraduate at a women's college, I became aware of differences in teaching methods and the classroom climate when only females are present.

In the early 1990s I visited The SummerMath Programs at Mount Holyoke College, the Smith College Summer Science and Engineering Program for Secondary school Girls and the all-female maths class in my own rural Maine community. In these I observed the successful use of cooperative learning with secondary school girls. I attended a powerful workshop by Myra and David Sadker, who together worked to eliminate gender bias from America's schools (Sadker and Sadker 1995). I tried some suggested techniques in my own mixed-sex classrooms and witnessed a more effective learning environment for all students, not just females. My two areas of scholarly activity intersected: I re-read books I had originally discovered when researching gender equity and found them equally relevant to reforming science education.

A recent publication affirmed these connections by strongly supporting the principles of "feminist pedagogy" that consider *how* students are taught in addition to *what* they are taught (Association of American Colleges and Universities 2008; Kuh 2008). Traditional science pedagogy puts females and members of other under-represented groups at a distinct disadvantage, especially in the important introductory-level university science classes. Large class size, competitiveness among students, the expectation that students will study alone and a lack of nurturing relationships with faculty all contribute to turning these students away from STEM majors. In the past efforts to increase the confidence and success of under-represented groups in maths and science have rarely considered that the teaching methods themselves are at fault.

As Seymour and Hewitt wrote so eloquently (1997, 314):

> Even if we knew how to teach girls to be more independent in their learning style, we must first consider whether it is desirable to change the collective identity of one gender group so they can more easily be fitted into educational settings which reflect the socialized learning styles of the other gender. Furthermore, some aspects of the learning environment in which women feel most comfortable – particularly cooperative, interactive and experiential learning contexts – are also congenial to many young men and encourage the development of skills and attitudes which have increasing value in occupational and social contexts beyond academe. For those faculty questioning the need for institutional change, the "problem of women" may need to be reframed. Moving pedagogy from a focus on teaching to a focus on learning, and from selecting for talent to nurturing it, will disproportionately increase the persistence rate of able women in S.M.E. [science, maths, engineering] majors. It also promises to reduce the loss of able male students.

We need reform in science education and we need it now. The reform must grow out of collaboration among educators at all levels. The educators, in turn, need to listen to what their students say about classroom methods that work for them. If we truly want to increase the number of science majors and create a more scientifically literate society, we must tap resources that have been ignored in the past. We need to engage not only the type of students who have always been successful with traditional lecture and note-taking but also those who respond better to different modes of teaching. We need to include Tobias's "second tier" (1990) in an expanded potential talent pool by responding to considerable data recommending that we replace lectures with more interaction among students; memorisation with conceptual understanding; and cookbook-style laboratories with inquiry-based exercises. Such recommendations are based on scientific evidence and when educators respond to this evidence they are "teaching science scientifically" (DeHaan 2005). Unfortunately, on a majority of campuses the instructor as information-delivering lecturer remains the standard. This model is not likely to attract more students to science careers or help citizens become more scientifically literate.

A reinvigoration of science teaching at research universities will not only engage more students in science but also can stimulate the creativity of their instructors: Gilbert Lewis's invention of the electron dot system occurred as he taught introductory chemistry at the University of California, Berkeley (Lewis 1916). When faculty invite students to question what and how they for the entire class and can also determine their overall percentage at a certain point in the semester. Blackboard and other online systems (some of them with free public access) offer many other communication services, most of which I have yet to explore. In the future I will use a communication network for members of a cooperative learning team.

THE MURKIEST POINT

In *Classroom Assessment Techniques* (1993), Angelo and Cross describe the Minute Paper as the technique used most often and by more university teachers than any other in their book. For this simple method the teacher stops class two or three minutes early and asks students to write answers to two questions: "What was the most important thing you learned during this class?" and "What important question remains unanswered?" Students submit these as they leave the classroom and the instructor obtains important feedback on student learning.

Even easier is their Muddiest Point, for which the teacher asks students to jot down a quick response to one question: "What was the muddiest point in ____________?" The blank in the question could be a lecture, discussion, homework assignment or laboratory exercise. Faculty invest little time to obtain a lot of information about which elements are most confusing for students.

A similar method I use at the end of every class meeting is something I've termed the Murkiest Point (nicknamed by my students as "murkies"). As I describe in Chapter 3, at the end of each class meeting students take a few minutes to respond to either "What was the murkiest point today?" or, if the student understood everything perfectly, "What was the most interesting point today?" Some students may respond to both. To provide students with an incentive to consistently submit a murky, I use the murkies to record attendance; otherwise, some students will zip up their backpacks and promptly depart at the formal conclusion of the class, skipping this important opportunity for communication. I try to read the murkies as soon as possible to gain feedback on the success of each class meeting while the events are fresh in my mind. At the beginning of the next class, I clarify topics about which any student expressed confusion. I generally do not use the student's name when I respond to a question because I want to avoid having the student feel self-conscious about asking what they may perceive as a stupid question – a common cause for reticence during class. Students depend heavily on this method of communication and often remind me if I forget to distribute the pad of paper at the beginning of the class period. They also want to ensure that their attendance is duly noted!

An important aspect of each method above is encouraging students to think about the big picture: "What concept remained confusing at the end of the class?" "What concept did you understand most clearly today?" Through your teaching methods, you should underscore the central themes of a topic. The murkies are a way to determine whether you succeeded on a particular day.

Chapter 12

Cooperative Learning

Cooperative learning is an integral part of Lecture-Free Teaching and begins within 15 minutes of the first class meeting, with the construction of learning teams. Chapter 10 describes both my methods for creating groups (Wood 2007, 2009) and those of other science educators from a variety of disciplines and types of courses (Crowe and Hill 2006; Dinan 2006; French 2004; Jensen, Moore and Hatch 2002; Lord 2004). The consensus is that groups should be heterogeneous because, within a diverse group, students have access to a variety of perspectives during the learning process. Most instructors randomly assign students to permanent groups that work together for the entire semester. When students work together in small learning teams to explain scientific information to one another or to use factual material to solve problems, they readily discover their own misconceptions based on prior knowledge or confusion about what they have read in the textbook.

THE VALUE OF COOPERATIVE LEARNING

Powerful evidence has existed for decades about the effectiveness of cooperative learning at all levels of education and in all disciplines (Johnson and Johnson 1989). With this instructional technique students work together in small groups on a learning task. The method has significant potential for teaching a class of diverse students, even when some students have special needs (Putnam 1998). Since Herreid (1998) first published his article "Why Isn't Cooperative Learning Used to Teach Science?" more science educators have successfully used this method and for them its value is undisputed. A folder in my file drawer bulges with articles supporting cooperative learning; these studies report that with cooperative learning, students take more responsibility for their own learning, develop higher-order thinking skills, retain more information, are more satisfied with the class and express positive attitudes about the subject matter.

In any education setting, individuals employ distinct learning styles. Goran and Braude (2007) suggest that although some students learn best through visual, auditory or kinesthetic modes, cooperative learning activates yet another mode. They describe this fourth modality as social learning, during which students become active participants and more effectively acquire problem-solving skills.

Cooperative learning is well suited to a relatively small class size. But even in a large lecture hall setting, students in astronomy, biology, chemistry and physics demonstrate increased engagement and conceptual understanding when the instructor leads collaborative activities during class (Adams and Slater 2002; Cooper 1995; Crouch and Mazur 2001; Klionsky 2001/2002; Mazur 1997). A veteran of many years of using cooperative learning, Lord (2001) summarised more than 300 articles by listing 101 reasons to use this pedagogy to teach secondary school and university science.

For the book *Making the Most of College: Students Speak Their Minds*, Light (2001) and his fellow researchers interviewed more than 1 600 Harvard undergraduates. Among other results, they found that how students study and do their homework assignments outside class is a far stronger predictor of engagement and learning than are the particular details of an instructor's teaching style. Students who study outside of class in small groups of four to six, even just once a week, benefit greatly. Earlier researchers also reported improvement in academic performance when science and maths students formed learning groups outside class (Hufford 1991; Treisman 1992). In the past collaboration on homework assignments was considered a form of cheating. Now when professors assign homework, they may send the opposite message by encouraging cooperation among students as a way to enhance learning. Some science faculty restructure their homework assignments so they are actually designed for groups (Light 2001).

Finally, an important aspect of cooperative learning to explain not only to your students but also to administrators and colleagues who may look askance at your teaching techniques is that this method models how people interact in the workplace and, in particular, in the scientific research community. Unfortunately, science education favours competitive rather than collaborative learning. Competition interferes with normal social interaction between students and creates isolation, suspicion and a protective attitude towards the acquisition of knowledge and skills. With cooperative learning, students discover that working together enhances comprehension, provides intellectual discussion and offers the emotional support necessary to persist in a challenging course. College seniors almost universally cited collaborative learning strategies as an important way to address intrinsically difficult material (Seymour and Hewitt 1997). The skills acquired by students during

Chapter 14

Service-Learning

More than a decade ago a colleague – a health educator and also coordinator of the newly formed Campus Service-Learning Program at my school – encouraged me to incorporate service-learning into my Human Nutrition course. Before that I had barely heard of service-learning and could not imagine its possible function in a science course; now it is the foundation of at least one of my courses each academic year. This initial experience with service-learning led me to attend a week-long Problem-Based Service-Learning Workshop sponsored by the Campus Compact (*www.compact.org*), which introduced me to a hybrid of Problem-Based Learning (discussed in Chapter 12) and service-learning. Clearly, not all Problem-Based Learning is service-learning, nor is all service-learning centred on problem solving. With Problem-Based Service-Learning (PBSL), students work in teams to find solutions to problems involving real needs in their communities. Ideally, as they do this, they acquire relevant knowledge, increase their understanding of academic concepts and make important connections among ideas from their reading, teachers and fellow students (Gordon 2000). Attending this workshop inspired me to design service-learning projects for my non-major science courses.

ACADEMIC SERVICE-LEARNING

The term *service-learning* has a variety of connotations. The traditional meaning implies providing charitable services, but situating the adjective *academic* ahead of this phrase emphasises the application of classroom knowledge and skills in the community. In this academic form, service-learning encompasses more than teaching civic responsibility and shares attributes with what has been called *civic engagement* (Avard 2006; Rhoads and Howard 1998;

Tai-Seale 2001). Service-learning can be a type of experiential education that is “a marriage between occupational and/or academic learning and service to the community” (Prentice and Garcia 2000, p. 9).

A growing number of university science courses incorporate service-learning. For an introductory environmental science course, students evaluate campus academic buildings and find ways to encourage and increase energy conservation (Bixby et al. 2003). Partnerships of college undergraduates with F–12 students include organising an Earth science fair at a local primary school, as well as long-term formal and short-term informal outreach (Francek 2002/2003; Rao, Shamath and Collay 2007). In an informal educational setting designed for students pursuing science careers, participants learned about environmental education programs and applied their training at a local nature centre (Haines 2003). Others engage in more traditional partnerships with external community organisations (Abrahams, Gillis and Taylor 2000; Grossman and Cooper 2004; Phillips 1997).

I designed two examples of academic service-learning to enhance my Lecture-Free Teaching methods so that they follow three basic steps of preparation, participation and reflection, which are considered essential for effective service-learning (Lott and Michelmore 1997). The examples I describe below, however, are quite different from each other in terms of how they support the learning goals of the courses.

ENVIRONMENTAL ACTION IN A NON-MAJORS SCIENCE CLASS

This service-learning project takes place during the second semester of a two-semester course sequence that fulfils my university’s general education curriculum science requirement for non-majors. Sciences I introduces the scientific method and major unifying theories from physics and the Earth sciences, with applications to real-world problems; Sciences II takes the same approach but focuses on meteorology, chemistry, biology and environmental sciences. I teach the course as a combined lecture-laboratory, as described in Chapter 8.

When I first began teaching these courses, one objective was to find ways to better engage these non-science majors, many of whom professed minimal interest in science or had poor preparation in science and maths. I also sought to connect the broad topics covered during the two semesters. Finally, I wanted to use writing as a tool for learning science as well as for improving communication skills. Because environmental sciences, the final content area in the two-course sequence, relates to all of the content topics and real-world problems, I decided to use this subject as the focus of my service-learning endeavour. The activity gradually evolved into what I call an Environmental Action Project, with considerable potential for further development.

My first attempt to lead an environmentally themed service-learning project exposed problems due to uneven effort among students. When cooperative learning teams visited different primary school classrooms, some teams

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