GUIDING PRINCIPLES FOR TEACHING
Distilled From My First Few Years of Teaching

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All I really need to know about teaching I learned in ... kindergarten?[1] For me, nothing prepared me better for my role as a teacher than my first few years of teaching. On one hand, I could clearly identify with my students, who also faced a new learning situation. On the other hand, I could clearly see the challenges that needed to be bridged by myself as a teacher. Those first few years of teaching heightened my awareness of the gap between what a teacher teaches and what the students learn. I wrestled with a number of issues, including

- *How to encourage students to learn concepts and to understand relationships between variables, rather that just "plugging" numbers into equations*
- *How to teach problem-solving skills that would enable students to solve a variety of problems*
- *How to keep students motivated by balancing encouragement with "threats"*

I began my search for the guiding principles that underlie good teaching by attending several workshops and by reading articles and references on effective teaching and learning (see the end-list of references). It was my first-hand experience in teaching, however, that brought those guiding principles to life. The following paragraphs highlight some of the insights and experiences that proved helpful during my formative years of learning to teach.

My perspective of my role as a teacher was changed one day when I found myself in a learner's situation. On this particular day, I was to meet a group of friends at an Italian restaurant. I had been to this particular restaurant a number of times, but each time I had been a passenger in the car—I was busy listening, talking, gazing out the window, and looking at other passengers in the car. Now it was my turn to drive, and I found I could not remember exactly how to get there! Does this sound familiar? Now, imagine yourself, the teacher, as the driver and your students as the passengers in your classroom. My experience of being the passenger, or the "learner," helped me to formulate and adopt four guiding principles for teaching and interacting with students:

- *Choose the best path for learning*
- *Outline the path taken*
- *Engage the students in their own learning*
- *Promote an environment that encourages questions, learning, and respect for others*

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CHOOSE THE BEST PATH FOR LEARNING

When choosing the best route to an end destination, the driver should consider if the route is interesting and scenic and if it minimizes distance, or if it contains a number of confusing turns or potential delays. Similarly, one of the responsibilities of a teacher is to choose the best way to convey an idea or a concept. Whenever possible, when illustrating an important idea I enjoy using an in-class demonstration or a real-life example, or developing a physical picture to capture the interest of the class. For example, in a fluid mechanics course, the mechanical energy balance is used to predict the water flow rate through a siphon.[2] Before the demonstration of a siphon, the class is asked to determine how the water flow rate is affected by the position of the tube outlet. They are then asked to estimate the water flow rate through the smooth tube when the outlet of the tube is placed a certain distance below the water level in the tank. Their estimate, obtained by using the mechanical energy balance, is then compared to the measured flow rate. They are then asked to explain the differences. Demonstrations and real-life examples are fun ways of presenting concepts; moreover, they serve to connect classroom learning to real-life applications.

In addition to choosing a scenic route, the best path for learning should also be one that minimizes frustrations and "busy work"; one that includes important "landmarks." For example, derivations illustrate the powerful tool of beginning with basic principles and arriving at a description or model of a given phenomenon. But since students often become frustrated, bored, or lost when doing derivations, to teach them how to derive relationships, a handout with the partial derivation is distributed. It includes intermediate results (*i.e.,* landmarks) and some of the reasoning behind the individual steps in the derivation (*i.e.*, directions). The first direction in doing a derivation is to develop a physical feel for the relationship between the variables. For example, how would you expect pressure drop across a pipe to change with pipe length, flow rate, and fluid properties—and why? The last landmark in the derivation is to check the reasonableness of the derivation, *i.e.,* check the initial predictions with the results from the completed derivations.

Pointing out the reasoning and providing intermediate answers in solving a problem help students come up with their own plan for solving problems. These handouts teach important problem-solving skills while at the same time reducing the roadblocks that many students encounter in derivations or in solving problems. Out of the classroom, thought-provoking questions, hints, and intermediate answers for homework problems can also be made available on the courses's web site.

In addition, whenever possible, MAPLE, Mathematica, or EXCEL can be used to minimize the work associated with trial-and-error calculations while illustrating the relationships between variables. For instance, in determining an economic pipe diameter, the pumping costs associated with skin frictional losses and the pipe costs are calculated at a given pipe diameter.[3] These calculations can then be repeated at other pipe diameters using an EXCEL spreadsheet rather than being repeated manually. A plot can then be generated on EXCEL to illustrate the sensitivity of the pumping costs and the piping costs with changes in pipe diameter.

OUTLINE THE PATH TAKEN

As the driver, I have a fairly good idea of how I am going to arrive at my destination. Not having traveled this way before, however, my passengers have no such picture. Similarly, I have a good idea of the important concepts that should be covered in each of my courses and how these concepts are connected and related. This is an overall perspective on the course that my students do not have. Hence, one of my guiding principles in teaching is to outline the path we will be taking in the course.

For example, in my course on fluid mechanics, I use a flowchart of a chemical process to point out the problems we will analyze in the course. The concepts of fluid mechanics that are relevant to the operation and design of a chemical process may include estimating frictional losses through pipes, various fittings, and various unit operations such as a packed column, and then using these estimates of frictional loss to select an appropriate pump size and an appropriate impeller speed. As each topic is covered in the course, we refer back to the original flowchart to illustrate the relevance of the concepts and to gauge the progress we have made in the course. The path is outlined at other levels as well, such as outlining the strategy for solving a particular problem or outlining the lecture for that day.

ENGAGING STUDENTS IN THEIR OWN LEARNING

I am best able to retrace an unfamiliar route on my own if on a previous trip I was involved in either determining the route traveled or in locating the relevant landmarks and road signs along the way. Similarly, students are best able to understand the concepts laid out in a lecture if they are actively thinking through the individual points of the lecture or are engaged in solving problems along the way. Conveying the concepts in an interesting way, using relevant examples and applications to real life, outlining the points of a lecture in an organized and simple-to-follow manner are essential in keeping the students mentally engaged during a lecture. Even the best-laid plans, however, may not be sufficient.

When appropriate, students should be guided and encouraged to arrive at the concepts and conclusions themselves through a sequence of well-posed thought questions.[4,5] Cooperative learning involves this type of activity since the students ask and answer each other's questions in arriving at a solution.[6] Students actively involved in the solving of problems, as compared to those following the professor's solution, demonstrate the highest retention rate. Adequate guidance, thought-provoking questions, and intermediate answers are needed in order to reduce the frustration that can occur during problem-solving.

To make the most of the class time, students must keep up with the course in order to follow the lecture and to be well prepared for problem solving during the class. Daily reading assignments, frequent in-class quizzes, and small but frequent homework assignments discipline students to keep up with the course.

PROMOTING AN ENVIRONMENT THAT ENCOURAGES QUESTIONS, LEARNING, AND RESPECT FOR OTHERS

My own experiences as a learner taught me the importance of a learning environment that focuses on and encourages growth and development. Students will feel open and free to ask questions in class or during office hours if they sense that I really want to understand their questions and am enthusiastic and patient in responding to them. I try to address each question as a good question. I realize that being a different type of learner or being unaware of what is really confusing them may make it difficult for me to initially understand why they asked a particular question; therefore, my answer may require multiple explanations or require probing with further questions. In any case, I believe students should be encouraged and applauded when they choose

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ogy can understand a seminar in microfluidics. Similarly, most chemical engineers expect that they can teach any course in the undergraduate core curriculum—a feature that is not true of other engineering disciplines.

A burden that is placed on the graduate student who is interested in applying chemical engineering skills to the study of problems in bioinformatics and genomics is the need to learn the "life science vocabulary" in addition to the chemical engineering vocabulary—a burden that can add significant time and course requirements to the graduate experience. While the feature of a common language in our profession is a strength that brings us together, it also makes it difficult to think about changing the core curriculum in any significant way. We should take care to maintain our language and ties across the various research topics. At the same time, we should increase the awareness of students and educators about similar emerging areas that bridge scientific disciplines by creating opportunities and forums such as the Topical Conference in Dallas, Texas.

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to wrestle with understanding concepts.

Knowing the students personally is one of the highlights of being a teacher. I enjoy learning from them! Students have a depth that is not always evident just from classroom interactions. Moreover, knowing the students personally creates a rapport that allows us to joke with each other and to feel more at ease. When I know the students, I can also identify those students who are enthusiastic and who are positive role models, and I can encourage them to help set a positive tone in the classroom.

My department chair was enthusiastic in encouraging me to pursue different ideas in the classroom when I first began teaching. I sensed that he did not think of me as I was at that particular time, but instead saw my potential for becoming a good teacher. His attitude made a real impact on me, and I have embraced it in my own interactions with students. I respect them and keep in mind that none of us has yet arrived at our destination—that we are all still part of the process of becoming assets to our society.

I am still involved in the process of becoming a better teacher. The guiding principles detailed in this essay will continue to evolve. Learning new things and adapting them to the classroom keeps teaching fresh and exciting as I continue my journey as both a learner and a teacher.

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