Teaching the e-Student: Paradigms, Processes and Problems

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Thank you. Thank you for coming today. And, I thank Professor Lee Seidel of the Teaching Excellence program. This luncheon and lecture were made possible by the very fine efforts of Professor Seidel. I thank the University for bestowing on me this tremendous honor. My students, my M.S. thesis advisor Professor Sol Weller, my Ph.D. dissertation advisor Professor Ralph Weiland, Professors Stephen Fan and Gael Ulrich, friends and family members have played a significant role in my professional development, and I would like to place on record my sincere thanks to each and every one of them. I dedicate this lecture to my teachers, my wife Geetha, my children Ajay and Anu, and to my parents and sister. They have given me their love, support and encouragement.

I came to this great country as a graduate student twenty years ago. After completing my bachelors' degree, at age twenty, in Chemical Engineering, I worked for a national petrochemical complex for seven years. This petrochemical complex was the first of its kind in India, and competition to land a job in the company was fierce. I remember taking a six hour all-India written examination on the fundamentals of chemical engineering (similar to the Professional Engineering exam in the US). More than 5000 students took the examination to compete for 20 positions. Based on the performance in the written examination, about 200 students were invited for a personal interview followed by a group interview. The promise of working in a giant complex from start up to commissioning was an exciting prospect, and I was eager to gain hands-on experience. All the plants were licensed by foreign vendors, and there was the added promise and future prospect of working in a petrochemical plant abroad. I was excited about chemical engineering, and eager to apply all the knowledge I had acquired. I owed my success in the examination and later on in my job, to the knowledge my teachers had given to me.

I credit my secondary and high school teachers as well the professors at my university. In Indian tradition, the “Guru” (teacher) has a very important place. The word Guru is made of two parts: Gu means darkness or ignorance and Ru means dispeller or remover. Thus Guru literally means remover of ignorance. The student or “Shishya” gains knowledge from the guru. The Vedic adage, “Matha, Pitha, Guru, Deivam” (mother, father, teacher, God) places the teacher before God and immediately after one’s parents. A special day "Guru Poornima" is dedicated to the Guru. We may argue that in ancient times there was no phone or radio or television or the Internet, and the only means of communication was through word of mouth and this is the reason behind the success of the Guru-Shishya (teacher-student) tradition. Clearly, the Guru-Shishya tradition involved a personal bonding between the two. My teachers, both in high school and at the University, made it a point to get to know their students and more importantly, to be available to them at all times. In his book *What Matters in College*[1], Alexander Astin states that the quality of the college experience is strongly affected by student-faculty interactions. Astin collected longitudinal data on 24,847 students at 309 different institutions and determined the influences of a host of institutional characteristics on the students' college experience. The data included 146 input variables that characterized the entering students, including demographic measures, information about parental education and socioeconomic status, precollege academic performance measures, and self-predictions of a number of outcome variables; 192 environmental variables relating to institutional and faculty characteristics, including measures of the size and type of the institution, faculty demographics and attitudes, institutional emphasis on research, and the nature and extent of student-faculty and student peer group interactions; and 82 outcome variables, including measures of academic achievement, retention, career choice, self-concept, patterns of behavior, self-reported growth in skills, and perceptions of and satisfaction with the college experience. According to Astin, the frequency with which students talk with professors outside class, work with them on research projects, and assist them in teaching, correlates with student grade-point average, degree attainment, enrollment in graduate or professional school, every self-reported area of intellectual and personal growth, satisfaction with quality of instruction, and likelihood of choosing a career in college teaching.

I was at the University of Salamanca, Spain this March, and I was invited to give a seminar in Aula Unamuno, one of the oldest lecture halls dating back to the 16th century. Adjacent to this hall, is the oldest lecture hall of Fray Luis de Leon with panels worked in parchment, clearly of late Gothic or early Renaissance (Figure 1). The Augustinian teacher was one of the most outstanding figures of Spanish lyrical poetry in the 16th century. The benches and wooden floor have been preserved. The pulpit with six steps overlooks the hall and boasts a lectern, a soundboard and a seat for the lecturer. The Professor (Fray Luis de Leon) would stand in the pulpit. In the foreground, one can glimpse a double set of the original wooden benches on either side of a central aisle. It was the duty of the lecturer to read from the text and to repeat the lesson while the Professor stood watching. Teaching involved repetitions and academic debates all involving official texts to which constant reference was made. Texts included the work of Hippocrates, Euclid, Ptolemy, Aristotle, and Latin and Greek literacy authors. Teaching duties consisted of elucidating texts, repetition, glossing, commenting, transmitting and conciliating possible contrary opinions. It was the duty of the Professor to do the latter. After the lecture, the Professor would move to the lawn and students would seek clarification (sometimes for hours) on topics or questions that were not yet clear to them. There was active learning and one on one interaction between the Professor and the students even in the 16th century.

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[1] A.W. Astin, *What Matters in College: Four Critical Years Revisited*. San Francisco, Jossey-Bass, 1993.

Figure 1: Classroom of Fray Luis de Leon, University of Salamanca

I enjoy teaching, and I strongly believe in class participation. Over the years, I have observed that the attention span of most students is typically fifteen minutes. I refer to this as the Sesame Street syndrome. The fundamental premise in Sesame Street is that children have a limited attention span, and it is therefore important to switch themes every few minutes. The Information Superhighway has aggravated this problem. As a college student, I remember spending hours on a chemical-engineering problem. My classmates and I would not rest until the problem was solved. A successful solution to the problem required frequent visits to the library as we would pore over reference books and mathematical handbooks. In contrast, the average e-Student (a student dependent on the electronic medium as every student in engineering and science), spends a fair chunk of his or her time browsing the Internet or chatting or sending email to friends or downloading music or burning CD's or watching the latest movie on DVD. Typically, an hour or two is allocated for homework. Google.com is always available for literature search and the putative rule is that the first few hits are the best sources. Where then is the need or the time to verify the authenticity of the data or the source? e-Students have been exposed to interactive computer games, where learning takes place between the player and the computer from early childhood. e-Students are more likely to try to put a piece of equipment together by trial and error rather than by reading the instructional manual. These students also have the tendency to plug everything into a process simulator or software package (where feasible), and accept whatever the computer spits out. They often fail to think critically about the answer. Holding the attention of an e-Student for an hour is a challenging task. The classical approach of writing a bunch of equations on the board and assigning homework is guaranteed to fail. Students tune out in a matter of minutes. The challenge is to take an abstract concept (in thermodynamics or in reaction engineering for example), and to make it interesting. This can be achieved by drawing examples from other disciplines, or from day to day experiences. My stint in the petrochemical industry has been very useful since I am able to draw from my experience and provide real-life examples. Even an analogy in culinary science can sometimes drive home the point. For instance, one of the experiments that I assign in the Biochemical Engineering class is, "How to make a tasty pizza." Many of the growth stages in fermentation and the associated equations can be explained and understood very easily as a result of this experiment. Students also learn the art of making a delicious pizza!

Which learning style works best for the e-Student? Students have different *learning styles* - characteristic strengths and preferences in the ways they take in and process information. Some students tend to focus on facts, data, and algorithms; others are more comfortable with theories and mathematical models. Some respond strongly to visual forms of information, like pictures, diagrams, and schematics; others get more from verbal forms--written and spoken explanations. Some prefer to learn actively and interactively; others function more introspectively and individually. Using the Silverman-Felder[2] model, an e-Student's learning style may be defined in part by the following questions:

1. What type of information does the e-Student preferentially perceive: *sensory*---sights, sounds, physical sensations, or *intuitive*---memories, ideas, insights?

2. Through which modality is sensory information most effectively perceived: *visual*---pictures, diagrams, graphs, demonstrations, or *verbal*---sounds, written and spoken words and formulas?

3. With which organization of information is the e-Student most comfortable: *inductive*---facts and observations are given, underlying principles are inferred, or *deductive*---principles are given, consequences and applications are deduced?

4. How does the e-Student prefer to process information: *actively*---through engagement in physical activity or discussion, or *reflectively*---through introspection?

5. How does the e-Student progress toward understanding: *sequentially*---in a logical progression of small incremental steps, or *globally*---in large jumps, holistically?

For the past few decades, most engineering instruction has been heavily biased toward intuitive, verbal, deductive, reflective, and sequential learners. However,

[2] *ASEE Prism*, *6*(4), 18-23 (December 1996).

relatively few engineering students fall into all five of these categories. Thus most engineering students receive an education that is mismatched to their learning styles. This could hurt their performance and their attitudes toward their courses and toward engineering as a curriculum and career. The goal is to make sure that the learning needs of students in each model category are met at least part of the time. This is referred to as "teaching around the cycle."

e-Students are constantly being bombarded with information, both in and outside of class. The volume of this information is much greater than they can effectively process. e-Students tend to be practical and learn best when given facts and procedures. Most science courses focus on abstract concepts and theories and put them at a disadvantage. Most e-Students are *sensing, visual* learners while the information presented in almost every lecture course is overwhelmingly verbal. Professors should not be surprised when many of their students cannot reproduce information that was presented to them a week before. Surprisingly, most e-Students are *inductive learners*, and prefer to learn by seeing specific cases first and working up to governing principles and theories by inference. Most college instruction (at least in science and engineering) is exclusively deductive - probably because deductive presentations are easier to prepare and control and allow more rapid coverage of material. e-Students also tend to be active learners. The activity can be external such as discussing problems, brainstorming or working in a group. Lecturing without student interaction is active only for the professor, which is one reason why professors often feel they have learned more than anyone else in the class.

Teaching around the cycle can be done in a variety of ways. In my “Process Dynamics and Control” class, I hand out a detailed course outline on the first day of class. I follow the course syllabus rigorously, and the course appears to be tilted heavily toward the small percentage of non e-students. The laboratory component on Wednesday afternoons, being inherently sensory, visual, and active, compensates for a portion of the imbalance. For the e-Students, I try to balance the descriptions of physical phenomena, results from real and simulated experiments (laboratory experiments plus a software program called Control Station), demonstrations, and problem-solving algorithms - with conceptual information - theories, mathematical models, and material that emphasizes fundamental understanding. I make extensive use of flow sheets and actual piping and instrumentation diagrams from the petrochemical industry to illustrate a concept. Problem formulation and mathematical derivations and solutions are tested in the laboratory or in simulated experiments when feasible. I spend the first five minutes of every lecture reviewing the material presented in the previous lecture. Here is where I expect students to actively participate in the discussion since they do the review. Every now and then, I deliberately make a mistake in a derivation to see if students are paying attention. Since the course is highly structured, there is a logical flow of course topics. However, I try to point out connections between the current material and other relevant material in the same course or in other courses, or even in other disciplines or based on everyday experience. Process Control is important in almost every industry, and we also discuss the safety aspects in the design and operation of a chemical or petrochemical plant. In addition to assigning daily homework that simply tests the understanding of fundamental concepts and increases speed and accuracy; I assign open-ended projects or problems. A series of regular assignments with frequent feedback elicits more work and higher levels of commitment to the class than one long assignment. Following this principle, the open-ended project is broken into smaller parts with assigned due dates. Students need feedback during or shortly after their first attempt so that they do not keep practicing incorrect methods. I have found that the feedback that I provide when I return the initial reports is very useful in the learning process. Feedback a month later is not useful. There should be an opportunity for the students to practice again after they have received the feedback. For instance, after a laboratory or design report has been returned to the student with the usual excessive amount of red ink, it is most effective to require the student to produce a final, corrected clean copy. Since e-Students are adept at computers and word processors, this is not such a difficult task. Computer aided instruction can provide very easy practice particularly if it is interactive. Students do complain on occasion about the amount of homework or work they receive. I tell them a little story about Pablo Casals. When Pablo Casals reached ninety-five, a young reporter asked him a question: "Mr. Casals, you are ninety-five and the greatest cellist who ever lived. Why do you still practice six hours a day?" Casals answered, "Because I think I'm making progress."

In Biochemical Engineering, I do things a little differently. The course is not as structured as Process Control. We visit a number of biotech companies in the area. Sometimes, we go through experimental observations and data before I present general principles and I encourage the students to inductively come up with a model or mechanism. This approach is more successful than the conventional approach of deriving equations on the board and solving problems. Sometimes when we discuss graphs or trends, I also encourage the students to think of or design an experimental or lab procedure to generate the data. Other questions during discussion include, "What assumptions are implicit in this derivation or result?" Or, "Suppose the lab experiments do not agree with the formula or reaction mechanism we have just derived, how many explanations can you come up with?"

In the biochemical engineering laboratory, we have an enzyme kinetics experiment in which tyrosine is converted to dopachrome (an orange to red pigment) using an enzyme, tyrosinase, from mushrooms. One of the intermediates of the reaction is L-Dopa. The students are given a handout on the experiment a week before the actual lab with the expectation that they will do some research and become familiar with the background material and the experimental procedure. During the lab, I sometimes ask the students, "What is the significance of L-Dopa or dopachrome (especially the orange or red color)?" Usually, there is an awkward, embarrassed silence, and I receive vague answers like, "It is useful in studying reaction kinetics." I then look around the lab, and if someone has red hair, my job is easy. If not, I will ask the students if they have heard of melanin. Invariably someone will answer, "skin pigmentation." You can see the eyes brightening, faces smiling and a sense of triumph sweeping through the room. I ask them to do research on L-Dopa and on melanin and include a brief section in their lab reports. They are surprised to learn that L-Dopa is a drug used to alleviate some of the symptoms of Parkinson's disease and that melanin provides more than color. It also provides powerful protection against UV and visible light and that you can even get melanin glasses! I then ask them to investigate the different sources of tyrosinase (mushrooms, bananas, melanocytes), and we sometimes do an experiment on extraction of tyrosinase from potatoes. Students also address the following question, “Can we predict the darkening of fruits under varying conditions of pH and temperature?”

I would now like to address the problems of technology. Technology has provided us with new tools to solve many problems, especially in engineering. Unfortunately, the use of these tools is a double-edged sword. The use of sophisticated software allows students to be more creative by exploring different solutions. e-Students are often more likely to blindly accept the answer the computer offers. I remember assigning a problem in my Reaction Engineering class, and one group came up with a reactor length of 25 miles. When I asked the group if it was feasible to have a reactor of this magnitude, the response was, “But this is what the computer gave us!” Clearly, critical and creative thinking was not employed in this case. While new technology can certainly facilitate the generation of creative solutions in nanoseconds, it also requires students to examine things more critically.

The University acquired "Blackboard" a few years ago, and I have been an enthusiastic participant in the program. I am able to post all assignments, homework solutions, projects, and licensed software on the web, and students have access to the information instantaneously. In addition, students can check their grades electronically. Electronic quizzes with instant feedback promote a good understanding of the subject material. Blackboard also offers a chat room, and I have electronic office hours at night. I have noticed that students have responded very favorably, and overall their performance has improved.

The combination of visual and verbal information, self-tests of knowledge and conceptual understanding, practice in problem-solving methods, access to the teacher and immediate individual feedback provided by technology are far more likely to promote deep learning than the passive environment of the traditional lecture class. Technology is not a panacea. I am not convinced that distance learning is the way to go for all students even though it may be a good and viable option for part-time students who hold jobs. The use of the Internet to display text and pictures does not promote much learning no matter how colorful the graphic images are. Technology will never be able to do some things that good teachers do routinely, such as advising, encouraging, motivating, and serving as mentors for students, helping them develop the communication and interpersonal skills they will need to succeed in their careers. Most successful people can think back to at least one gifted teacher who changed their lives by doing one or more of these things. A software program or robot or even the same gifted teacher at a distance learning site will not have the same level of success.

I firmly believe that the better students should be engaged in research, even in the sophomore year. Many of our brighter students with undergraduate research experience have gone on to graduate school to pursue a MS or PhD degree in Chemical Engineering. It is always gratifying to see undergraduate students participate in research. A successful research experience can more readily be achieved if students in science and engineering have a good liberal arts education.

I would now like to reflect on the liberal component of the education of an engineer or scientist. This has added relevance in light of the recent report submitted by the general education study committee, of which I was a member. The notion of a liberal education in the tradition of the West from Plato to the Renaissance can be examined in detail. Two problems emerge when such an exercise is carried out. The first is the question of the role that scientific education plays in general education, and hence the nature of topics that go into the education of an engineer or scientist. The second is the question of how far the teaching of the humanities can be unbiased. It is certainly accepted that some acquaintance with the basic physical and biological sciences and with mathematics is an essential part of a university education. What about liberal arts education for the scientist or engineer? Two undergraduate students, Al Greenwood and Aaron Tomich participated in the IROP program in 1999. Both Al and Aaron were required to take courses in Spanish Culture before they left for Spain. Their success in Spain can be attributed to a large measure on their preparedness before they left for Spain, and also to their exposure to the rich cultural heritage of Spain. During my visits to Spain, I have had the opportunity to visit a number of interesting places in and around Madrid. The Alhambra palace in Granada stands out in my memory. The Moorish architecture is spectacular, and the palace is certainly an engineering marvel. The "Sala de los Abencerrajes" on the south side is perhaps the most beautiful gallery in the Alhambra, with a stalactite ceiling and a star-shaped cupola reflected in the pool below. When I gave a seminar at the Institute of Catalysis, I drew a comparison between the superb stuccowork with its intricate pattern of honeycomb cells, and a honeycomb catalyst that is used in the catalytic converter of every automobile. I fully endorse Ashby's[3] opinion that the path to culture should be through one's specialism, for the "*sine qua non* for a person who desires to be cultured is a deep and enduring enthusiasm to do one thing excellently." A liberal education is essential for both undergraduate and graduate students in science and engineering. A liberal education should enrich the mind with some of the literary and artistic treasures of the past, so that we may be able to see the perfection and beauty of the Alhambra; to bask in the mellifluous notes of Rodrigo's Concerto de Aranjuez or the lilting music of Manuel de Falla; or, to appreciate the meticulous brushwork and astounding interplay of space and perspectives of Velazquez's *Las Meninas*; or perhaps, to just remember the soul-inspiring verses from Lorca's *Poemas del Canto Jondo.* It is important to awaken students to issues that are less clear-cut than the choice of a catalyst and to raise more difficult problems than the solution of a partial differential equation.

Chemical Engineers do indeed cover an extraordinarily wide range of topics: chemicals, petrochemicals, pharmaceuticals, fuels, polymers; manufacturing, patent law, environmental protection and the list goes on. How can we ensure that e-Students possess that admirable breadth that we prize so highly? Integration of knowledge, which allows the student to relate what he/she learns in one classroom to what he/she learns in another and to realize that his/her life as a professional is not opposed to but part of his/her personal life, is something that we should strive to achieve. Chemical Engineering faculty are fond of claiming that chemical engineers are very versatile. Versatility, like creativity, is possible when the generous mind

[3] E. Ashby, *Technology and the Academics*, London, Macmillan, 1963

has learned to interrelate and consolidate a wide variety of different experiences. I think it is important for a teacher to have the courage to go beyond the narrow confines of his or her particular subject. When I discuss reactors and reactor design, I also mention human failures like the Flixborough disaster or the Bhopal tragedy. A discussion of reactors to manufacture fertilizers, invariably leads to a discussion about starvation in underdeveloped countries or to Monsanto's infamous terminator genes.

e-Students are exposed to an ever wider range of topics. Their response is to compartmentalize the astounding amount of information they receive. There may be subunits for mathematics, chemistry, economics, programming, and of course all the information they receive on the ubiquitous Internet. Thus the overwhelmed e-Student tends to organize his/her mind with an I/O or on-off switch; in Reactor Design, switch A may be open but all others are closed. I have often expressed surprise that students in my class cannot integrate or differentiate a simple expression. Even something as innocuous as changing a variable can have disastrous consequences. For example, most students use mathematical variables 'x' and 'y' in their calculus class. When we change the variables to P and T (for pressure and temperature), students react like deer caught in the headlights! Most e-Students have difficulty in seeing the continuity of knowledge. I believe it is important to stress the interrelationships between all knowledge.

It may be useful to use a visual analogy to illustrate this further. Earlier, I referred to the astounding interplay of space and perspectives in Velázquez's *Las Meninas*. The painting appears to be simple (Figure 2). We are standing just to the right of the King and Queen, whose reflections we can see in the distant mirror, looking down an austere room in the Alcazar (hung with del Mazo's copies of Rubens) and watching a familiar situation. The Infanta Margarita doesn't want to pose. She has been painted by Velázquez ever since she could stand. She is now five years old, and she is fed up. But this is a major project and a large painting, and somehow the Infanta must be persuaded. Her ladies-in-waiting, known by the Portuguese name of meninas, are doing their best to cajole her, and have brought her dwarfs, Maribarbola and Nicolasito, to amuse her. Palomino tells us that this masterpiece was finished in 1656, and that while Velázquez was painting it, the royal family often came to watch him work.

Figure 2: Las Meninas, Velázquez

According to Hisham Bizri[4], the symbolization of virtues which are tied to the throne and that of the devotion and service it inspires are suggested by the positions of the figures which form a circle. The symbolic circle represents the fatal duality of negative and positive ruling over human destiny. Behind each benediction, there is a curse, and behind each danger, a fortune.

The image on the rear wall is not another painting. You are looking at a mirror. Instead of reflecting the room, the mirror ignores what we see and restores visibility to that which resides outside our view. It reflects what the figures in the painting are looking at - they are King Philip the fourth and Queen Mariana. The painter makes himself divine-like by contemplating his own world from outside it. "It seems almost vulgar to ask what he was like, he has so carefully effaced himself behind his works; and in fact it is chiefly from them that we must deduce his character. Like Tiziano, he shows no signs of impulsiveness or non-conformity, and like Tiziano, his life was apparently one of unbroken success.

In the time of Velazquez, there was a figure known as “Sargatanas” or “the lame devil.” He had the power to open all locks and make visible everything inside houses. Could he be the same figure as Jose Nieto, the man standing in the doorway? Jose Nieto and the Infanta can be said to establish the boundaries of the physical world; the former by showing the ultra-distance of the world of ideas as suggested by deep perspective, and the latter by showing the immediate presence of

[4] Hisham Bizri, Electronic Visualization Laboratory, University of Illinois at Chicago

frontal perspective. In between these two, the mirror lodges the shadowy world of divine things.

This painting illustrates a common problem that we encounter when we try to integrate our experience. Even when the individual parts are clear like the various figures in *Las Meninas*, and in the students' understanding of individual subjects or topics, integration is difficult to achieve without assistance, and we as teachers should provide that assistance. Without the help of Bizri, it is difficult to understand the nuances in the painting or to realize the intricate relationship between every aspect in the painting. In my own field, I think it is important to make an effort to show students that there is continuity between engineering and the "other side of campus." I believe that the most influential method of teaching is to teach by example.

In conclusion, is there a magic formula that works for e-Students? Clearly the answer is no, and it is important not to make frequent changes in one's teaching style or to try too many different things over a short period. As Frank Smith noted, "The teachers who get burned out are not the ones who are constantly learning, which can be exhilarating, but those who feel they must stay in control and ahead of the students at all times." New and young faculty members should try to individualize the learning environment according to different learning styles, make the students learn actively and be enthusiastic about teaching. However, if you do succeed in your initial attempts, try to hide your astonishment!