Teaching for Creative Engineering Students

Engineering is a discipline about creation. Theodore von Karman said, *"Scientists study the world as it is; engineers create the world that has never been."* One of the most distinct features of engineering is that it synthesizes knowledge to produce an unprecedented object, which could be a new device, a material, or a software that have not been produced before. Therefore, I believe that teaching in engineering should inspire and guide students such that they develop themselves not as a passive follower or supporter but as an active creator and leader. To accomplish this, there are three essential tenets in my teaching philosophy: (i) help students to understand the importance of fundamental principles, (ii) guide students to develop their critical thinking skills, and (iii) share my enthusiasm for engineering with students.

Understanding Fundamental Principles Great inventions in science and engineering are often based on a simple idea, which originates from fundamental principles and concepts. Once a new idea is established for a simple research problem, it is extended and enhanced to yield novel solutions to various sophisticated engineering problems. For example, in control system engineering, the Laplace transform is a basis for classical controller design in the frequency domain, and in astrodynamics, the theory of dynamics in stable and unstable manifolds are used to design fuel-free interplanetary trajectories. However, students are often overwhelmed by complexity of mathematical engineering analysis. Without understanding the key idea behind complex engineering approaches, students cannot propose creative solutions to challenging engineering problems. My first teaching goal is to help students recognize the importance of fundamental concepts and principles.

To achieve it, I try to emphasize the motivation of fundamental principles and illustrate their importance through specific examples. In particular, all topics of mathematical analysis are motivated by engineering applications taken directly from core engineering courses, and lectures are based on hands-on laboratory exercises, including a thorough integration with computer programming. A recent case study shows that introducing an engineering-based mathematics course in an earlier level is effective for improving student retention and success in future engineering courses. I also try to provide an opportunity to infuse modern scientific tools and research methods into the curriculum at the earliest level. This allows students to be exposed to engineering research activities prior to the completion of the traditional math requirements. More importantly, students will have a chance to experience the excitement of research and discovery in engineering, thereby improving motivation and retention.

Critical Thinking Critical thinking is another important skill for creative engineers. It is an intellectual process of gathering information and facts, and evaluating them to obtain a well-justified conclusion. It includes the ability to recognize problems, understand the importance of prioritization and order of precedence in problem solving, gather pertinent information, interpret data to appraise evidence and evaluate arguments, and draw warranted conclusions and generalizations. These are particularly important for engineers since they enable one to analyze a given problem, conceptualize one's idea, evaluate feasible answers, and share the results with others in a systematic way. This is in contrast to mere possession of a set of skills and routine practice of them, which occasionally characterize a bored student.

To enhance critical thinking skills of students, I teach by *research-based* approaches. According to a recent study in higher education, the methods to integrate teaching and research can be categorized as follows: whether emphases are on research contents or on research process and problems; whether students act as a participant or an audience. The teaching-research nexus is referred to as *research-based* when teaching is focused on research process with active student participation. It is research-based in the sense that the curriculum is largely designed around inquiry-based activities; the experiences in processes of inquiry are highly integrated into the student learning activities; the division of roles between teacher and student is minimized. So, the two-way interaction between research and teaching is deliberately exploited. Therefore, students will be better able to understand the nature of the knowledge construction process.

Enthusiasm Third, I try to share my enthusiasm for engineering with students. From my own experiences in teaching and learning, I have found that if students do not have a passion or strong interests for the subject, they cannot learn efficiently and thoroughly.

The process of creation in engineering is not smooth or predictable in general. When faced with unexpected problems, an engineer may be confounded for a long period of time before he or she finds a solution. Passion and enthusiasm are strong motivation to stay focused and patient throughout a seemingly endless, solution-seeking process. Unfortunately, enthusiasm cannot be taught directly by logics. However, I believe that sharing my enthusiasm for engineering with students both inside and outside of the classroom will motivate them strongly.

Outreach I recently established a partnership with the first robotics team at the Bell Multicultural High School (BMHS) in DC, which is mainly composed of underrepresented students from low-income families: according to the report from District of Columbia Public Schools, 97% of students are either Hispanic or African American, and more than 86% are qualified for a free or reduced lunch program.

Students in the first robotics team of BMHS were invited to GWU, where they participated a one-day workshop entitled *Past, Present, and Future of Control System Engineering*. It started with a presentation on the history of feedback controls, illustrated by the ancient Ktesibios water clock, steam engine flyball governor, and *Google* self-driving cars. Then, the fundamental concepts of proportional-derivative (PD) control were discussed, and students had hands-on experience of designing their first PD control system for a ball balancing problem via *Matlab Simulink*, where the controlled motion was visualized by real-time animation through a Simulink block. After having informal lunch with students at GWU, they had tours of the robotics laboratories at GWU, where operations of ground robots and aerial vehicles were demonstrated. At last, they played a competitive game to move around an object such that its position and attitude measured by a motion capture system matched with given coordinates as quickly as possible. Feedback from students

(a) First PID control design with Matlab Simulnik

(b) Lunch with undergraduate/graduate students

(c) Demonstration of a quad legged robot

(d) Demonstration of indoor flight of quadrotors, and hands-on experiences in motion capture system

Figure 1: Outreach event for the first robotics team at the Bell Multicultural High School

was extremely positive, and the director of the team was so pleased with the workshop that he suggested to offer it to all of the other public schools in DC.

Conclusions I look forward to teaching various topics in engineering and mathematics to students throughout my career. It is my great pleasure to see a student develop as a creative engineer under my guidance. I am interested in teaching a large number of subjects in engineering, applied mathematics, and computer science. I also would like to organize an independent study class so that students can study various fields of their own interest.

Comments from Students

"You're a great asset to the MAE department and I have friends who wish to retake classes to have you as a teacher."

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"He is very enthusiastic and helpful. He is always willing to assist and help his students."

Received help whenever I needed it and he has a
very thorough knowledge of the subject – definitely one of
the best professors here at Florida Tech!

"Easy to understand. Simplifies material so it is easier for students to learn."

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Simplifies material so it is easier for students to learn
relates material to book

"Always available for help outside of class."

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"Professor Lee is easily the best professor in the MAE department. Every course by him that I have taken is extremely organized and proceeds in a logical, straightforward manner (even when the subject matter is not so straightforward), and this course is no exception. Professor Lee covers both the rigorous mathematical background needed for stability analysis and applications of nonlinear control to the real world. The subject matter can be really quite complicated, but Professor Lee does a fantastic job breaking it down and explaining it to the class. His homework assignments take difficult problems and help guide you toward solving them correctly (if you are willing to put the time in) by having multiple parts. This is probably the best course I've taken at GW."