Principles for Engineering Education

Part 3

By Eric M. Hines, Ph.D., P.E.

In the previous two articles (STRUCTURE® magazine April 2012 and June 2012), I discussed four principles that are critical for improving the "technical and practical quality of education for structural engineering students."

1) Theory and practice are indivisible.
2) Engineering is a creative discipline.
3) Drawing is the language of the engineer.
4) There is more than one way to model every problem.

In this final article, I continue my discussion in the context of my Junior level course *Steel Design* at Tufts University, and I will offer conclusions for the entire series.

The purpose of design in university engineering education is not to expose students to all the problems they will see in practice, and it is certainly not to teach them how to use the code.

My students arrive swimming in tools that are so sophisticated, they don't even recognize them as tools. It is my responsibility to narrow the field. *Steel Design* restricts students to pencil, paper, scale and calculator. Restricting the tools allowed in *Steel Design* and explaining this philosophically over the course of several weeks helps students understand a type of imagination that is unique to engineers. For instance, I teach my students how to bound a problem. Bounding a problem not only presents an immediate conservative solution, but it also allows an engineer to judge whether further investigation will lead to improvement of the design. We don't keep our work simple because we are stupid or lazy, we keep it simple because we are sophisticated. Simple work can be checked. It can be communicated, and it can be mulled over in one's subconscious. Flashes of inspiration in the shower and sleepless nights are only helpful to those who understand what they are doing.

Prior to the rise of computational analysis, the nature of hand calculations was twofold – developing a process and an answer. The purpose of hand calculations now has shifted more toward process. Engineering calculations are a form of communication. And ultimately, they are a record of an engineer's thoughts – right, wrong or indifferent. In my practice, I have learned that remembering the process by which I arrived at an answer is as important to me as having the answer itself on record. I tell my students that we probably differ in terms of how we approach our mistakes. They somehow believe that a wrong answer reflects their lack of intelligence. I know that a wrong answer is an inevitable result of my humanity, so I have to work according to a discipline that will allow me and my colleagues to catch my mistakes. Clear communication of my thought process is fundamental to this discipline.

Steel Design requires 4 contact hours per week, with two 75 minute lectures and one 75 minute studio run by a practicing professional appointed for one semester as an "Engineering Fellow". The course proceeds in three phases.

Phase I introduces the language of steel design, and therein introduces students to relationships between systems and details. These relationships form the heart of engineering design. This phase aims to provide students with the basic vocabulary and grammar for expressing structural ideas in steel. It is appropriate to design a whole building, but it is also appropriate to use only the most simplified loads and analytical methods. The level of design is conceptual, the kind students may practice in 10 years, but the drawings and details produced are real and could be used as the basis for construction. The object is not for students to hit the ground running when they start work, but rather to help them understand how calculations, member selection methods and codes are at the service of drawings. The work produced during Phase I over the course of four to five weeks forms the basis from which detailed analyses and construction documents could be executed if there were time.

Phase II creates a space of approximately four weeks to review fundamental principles and engineering methods that facilitate creative thought in structural design. Students begin to develop an understanding of modeling – the act of approximating reality with calculations. Emphasis is placed on comparing approximate and exact solutions along with the nature of the approximations and exactness. Finally in Phase II, the importance of drawing is extended from representation of physical objects in Phase I to the representation of conceptual objects. Students' understanding of drawing as a language, possessing similar richness to words and mathematics, is deepened in preparation for their work in Phase III.

In recent years, Phase III has consisted of two design assignments related to my current work. Assignments are stated in a few lines, and provide the context for countless design solutions. Lectures discuss my work on these and other projects, with particular emphasis on my design process. Student work is evaluated during Phase III in a studio environment, where students pin-up and explain their work to classmates, professors and Engineering Fellows.

Conclusion

About three years ago, I reached a turning point in my teaching. I had become disillusioned, wondering if I was ever going to produce work that could be expressed in textbook problems. Every real problem, no matter how simple, needed some context in order for its reality to make sense. I eventually realized that my professional work would defy the textbook format for the rest of my career. Reality is messy. I decided that it wasn't my work that was flawed so much as it was the textbooks. Textbooks deliver example problems in step-by-step format – and teach students to look for the steps as opposed to thinking for themselves. Textbook problems are nicely typed and give the impression that whoever solved them made no mistakes along the way. My point here is that I had to gather up some courage in order to take reality seriously – and it has greatly benefited my teaching.

What should engineers learn in school and what should they learn on the job? Clearly, work exposes people to hundreds of problems. The question is whether these problems get integrated into a conceptual framework that sees them as variations on a few important themes. When the framework is not intact, it is more likely that these experiences continue to appear literally as hundreds of problems. The National Research Council highlighted the relationship between this conceptual structure and the essence of expertise in their landmark treatise *How People Learn*. The frequency with which my senior colleagues relate stories about their own undergraduate years emphasizes the persistent power and meaning of their education as the foundation for their practice.

The purpose of design in university engineering education is not to expose students to all the problems they will see in practice, and it is certainly not to teach them how to use the code. Rather, design classes ought to motivate and challenge students' fundamental understanding in the context of a creative process. The relationship between theory and practice is so strong that the two cannot be separated without doing violence to reality – which itself is a unity – no matter how messy it may be. Not all real-world problems are appropriate for educational purposes. And, simple examples which illustrate a theory as well as they reflect reality are rare indeed. It is a wonder, therefore, that the development of high quality examples for teaching is not an intellectual discipline in its own right.▪

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