Principles for Engineering Education

Part 2

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

In the previous article (STRUCTURE® magazine, April 2012 issue), I introduced 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.

I discussed the first and second principles in Part 1 and will continue now with the third and fourth principles.

Principle 3: Drawing is the language of the engineer.

Drawings are the real product of a structural engineer's work. A structure may well stand up if I didn't calculate it, but it cannot be constructed if I haven't drawn it. This principle has historical significance in the work of Karl Culmann, who founded the Department of Civil Engineering at the Federal Technical Institute (ETH) in Zurich in 1855 and published the first comprehensive work on graphic statics in 1866. Many engineers will agree that drawing is a language whose intellectual richness and power of expression matches or exceeds words and mathematics. Unfortunately, drawing shares a similar fate to practice in the university, and has been misunderstood as either a technical skill or an expression of artistic talent.

The best English language introduction to the work of Karl Culmann and his successor, Wilhelm Ritter, can be found in David Billington's The *Art of Structural Design: A Swiss Legacy*. In Culmann's words, "Drawing is the language of the Engineers, because the geometric way of thinking is a view of the thing itself and is therefore the most natural way; while with an analytic method, as elegant as that may also be, the subject hides itself behind unfamiliar symbols." Following this theme, I discussed drawing as a language in a more contemporary context in my 2011 paper "Conceptual Transparency." Colleagues of mine who are highly accomplished designers and who have long recognized the importance of drawing for engineers, Edward Allen and Waclaw Zalewski, have made Culmann's graphic statics accessible to a contemporary audience in *Shaping Structures* and *Form and Forces*.

When I develop a new design, I first draw what looks right and then I calculate. I encourage my students to do the same. Their drawings direct their calculations, and in turn, their calculations allow them to develop new drawings. Once this becomes the approach students expect to follow, they find that they make choices about their calculations, i.e. even their calculations require creativity. Suddenly the virtue of simplicity begins to make sense. Simplicity facilitates creative thinking, by increasing the number and quality of ideas that are generated, expressed and judged.

Principle 4: There is more than one way to model every problem.

This principle responds to the current tension between computational methods and hand calculations as they affect undergraduate education. Questions regarding the appropriate use of the computer in practice and teaching are reminiscent of the tension between machine production and handicrafts that began over a century and a half ago. Gottfried Semper, who was a colleague of Karl Culmann's, visited the 1851 Crystal Palace Exhibition in London and wrote a famous essay on this tension. Semper wished to remain optimistic about machines that "encroach deeply into the field of human art, putting to shame every human skill," and asserted that "there is no abundance of means but only an inability to master them." By the early 20th century, the question of machine production had come to dominate not only modern architectural discourse but modern society in general.

Our current use of computers has developed all the more rapidly in light of our hindsight regarding the history of machine production. What seems to be missing, however, is the intensive cultural discussion that flourished from the 1850s to the 1920s on the merits and weaknesses of the new tools. I can't help but feel that we are missing a cultural opportunity, and perhaps also an economic opportunity, in our reluctance to discuss what it means to have mastered our tools.

Since the scientific revolution of the 17th century, we have created unprecedented wealth by systematizing, dividing and refining our approach to labor and production. In the service of this grand project, engineering has developed a reputation for acting instrumentally, for rationalizing and optimizing. This reputation, however, misrepresents many of the stories behind the engineering that supports our modern world. What needs to be made transparent to students is that even the most mundane professional work requires a human way of thinking – drawing on experience, analogies, associations and feelings. By the way, I have been reminded by many students over the years that this is also the key to increasing participation in engineering by women and minorities. Understanding technical rigor in context makes it more rigorous. We don't need to make engineering more attractive, we just need to represent it as it truly is. The interaction of the human and the technical is the lifeblood of our modern world, but this interaction is hard to understand and discuss. For this very reason, we ought to value this discussion as one of our most cherished and important intellectual disciplines.

While our trade journals are filled with articles advertising an ability to keep pace with our latest tools, a few simple observations seem to escape discussion. For instance, building professionals in general have grown more uncomfortable with drawing by hand. This makes it harder to express and discuss new ideas at meetings. Necessity no longer requires younger engineers to calculate by hand. This has removed the old safeguard that proficiency not attained in school would be acquired in practice. For the first time in history, it is possible to practice for ten years and not have advanced beyond fundamental understanding attained as a student. Superior computational power has reduced the apparent need to think long and hard about how best to model structures. This has promoted a literal approach to modeling which is highly inefficient and often incorrect. It has also indulged a culture where professionals and students alike are unable to explain their results. In response to questions regarding structural behavior, I have heard the phrase, "Would you like to see my spreadsheet?" No! I would not like to see your spreadsheet. I would like for you explain to me what is going on. Habitual work on the computer has diminished both a sense of scale and the means of expression available to engineering students working on paper.

When I calculate, my pages are filled with sketches, notes, tables, equations, numbers and graphs – each is a means of expression appropriate to its purpose. Taking Karl Culmann at his word, I often develop my force diagrams directly on top of a picture of the structure or detail. Drawing, calculation and understanding are connected. It is not enough to understand the concepts internally. An engineer must convey the same understanding to someone else.

An understanding of the creative process allows me to explain my choices of tools. As a professional, no explanation is required. As an educator, however, my job is to help my students make sense of the world, so I struggle to understand why I practice the way I do. Teaching keeps me honest. For each situation, I judge the value of my tools based on three criteria:

1) How quickly and directly can I express the idea?
2) How much does this expression facilitate judgments and inspire further ideas?
3) How well may I expect this expression to communicate?

This is especially helpful in determining the appropriate use of the computer. While I belong to a generation of engineers proficient with all types of software, I find that many problems can be solved more quickly by hand – especially if I model them in an efficient way. Other problems are solved more quickly by the computer, but their solution offers less fundamental insight. This poverty of insight has a tendency to obstruct the sound judgment and generation of ideas. Still other problems, however, are solved elegantly and quickly on the computer. The best tool for a given situation is not a foregone conclusion. I am responsible to judge which tool best suits my present purpose. To judge well is to have mastered my tools.▪

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Part 3 of this series of articles will be included in an upcoming issue of STRUCTURE.