PRINCIPLES FOR ENGINEERING EDUCATION

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As a practitioner and educator, I was invited to discuss ideas for improving the "technical and practical quality of education for structural engineering students." To this end, I would like to introduce four principles which I think can help accomplish this NCSEA goal. While I agree that engineering students today are in danger of missing fundamental technical knowledge that was common a generation ago, I think that the roots of this problem are human and not technical. Solving the problem therefore requires recourse to human principles:

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.

These principles are no doubt familiar to many engineers. As I understand them more clearly through my experiences and discussions with colleagues, I communicate them more explicitly to my students.

PRINCIPLE 1: THEORY AND PRACTICE ARE INDIVISIBLE.

There is only one real world. Theory attempts to make sense of it. Practice attempts to assume responsibility for it. Engineers' technical quality shines brightest when they recognize the limits of theory and design so that these limits become irrelevant. I first learned this from Professor David Billington at Princeton University through his lectures on the great works of structural engineering and his book *The Tower and the Bridge*.

A review of the historical literature suggests that the distinction between theory and practice developed as a matter of convenience. Unfortunately, this distinction became pervasive during the 20th century and led to the misconception that professional activity amounts to the mere application of scientific knowledge. *Scientific Culture and the Making of the Industrial West*, by Margaret Jacob, discusses how the natural integration of theory and practice in 18th century England stimulated the industrial revolution in advance of other countries by more than a generation. As the industrial revolution grew in scope and complexity, well-meaning attempts to divide responsibility between the creation and application of technical knowledge resulted in the now common distinction between theory and practice. Considering professional knowledge in general, Donald Schön argues in *The Reflective Practitioner* that this distinction was canonized in American higher education at the end of the 19th century during the founding of American professional schools. These authors help us to understand the assumptions on which our current approach to professional education is based. If the American medical profession struggles with the epistemology of the modern research university, then how much greater is the challenge to engineering, which was not part of this initial professionalization inside the American university?

Professionals recognize that problems need to be framed before they can be solved. We recognize that a given problem may be both framed and solved in a multitude of ways. To call this "practical" is to completely misunderstand the intellectual depth required for good judgment. Judgment in structural engineering requires mastery of our discipline. Things that are "practical" are important pedagogically only insofar as they call this mastery to account. For this reason, I often remind my students that the purpose of a design course is to *motivate and challenge their fundamental understanding of structural behavior*. I have come to this conclusion over time as I have learned that even students who get good grades don't understand structures very well. Theory is valuable—but only insofar as it is understood, and only insofar as it describes reality. Theory is the foundation of professional practice, but practice is the discipline of theory.

PRINCIPLE 2: ENGINEERING IS A CREATIVE DISCIPLINE.

Engineers ought to understand their work as creative even if it is not artistic. Creative work requires choices. If there is more than one way to do something, creativity comes into play. The creative process has three stages:

1. An idea is *generated*: and exists in the imagination only.
2. It is *expressed* in language: drawing, words, mathematics.
3. Only then can it be *judged*: through thought, feeling and discussion.

The creative process becomes an artistic process when expression is intended to evoke an emotional response. Understood in this way, Engineering, Mathematics, the Arts, the Humanities and the Sciences need not vie for superiority. They are all creative endeavors, each with distinct intentions.

In engineering terms, one might describe the stages of the creative process as highly non-linear and coupled. The generation, expression and judgment of many ideas proceeds iteratively and in parallel. Modes of expression may change over the life of an idea, people may alter their judgments, and the idea itself may evolve. Thus, in the context of teaching, high quality design problems are those that can be thought about rigorously and simply while requiring several choices to be made. Teaching the discipline of creativity also requires room for students to iterate on their own designs, so educators must make hard choices to give up breadth in the interest of mastery.

Understanding creativity as a process of choice-making frees it from the exclusive mystique surrounding modern art and invention. It also frees creativity from the assertion that novelty is required. If the creative process is misunderstood as consisting of its first two stages only (generation and expression), the result is a fundamental lack of rigor. When engineering students recognize that the rigors of judgment are as essential to creativity as the openness of generation and the energy of expression, they can learn to withhold judgment of an idea until it has been appropriately expressed. Inability to recognize the place of rigor within a larger process leads many engineering students to short circuit this process. They believe that ideas come into being fully formed, that they must solve each problem correctly on the first try, and that to offer spontaneous responses is to demonstrate stupidity. These prejudices rob students of their courage.

Parts of the creative process can be taught, and parts of it cannot. The unteachable parts may be understood in terms of inspiration, talent and wisdom. The teachable parts may be understood as the discipline of creativity:

1. Generation: it may not be possible to teach inspiration, but it is possible to share the development of one's own ideas honestly and transparently. It is possible to tell the stories of real engineers and artists.
2. Expression: it may not be possible to endow talent, energy and commitment, but educators can teach the use and meaning of fundamental languages such as drawing, words and mathematics.
3. Judgment: it may not be possible to teach wisdom, but it is possible to value it and to demonstrate it.

The discipline of creativity accepts the necessity for iteration, and so requires engagement of the creative process with speed and courage. In this context "speed" is necessary to ensure that the expression of ideas is uninhibited and that judgments are disciplined. "Courage" is necessary to temper one's fears of expressing a bad idea or facing a tough decision. Since most engineering projects are the work of more than one person, individuals need to be aware of interpersonal interactions that can either fuel or inhibit the creative process. We should not shy away from the potential discomfort these interactions present. In doing so, we miss opportunities. Understanding the principles of the creative process provides strength to see the process through.