

## STATEMENT ON TEACHING

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### 1 GENERAL REMARKS

My perspective on teaching has been strongly influenced by my experiences as a manager of an engineering office. In this capacity, I was a consumer of the product supplied by the system that prepares graduate engineers for the profession, and thus had direct experience of how well this product performed its intended function. The importance of education, and the problems currently facing engineering education, were made evident to me each time I hired a recent graduate. I would take great pains to select the best candidates from the best universities, yet none of these engineers was able to generate even the most rudimentary design concept in response to a clear definition of design requirements. Once a concept had been developed for them, they could generally do a reasonable job of calculating its response to loads. The blank piece of paper, however, which is the starting point for all bridge designs, posed a seemingly insurmountable conceptual barrier. It could certainly be argued that these graduates entered practice not knowing how to design.

Conversations with my peers in industry revealed that my observations are indicative of a situation that is widespread. The inability of recent graduates to put new ideas onto a blank piece of paper is certainly consistent with the realities of the current structural engineering curriculum, which is heavily weighted towards methods of calculating the response of structures to load and the capacity of simple structural elements to carry load. The conventional wisdom would appear to be that design can be safely left out of the curriculum because graduates will learn it anyway once they enter practice.

I disagree with this view. Although an apprenticeship in industry can be an important part of an engineer's education, design is too important to be left entirely to the vagaries of the workplace. Given the imperative of short-term profitability that currently prevails in most firms, it is rare for employers to invest the time and resources required to provide adequate training in design. If we want engineers to be good designers, therefore, universities must take design seriously.

I joined the University of Toronto because I want to help renew the practice of bridge design. A major component of this initiative is to transform the way we educate engineering students to become designers. Regardless of how well we succeed in creating new knowledge through research, few benefits will arise from this knowledge if we do not have designers who can use it to create innovative new works of engineering.

I believe that I can make a special contribution towards improving the way we educate designers, because I am one of the few professors of engineering at the U of T to have spent a significant period of time in design practice. I, too, have struggled to put ideas onto a blank piece of paper and I know how daunting this can be. I can provide students with much more than empathy, though. By facing, on a daily basis, the challenge of generating new ideas on real design projects, I gained a fundamental understanding of the essence of the design process. Given that design is a practical activity, I believe it makes sense to teach students to design using an approach that is based on an understanding of design that originates in actual design practice.

To be good designers, engineers require *knowledge*, *skill*, and *values*. Each of these elements is important in its own right and must therefore be included in the design curriculum. The meaning of each of these elements within the context of design education is discussed in the following subsections.

## 2 BASIC ELEMENTS OF DESIGN EDUCATION

### 2.1 *Knowledge*

In this context, knowledge refers to the conceptual raw material and tools that designers use to generate new ideas. In engineering, knowledge is primarily (though not exclusively) scientific. Knowledge is the primary focus of the current engineering curriculum. In civil engineering, for example, future structural engineers are taught the principles of mechanics, methods to calculate the response of structures to load, and models for determining the load-carrying capacity of simple structural elements.

This is a good start, but unfortunately the curriculum does not get much farther than this. We have given our students some powerful conceptual tools, but we do not show them what to do with them. We must also give students a body of knowledge of real, entire, and completed structures. We must guide students through the analysis of these structures to show them how their knowledge of mechanics and materials can actually be used as a basis for important design decisions.

A body of knowledge of real structures also gives designers starting points, i.e., ways of putting an idea onto the blank sheet of paper. If students study a wide variety of real bridges, they will be able to use this knowledge to develop workable initial design concepts of their own. The intent is not for them to copy, but rather to assess how well the known solution satisfies the requirements of a specific project and to use the insights gained from this assessment as inspiration for the development of new concepts. Particularly valuable in this regard is for students to get to know structures that were designed and built before computers were used to calculate the response of structures. This gives students an appreciation for the power of simple calculations as a tool for generating and validating new ideas, as well as the limited utility of complex, computer-based methods of analysis. Roebling's Brooklyn Bridge is an excellent example of an extremely complex bridge that was designed using only very simple methods of analysis.



The curriculum must regard knowledge as a resource that is constantly expanding. We currently give our students the same conceptual raw material and tools as were used in the design of bridges thirty years ago. We need to give them the knowledge they will need to design the bridges of the future. It would appear evident that, by increasing the body of knowledge we have to work with, we also increase the variety of possible design solutions. This is critical because of the potential benefits to society that will arise from the use of new technology, but also because not moving forward on this front will further contribute to the commoditization of bridge design. In deciding how to expand the body of knowledge taught to future designers, we must also be aware that the problems that will be faced by the engineers of tomorrow will be increasingly less likely to fit neatly into the compartments of the traditional academic disciplines.

## 2.2 *Skill*

Skill is the term used to describe the ability of designers to generate new ideas from available conceptual raw materials and tools. This activity is intensely creative and, as such, is very personal in nature. Every designer approaches design situations in ways that suit his or her own background and perspective. It is thus counterproductive to teach students a rigid “design methodology” that is expected to work for all designers in all situations.

Rather, the teaching of design skills is best done by giving students opportunities to do design, so that they can discover for themselves how best to generate new ideas. The traditional way to do this has been through design projects. The hallmarks of good design projects are:

1. Projects that are sufficiently complex to provide students with a “real-world” design experience and sufficiently simple to permit a focus on specific pedagogical objectives
2. Projects that allow students to make mistakes and learn from them. One of the primary purposes of design projects within the curriculum is to give students an opportunity to grapple with the unstructured nature of the design process, which involves false starts, blind alleys, conflicting requirements, and compromises. It is by facing these challenges on their own in an environment that is accepting of mistakes that students learn how to deal with setbacks in design and how to use these setbacks to their benefit as starting points for developing new ideas.
3. Projects that allow students to succeed and to be proud of what they have done. Design is what engineers do. We should not give students the impression that a significant portion of their class is not suited to be designers. Although it is true that only a small percentage of engineering students go on to become brilliant designers, most if not all of them have the ability to develop workable creative solutions to real-world engineering problems. In this regard, we must be careful about the use of “design-build” projects, in which students produce a model or a device that must then perform a specific function. All too often, a significant portion of the class produces devices that fail to perform adequately. As stated in the previous point, setbacks are an integral part of the design experience, but only when the designer is given the opportunity to learn from the setback and improve the design. Such exercises would have significantly more pedagogical value if students were given several cycles of testing to allow them to improve their designs. We must also be careful, however, to ensure that ultimate success is determined by the quality of the design and not merely on the quality of the workmanship.
4. Projects that are done in a setting that maximizes face-to-face interaction with teaching staff. The traditional paradigm of training to do any kind of creative activity is that of master and apprentice. Schools of architecture recreate this situation with “design studios”, in which students present their work to course instructors on a regular and frequent basis. The dialogue between student and teacher forces students to find their mistakes, to be aware of sloppy thinking, and also gives them an opportunity to feel good about good design decisions they have made. The closer we get to the one-on-one interaction of master and apprentice, the better will be the learning experience we provide to our students. Obviously, this type of teaching requires student/teacher ratios that are significantly lower than the numbers we normally see in lecture courses. There is often a temptation to have graduate teaching assistants handle the face to face interaction. Given the pool of graduate students we attract into civil engineering, it is rare indeed to find any who have had the breadth and depth of design experience that would make them suitable for this type of teaching.

The ability to draw is one particular skill that has long been used by bridge designers, and which has been neglected in the current curriculum. Drawing is not only a means of communicating ideas, it is a means of generating ideas. We need only look at the freehand sketches of the great bridge designers to realize this. Drawing is also a powerful means of linking the visible form of bridges and structural behaviour. By teaching our students to draw and showing them how drawing can be integrated into almost every aspect of their activities as engineers, we will help them to be better designers. Accomplishing this, of course, assumes that their instructors will also possess a suitable level of drawing skill. Generally speaking, this is not the case in most departments of civil engineering.

### 2.3 *Values*

Once we have developed a design concept, how do we tell if it is good or not? We need a basis of values upon which to base this decision. Currently, the curriculum teaches future structural engineers that good structures are ones that consume a minimum of materials and/or have minimum construction cost. This is a very narrow perspective. When construction cost is the only value, we tend to get structures such as Toronto's Gardiner Expressway (shown in figure to the right), which was surely a very economical structure to build, yet is universally disliked in Toronto.



We get better structures when we include values other than mere money in the design process. We need to demonstrate to students that values relating to the visual aspect of bridges are legitimate and are intimately linked to the "technical" decisions that they make in the design process. Again, an understanding of important historical structures helps to get this point across. When students see elegant, aesthetically significant bridges such as the Brooklyn Bridge and then study the relation between its visual characteristics and its structural behaviour, they will realize that engineers can and must deal with the aesthetic aspects of bridge design.

Other values of importance are ease of construction and minimal disruption to traffic during construction. The concrete segmental structure for the BQE Connector Ramp, shown in the figure to the right, was chosen not because it was the most economical (it was not), but rather because it was the fastest to build. This minimized disruption to motorists and residents of the neighbourhood. A designer whose only value was to minimize material consumption would have been hard pressed to develop the solution that provided an acceptable balance between several different design requirements, only one of which was cost.



If the designers of the twentieth century are to face new challenges, then they will need to be able to work with new values. The growing need for the structures we build to be environmentally sustainable is another value that will require innovative new design solutions that go far beyond conventional lowest-cost solutions.

We can teach values to students by means of critical study of completed structures. The point is not merely to calculate forces and structural capacities in these structures and demonstrate compliance with code, but to challenge students to determine whether or not the “right” design decisions were made. This requires that values be defined, either implicitly or explicitly. Was the structure easy to build? Will it be durable? Does it have a visual logic? Is it aesthetically significant? These are the kinds of questions that we need to challenge our students to answer. This is also an important opportunity for us as their teachers to provide leadership. If we are truly concerned about bridge aesthetics, for example, then we must be prepared to discuss the visual aspects of bridges with a critical perspective. If our values are reasonable and we are consistent with our critiques, then our values will rub off on our students.

#### 2.4 *Learning from the past*

The views on design education put forth in the previous sections are different in many regards from the conventional wisdom on the curriculum, but they are by no means revolutionary. In fact, they are largely consistent with the pedagogical approach of Wilhelm Ritter and Pierre Lardy, two remarkable professors of structural engineering at the Federal Institute of Technology in Zurich (ETH). Between them, these men taught four of the greatest structural designers of the twentieth century (Robert Maillart, Othmar Ammann, Heinz Isler, and Christian Menn). David P. Billington has convincingly shown how the body of work designed by these four engineers is directly related to the education they received from Ritter and Lardy.<sup>1</sup> The relation between the approach to design education that I have proposed here and the approach taken by Ritter and Lardy is discussed further in an article included in Appendix G.

It could be argued that there is no sense in adopting an educational approach from the past in a profession that needs to be looking forward. Although it is true that we should not be teaching our students to design the bridges of the 1950s (when Lardy was active as a professor), we can certainly benefit from the perspective of these two professors. Both Ritter and Lardy were active in moving the practice of structural design forward, by introducing their students to the principles underlying design using the new materials of their day. For Ritter, this material was reinforced concrete, and for Lardy it was prestressed concrete. So although the design rules for reinforced concrete taught by Ritter might now only be of historical interest, the courage, foresight, and technical rigour with which Ritter championed this new material is directly relevant to current opportunities presented to us by the new materials of the twenty-first century.

### 3 LONG-TERM PLAN

My long-term plan for teaching is to improve the way we educate designers by implementing an approach based on the three primary elements described in the previous section. My

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1. Billington, David P. 2003. *The Art of Structural Design: A Swiss Legacy*. New Haven and London: Yale University Press.

current efforts to implementing this plan involve issues within the current curriculum and also issues outside the curriculum.

### 3.1 *Issues within the curriculum*

My current teaching efforts are summarized in my curriculum vitae. In all of the courses I teach, I have begun to implement the elements of the pedagogical approach described in the previous section, including:

1. *Critical study of completed, entire, and real structures.* This has been the case primarily in CIV 356F and CIV 1164F, but I have also presented simpler examples in CIV 214S. My long-term objective is to run CIV 1164F and the lecture portions of CIV 356F entirely on this basis.
2. *Emphasis on visual methods.* I have devoted a significant portion of CIV 214S to graphical methods of structural analysis. I also require students in CIV 356F and CIV 1164F to prepare many sketches and drawings of the bridges they design in term projects.
3. *One-on-one interaction with students.* I insist on attending and leading all tutorials. There is important one-on-one interaction in the three-hour weekly tutorials of CIV 356F, which are run in a similar way to the critiques run in architecture studio courses.
4. *New technologies.* It is my goal for 2004 to incorporate concepts related to new materials in both CIV 356F and CIV 1164F.

I have also led a departmental task force on a fourth-year design project course. We expect to have a proposal ready for presentation to the entire department by May 2004. The structure of this course incorporates many aspects of the approach to design education presented in the previous section.

### 3.2 *Issues outside the curriculum*

There are important opportunities to extend the design education experience out of the classroom. I currently have three such initiatives underway.

I have received funding from C-DEN, an NSERC-funded network for design engineering, to develop an interactive web-based teaching module that will help students become familiar with the process of bridge design. The module is based on a real, entire, complete bridge. In working through the module, therefore, students will add to their own body of knowledge of completed structures. They will see the primary systems and details of the bridge, will be challenged to understand the reasons behind important design decisions, and given the opportunity to explore other possible design choices. The module is intended to be the first of many, each one featuring a different bridge. We have therefore provided the software underlying the module with sufficient flexibility to make it adaptable to a wide range of bridges.

I will lead an effort to bring an art exhibition on the art of structural engineering to the U of T in the fall of 2005. This exhibition was curated by Professor David P. Billington of Princeton University, and showcases the work of the four great Swiss designers of the twentieth century. This event will be of significant value in demonstrating to students the relation between the visible form of buildings and bridges, their aesthetic significance, and their structural behaviour. It should help to inspire more students to become good structural designers. There will also be a symposium on the art of engineering held in conjunction with this exhibition.

I have submitted a proposal for an NSERC Chair in Design Engineering, which was well received. The application was reviewed and we were asked to make specific revisions and resubmit. We expect to have the application sent back to NSERC early in January. This program is primarily intended to improve the quality of design education in Canadian universities. The proposal has a number of unique features, one of which is a partnership with industry to set up a residency program for recent graduates, to ensure that they receive good opportunities to continue their design training in the first crucial years of their professional life.