This article attempts to reposition engineering mathematics, and engineering mathematical education, into a sphere of influence different from the one in which it is traditionally envisioned (or assumed) to occupy. More significantly, the modelling comments we make embed engineering mathematics firmly into a “responsible decision making” or “public policy” context, and thus move the study of engineering mathematics from a largely individualist pursuit to a more collective undertaking. As a secondary effect, this argument leads naturally into a brief consideration of some of the biggest challenges facing both humanity and engineering in the 21st century.

It is sensible to start by saying a few things that are likely obvious (though implicit) to almost all who work within applied sciences. We, the practitioners of science, almost universally believe a number of key things about reality. We believe (i) that a physical world exists (the world is not entirely imaginary), and (ii) that we willingly influence this world (sometimes significantly) by our actions and choices. We also believe (iii) that the physical world responds to these actions in ways that are real, but not always obvious. Yet we believe (iv) that the consequences of our actions usually include some combination of beneficial/desirable and detrimental/undesirable outcomes. With a bit more reflection, most of us also would believe (v) that even though the consequences of our choices and actions may have wide influence both on human and natural systems, the evaluation (or weighing) of the positive and negative outcomes takes place largely within a human system of values, beliefs and expectations.

Since a statement like this is a little abstract, it is helpful to provide a simple illustration. So imagine that we clear a piece of land beside a river, cultivate a field, plant seeds and eventually harvest a crop. Each action is taken in anticipation of how both people and nature respond to our unfolding actions, but each outcome is latent with possibilities of other outcomes, some of which we don’t intend and might not anticipate. For instance, the river could flood and our crops drown or wash away before harvest. In anticipation of the flood, or in response to some observed historical one, we might seek to divert river water away from the field, an action that might have other consequences to other places and other people. The evaluation of the desirability of the outcome—a settled piece of cultivated land—will depend not only on who does the evaluation, but likely also on such issues as over what time, and from what perspective, such an evaluation is made. A politician, an historian, an ecologist, a hydrologist and an economist might all have quite a different verdict on the value, significance and success of the whole set of human interventions.

Anticipating consequences
As long as the consequences of our action are predominately personal—that is, as long as they matter supremely to those who act and less to those who observe and experience—we might be prepared simply to take the actions that seem best to us. However, if there is at least a possibility of larger-scale or longer-term consequences, simply taking action might not be reasonable, responsible or even possible. Our neighbours might object to our planned actions and even
be prepared to block them; or our plans might effectively require their co-operation, since without some collective action individual actions might be of much less value. Indeed, this is essentially the definition of public policy as the process for decision making involving collective actions and consequences. In a profound way, public policy analysis often explicitly or implicitly invokes mathematical reasoning and an anticipated chain of consequences with the expressed goal of making public decisions that have outcomes that the collective prefers. Put another way, we ask: What is the sequence of actions and incentives that delivers the most benefits to the most people? But this is not an easy task. If individual preferences vary along some kind of spectrum, we must assume there will be individuals whose preferences will run counter to those of others and hence to the “collective.”

We see evidence of these tensions all the time. Almost any public policy along the lines of “the needs of the many outweigh the needs of the few” will almost inevitably come into conflict with the deeply felt but contradictory interests of the few. The current tension between provincial policy to promote wind power overall can create perceived risks and impose costs for those citizens in whose communities the pylons and turbines are to be installed. A related and long-standing tension lies between the need for urban societies to dispose of waste, and the reluctance of other communities to serve as the depository. The relevant question for policy is whether the collective good is the sum of individual goods, or its average.

But what precise role does mathematics play in such cases? It is at least this: when collective action is desired or likely to be rewarded or punished, there are huge potential benefits or incentives to formally and consciously anticipate both human and natural responses prior to our proposed actions. Such a “formal method of anticipation” has a more common name, and it is simply modelling. Our models act as stand-ins or substitutes for the reality of direct action and, in the 21st century, such models are almost invariably hybrid mathematical and conceptual constructs showing through symbols an association between actions (decision variables) and consequences (output or design variables). Voinov et al. (2010) make the strong point that even the construction of such models, in complex fields like the earth sciences, largely takes place in the context of community.

Although this description positions mathematical modelling as a practitioner of science would understand it, it is not necessarily the way mathematicians describe mathematics to themselves. But we will let the mathematicians worry about the thorny problem of the essence of mathematics. What is more relevant in the current context is this: as obvious as the statement “math as purposeful modelling” is for many, this approach is seldom the explicit motivation or preoccupation of engineering mathematics courses. The average engineering student—and the authors have polled many over the years—tends to view mathematics as an exercise or aptitude test, a necessary and rather unpleasant initiation into the world of engineering through a strange and alien wasteland. Mathematics (particularly as taught in explicitly mathematics classes) tends to be seen as an abstract system of symbol manipulation, not as a way of collective and responsible decision making. From the perspective argued here, engineering mathematics should instead be viewed as a direct extension of what it means to make (and document) better collective decisions. Thus, the need to couple the mathematic model to the decision should be the overwhelming priority.

A CHANGED PERCEPTION

It is perhaps dangerous to invoke a stereotype, but since in this case it makes our point efficiently, we cautiously run that risk. So, in this vein, we sketch the caricature of the mathematically gifted student—someone who is, in our popular imagination, socially inept, head in the clouds, cut off from the normal interplay of society, certainly at home with numbers but seldom with people. This is precisely the student who historically might be most likely to be encouraged to enter engineering. By contrast, the person who cares about collective actions, who is seen as socially oriented, is often imagined as (or self-consciously chooses to be) technologically inept, unskilled with gadgets and inept with numbers, but surrounded by a crowd of well-connected and influential people, would rarely be pushed into engineering.

However fitting or accurate such characterizations might once have been, such images do great harm to the kind of reconciliation that is urgently needed in engineering between having both a head and a heart. Or perhaps stated more concretely, there is a great need for engineers to understand better the relationship between the world of technology, in which engineering actions are generally taken, the complex “real world,” where the consequences of actions take place, and the often mysterious world of public policy, in which the consequence and meaning of those actions are evaluated and sometimes either constrained or encouraged. We assert with many that the large collective problems we will progressively face in this century—whether of food or employment, energy for comfort and health, wealth and water for the largest human population in history, resources from progressively more diffuse sources but in progressively larger quantities—mean that we must learn to do better than we have in the past even as we learn to live more gently on the planet.

Within engineering degrees, mathematics is clearly a fundamental skill that must be developed. However, it is all too often taught with the above
mathematically gifted student in mind. Although real-world examples and connections may be examined in passing, the subject is taught in very much the same way as it would be to a student pursuing pure mathematics, or perhaps to a scientist wishing to describe, but not necessarily change, the world. Emphasis is placed on formal manipulation; less emphasis is placed on achieving reasonable results within the decision-making context that motivated the need for the mathematical abstraction in the first place. What is needed—and increasingly so, given the global issues we are facing—is a distinct approach, an approach to mathematical education that is designed to give engineers the particular skills and perspectives they will need in their careers, to make, evaluate, troubleshoot, and document responsible decisions. And this will require great physical intuition, as well as the formal skills of abstraction and symbol manipulation. Mathematics, as used and applied by all engineers and by almost all practitioners of science, should primarily be an exercise in embedded and responsible decision making.

ALTERNATIVES

For a subject that is perceived as having straightforward, objective answers, math gives rise to much discussion and debate. When students ask from an early age why they need to study math, answers vary from simplistic (“So you can understand money”) to practical (“So you can get a job”) to philosophical (“So you can better understand the nature of the world”). There is not even agreement on the nature of math itself. On the one hand, some point to the inherent beauty in mathematics and its internal consistency. Math can be considered to pre-exist humanity and to have been only discovered by us; it is thus independent of us. On the other hand, some point to a more pragmatic character of math and focus on its utility in the real world. Math can be considered to be something that is not discovered by us, but invented or developed by the human mind. We employ mathematical methods to help us make sense of the world around us. Math is created by us and so dependent on us. Indeed, the ability of math to accurately describe or predict something about the world has often engendered a sense of wonder; Eugene Wigner’s 1960 classic paper, “The Unrea-
longer-term consequences (not just intercepts, asymptotes and end behaviour) and can be coupled with discussions on the value of the resulting predictions. Students should be exposed to questions in such a way that they are challenged to give not simply a “correct” answer but a thoughtful one.

The whole point is to appreciate that the sometimes dramatic consequences of our human behaviour can be formally anticipated and then adjusted in a mathematical model, and that this approach is not as an escape from reality, and is not taken with the presumption that our models are perfect, but rather embeds the conviction that responsible collective action is not only possible, but ethically expected and, potentially at least, both rewarding and rewarded.

Of course, how all this is fleshed out in university courses and in the minds and hearts of engineering interns is a huge and relevant problem. It will take careful thought and engagement to improve on what we have done. But what else is new? This challenge of continuous improvement is the essence of what it means not only to be an engineer, but also to be human. 

REFERENCES


Bryan Karney, PhD, P.Eng., is interested in the design, analysis and operation of various water resource and energy systems. He is the associate dean of cross-disciplinary programs in engineering at the University of Toronto, a professor of civil engineering, and a director in the consulting firm HydraTek and Associates Inc.

Anne Mather holds a BSc in mathematics and cognitive science as well as a B.Ed, and is teaching in Toronto.
CBC science guru among OCEPP’s new advisors

By Michael Mastromatteo

TELEVISION HOST BOB MCDONALD, who has earned a reputation for making science fun and accessible, has been named to the first-ever board of advisors for the Ontario Centre for Engineering and Public Policy (OCEPP).

The long-time host of CBC Radio program Quirks and Quarks, McDonald has been active in electronic and print media for more than 30 years. In addition to reporting on science issues for CBC’s The National, McDonald is host and writer for the popular children’s series Heads Up! on TVOntario.

McDonald was also the recipient of a 2008 Gemini Award for best host in a pre-school, children’s or youth program or series. Some see McDonald as the forerunner to the US-based Bill Nye the Science Guy.

McDonald is among a group of new advisors who will serve three-year terms with OCEPP, which was established by PEO in 2008.

The new OCEPP advisor is a tremendous supporter of the engineering profession and PEO. He served as moderator for the Engineering Innovations Forum in 2006, and in November 2007, took part in the two-day Presenting Our Profession conference organized by PEO’s Education Committee.

The OCEPP board of advisors was created in 2011 to provide advice in a number of areas, including the centre’s mission and focus, its policy engagement series, the annual policy conference, and the centre’s relationships with academic and professional associations.

The other recently appointed members of the advisory board are William De Angelis, P.Eng., chair, Consulting Engineers of Ontario; Gary Thompson, P.Eng.; Marie Carter, P.Eng., chief operating officer, Engineers Canada; Ken Clupp, P.Eng., Ontario Association of Certified Engineering Technicians and Technologies; Brian Surgenor, P.Eng., Queen’s University, and Charslie Searle, EIT, formerly of the Engineering Student Societies’ Council of Ontario (ESSCO).

Bernard Ennis, P.Eng., PEO director of policy and professional affairs, also serves on the OCEPP board of directors.

In a July 4 statement, PEO Registrar Kim Allen, P.Eng., FEC, said advisory board members will play a key role in shaping the centre’s strategic direction: “The inaugural OCEPP board offers an outstanding and diverse range of expertise, ideas and enthusiasm. All board members are committed to further enhancing OCEPP’s direction and impact.”

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