The Future of Engineering Education

An Interview with Rick Miller

Rick Miller talks with James Euchner about the state of undergraduate engineering education and what we need to do to attract and motivate the engineers of the future.

Rick Miller with Jim Euchner

Rick Miller is the founding President of Olin College, which seeks to redefine undergraduate engineering education and attract more students to the profession. In this interview, he discusses the challenges engineering faces and some of the ways universities can engage students in a broader mission, as well as approaches schools can use to train engineers in the 21st-century skills innovators will require.

JIM EUCHNER [JE]: You have spent a career in higher education—as a professor, administrator, and innovator. What is the state of engineering education in the United States?

RICK MILLER [RM]: I have a persistent, almost unshakeable concern about undergraduate engineering education. We lose so many students! In the US, only about four and a half percent of the bachelor's degrees that we offer nationally go to students who study any kind of engineering. And about half of the freshmen or first-year students who enter engineering anywhere in the country won't ever graduate engineering. We have a very leaky pipeline.

In addition, we are ignoring half the population. Only about 18 percent of the bachelor's degrees in engineering go to women, which is very unbalanced. Medicine and business and law all do much better than that, so something needs to change. These two things—the leaky pipeline and the lack of women in engineering—were my concerns when the Olin Foundation reached out to me, and that's how I wound up resigning from tenured employment at the University of Iowa, where things were going very well, and pulling my family back to Massachusetts to work at a school that didn't yet exist. When I arrived on campus, back in February of 1999, Olin College was not yet a place; it was only an idea.

JE: What were the underlying causes of your concerns?

RM: At the core of the problem was the fact that engineering students were not very engaged in their education. We in academia were teaching a lot by rote learning. Most of the courses had to do with analysis and calculus, with the unspoken assumption that more math is always better: it doesn't really matter what the problem is—if you use more advanced math it means you're a better engineer. We didn't spend much time teaching students to formulate problems, but we spent a lot of time teaching solutions that were highly technical and specialized. Even the textbooks are organized in chapters defined by analytic techniques: this is the solution for problems in two dimensions; this is the solution for problems in three dimensions; this is the solution for problems with cylindrical coordinates, and this is the solution for problems with rectangular coordinates.

This approach is way too formulaic, and it doesn't draw students into engineering. Their mindset when they walk into the classroom reflects this. They want to know, number one, "Is this going to be on the test?", and number two, "Which chapter is this from, and what formulas apply?" And that's pretty much what engineering education was, not just at one school but at every school.

Now imagine that you want to prepare people to be innovators, to be creative and to develop new ideas. This approach to teaching would be the most effective barrier that you could imagine. And it is our norm.

It seemed natural to me that we have to do better. Why have people like Steve Jobs and Bill Gates, and other innovators, dropped out? Why are there so many creative people at

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our large universities who are not interested in engineering? Why? Engineering does not present itself as being creative; it presents itself as being technical. It presents itself as being all about applied mathematics and applied science. We have to do better.

Even my own PhD—and I think I got a good education—was really about applied science. I learned how to write papers for reviewed journals about the science behind the things that we make. But the creative act of actually making things? That's a whole other game. That involves multiple intelligences that we don't look for or nurture in engineering education.

So when I made the leap to Olin College, the fundamental questions started popping up right away. What is an engineer anyway? Are we even attracting the right people into engineering? In the early years at Olin, we got 10 people together with the very serious responsibility of rethinking two things: What will it mean to be an engineer in the 21st century? And what will it mean to be educated in the 21st century?

We spent months on these questions, with a team that was not all engineers; we had chemists, physicists, mathematicians, and even a musician and an historian. We started with the assumption that it takes more than just equations to make an engineer. After many conversations, we eventually concluded some things that profoundly changed what we do. First, we defined the term: an engineer, in our vision, is a person who envisions what has never been, and does whatever it takes to make it happen. The science is just a set of power tools that enable engineers to make it happen; they are not fundamentally what an engineer is or does.

Let's break this apart. Engineering has to begin with a *vision*—if you can't envision it, you'll never make it. But do engineering schools look for students who are visionary or creative? That isn't on the menu for high school counselors when they're looking to match students with engineering schools. So that's a problem for engineering.

Second, engineers have to *do whatever it takes* to make something new happen. Well, that is going to require some leadership capability. Engineers need to have some degree of interpersonal intelligence, so that they can read emotion and read the motives of those around them. They need to learn how to be persuasive, for example, if they want to be able to raise money for a project.

Nothing really important gets done easily. It takes an enormous amount of dedication and commitment. We in engineering education need to tap into the deeper motivations of prospective engineers. Very few successful people, at least those I have known, got there because they were primarily interested in the money. Money was simply a byproduct of the passion and commitment they had to do something bigger than themselves. In the education of engineers, we haven't really looked for or tapped into that intrinsic motivation, the motivation from within. At Olin, we are trying to attract students motivated by some cause that's bigger than they are. It is a motivation that doesn't die very easily; once students find their passion, it can make engineering very attractive.

As president of Olin College of Engineering, Rick Miller is working to reshape engineering education.

JE: So what should we do about it?

RM: Let me make an analogy to music, because I think there may be insights [for engineering] in the education of musicians.

What if you had a son or daughter in high school who was a prodigy, with a talent for the violin? Suppose you sent that child to a conservatory of music that teaches music the way we teach engineering. The first year, they would study the theory of sound: the theory of the vibrations of strings, mode shapes and natural frequencies, and how instruments work from a physics point of view. The second year, they would take courses in music theory: they would come to understand point and counterpoint, harmony, and all the things that make music work in the abstract. In the third year, they might begin to study orchestration. Then—if they were still there in the fourth year—we might ask them to play some scales on a real violin. And that's it; then they would graduate.

Now, if we taught music that way, there wouldn't be very many musicians. What kind of a real musician would tolerate this? They would drop out. For real musicians, making music is like breathing oxygen; they have to do it every day. Deep down, everyone knows that you develop the ability to make music by experience, not by reading books. As a result, at music conservatories, there's a recital at the end of every semester. No matter what stage you are in your career, you learn to stand up in front of a group and play, because that experience changes who you are.

I believe engineering is a form of performing art. It is not a routine where every problem has a unique answer. There are lots of different answers and there is a lot of room for creativity. Engineering has an audience, too. You have to learn to listen to the audience. We need to change the way we teach engineering to bring out its inherent creativity.

Let's look at another difference in the education of musicians and engineers. We teach engineering as a solitary discipline—it's done primarily sitting alone, doing homework problems in your room, taking an exam, making sure you don't talk to your neighbors. All of this is so artificial. If you taught music that way, you would make a recording in a room with a tape recorder and submit that for your final—you would never play for a live audience; you would never practice as part of a group.

By contrast, all really important music is done in a group. A string quartet can play together for decades, and they can play the same piece for decades. As they do, they get deeper and deeper into the nuances of what the artist is trying to say. It creates a type of teamwork that allows them to complete each other's sentences, so to speak, teamwork that is beyond the notes of the score. It's about the feelings and the music underneath the score; that's what has to come out. I think that if you look at the development of the Apple iPhone, you'll find that it's really that kind of art; it's really like jazz music.

We don't teach this way of thinking in engineering, the kind of thinking that goes beyond the technical problem to the process of deep, dynamic collaboration. Innovation, in particular, involves a really robust ability to improvise. Of course, jazz musicians know how to play scales and they can read music, just like engineers need to be able to do calculus and understand physics. But jazz music uses a different part of your brain. It's a completely different kind of skill that you can only learn live, in a group where there's a give and take.

We need to strive for that kind of thinking, so that the same portions of your brain light up when you're practicing science and engineering that light up for musicians when they're jamming. We need to develop an educational pedagogy that produces people who do that like breathing.

JE: I think we've all known people who have that character, but very few in the engineering world. You've also spoken of the importance of doing engineering in service of higher goals—not just problem solving, but addressing large, important issues. Can you talk about that?

RM: Absolutely. Let me start with some history. The National Academy of Engineering put together a list of the 20 greatest achievements in engineering and technology in the 20th century. It's a fascinating book. There are things we all know: electrification, clean drinking water, the inventions of the automobile, the airplane, the radio, the television, the Internet, space travel. It's an impressive record of progress.

But the issues we will confront in the 21st century are completely different in kind. The world now is challenged by complexity. At the root of the challenges in this century will be a remarkable growth in population. Today the world's population is about seven billion, and we're expecting it to be somewhere around nine billion by the middle of the century. In all of recorded human history, until about the beginning of the 19th century, there were no more than one billion people on the planet. We are in the midst of an amazing growth in population.

As we continue to increase in population, very serious questions arise in many domains: sustainability of the planet; security, as the competition for resources increases; global health, especially since a whole new level of pandemics is possible because of globalization. Everything we're going to face in the 21st century seems to be about some threat. Complicating this is a continuing expectation that every generation should have a life that is at least as good, and hopefully better, than the life of the previous generation. That's going to be unsustainable. If we continue with business as usual, it isn't going to work out.

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These problems are marked with complexity requiring a level of systems thinking that is unprecedented. All of our progress has created new challenges. Think of the airplane. Its basic job is to fly you from point A to point B, but that has consequences that we didn't anticipate at the beginning. Planes have an effect on the ozone layer, for example, that wasn't on the radar screen when people were first designing the airplane. They also have an effect on disease transmission, because they enable people to move very easily. Planes can even create a new tool for terrorists, as we've seen.

This is what I mean by complexity: you pull on a problem at one point, and another problem pops up in a completely different location. If you look at sustainability issues, they're amazing; they transcend time zones, they transcend political boundaries, and they certainly transcend disciplines. We need to produce people who think in a new way to deal effectively with these challenges.

The new challenge is educating engineers, not for greater technical depth, but for being able to see the whole picture, so that they can recognize connections between problems that seem separate. Young people are essentially wet cement; when they're young, you can help them make those connections. If you educate them too narrowly for too long, their attitude and behavior are hardened into real concrete, and then you have a heck of a time getting them to even recognize that there is a problem on the other side. Instead we spend the whole time arguing about who made the mistake, rather than solving it.

By the way, this whole conversation about grand challenges, about sustainability, about complexity, and about the human condition, is way more interesting to young people today than the formulas for stress and strain for designing a bridge.

I would say that between half and three-quarters of the young people in high school are naturally drawn to some kind of activity that allows them to feel like they are making a contribution in some way to solving these problems. If you redefine engineering, as we have at Olin, as envisioning what's never been and doing whatever it takes to make it happen, and you focus on the grand challenges of today, you would not believe the number of students who are interested in talking to you.

This has a very practical consequence for increasing the pool of high school students who have an interest in STEM (science, technology, engineering, and math). You don't tell them that it's about STEM; you tell them it's about solving important problems, and they discover later that it involves science and technology.

This is what medicine has done for a zillion years. They say, look, are you concerned about making the blind see and the lame walk? If you are, come and join us in the school of medicine. After you get there, you discover you have to learn biochemistry, which is not really very fun.

JE: I think that's a real insight. You've already demonstrated it can broaden the pool of prospective engineers because you've attracted more women to Olin than is typical for an engineering program.

RM: That's right, and I think that women respond much more strongly to this purpose-driven career, to the opportunity for making a difference in a person's life, than men do. There may be some biological reason for that, I don't know, but it's true. If you look at where women position themselves in engineering programs, they're disproportionately located in medicine or in environmental engineering, where they deal with people on a large scale, or in industrial engineering where they deal with the management of people. They're less populated in areas like mechanical engineering or electrical engineering, where the focus is really about devices.

So this approach seems to work. One of my goals is to make it the norm for engineering education, and not just at Olin. Tom Katsouleas [the Dean of Engineering at Duke] and Yannis Yortsos [the Dean of Engineering at USC] and I have been involved with the National Academy of Engineering in trying to spread the word. We've helped sponsor two national and one international summits on the grand challenges of the 21st century to try and get the conversation going on a large scale. The next one of these will be in Beijing in 2015. It turns out that the issues with engineering education are not just an American phenomenon; the kids in Europe and the kids in Asia and Latin America are just as concerned about the planet as we are.

JE: This is great. Given the changes you are trying to make, how does Olin College define success? How might a chief technology officer or director of research or engineering who was a graduate of Olin be different from a more traditionally educated engineer? What would you expect or hope to see as your students progress through their careers?

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RM: That's a good question. The whole purpose of Olin is to change the way we think about education and, as a result, to create innovators. What does that look like in the real world? For one thing, I hope that we instill in our students a sense of obligation that, after having been taught in this way, they should become a force for innovation and change wherever they go. About two-thirds of them have moved into an engineering profession somewhere, but a third of them go to other places. I hope that they will think differently wherever they are.

What do I mean by this? They'll be more open-minded. They'll imagine that everything they touch has an expiration date, that the rules for the company they work for should change over time. Our graduates should value fresh ideas. They should certainly understand teamwork, and it should be evident in their working lives. They will understand, as leaders, that creativity has less to do with your DNA than it does with your environment, and that they can control the environment to make people more creative.

They will seek to cause the collisions inside a company between people with different points of view. I expect them to put together groups of people who don't know each other and who have very different backgrounds and world views and focus them on a common problem worthy of their time and energy. And then give them a deadline, tell them that they need something practical, and then get out of the way.

What happens when you do this is that you create a lot of heat and a lot of sparks; you surface differences of opinion, and you get ideas that you wouldn't get if you had people with similar backgrounds thinking about the same thing. They would just shrug their shoulders and say that it can't be done. They wouldn't ask the questions that force you back to semantics. These are the methods that I hope will be second nature to graduates from Olin.

By the way, we have some data on what's happening to the graduates of Olin, and so far we're quite pleased with the results. Of course, our oldest graduate is just turning 30, so they're quite young, but one of the things we have found is that they are in really great demand in the corporate world. Most of the graduating class in May of this year—all who really wanted to—were admitted to graduate school or placed in a corporation by the time they graduated. The average starting salary for that class, somewhat unexpectedly, was more than $20,000 above the average starting salary for engineers nationally.

Corporations really like these kids. We've heard from corporate recruiters that they enter the company as if they already had several years of experience. And the reason, obviously, is that our project-oriented, design-oriented curriculum gives them a ton of experience. Before someone graduates from Olin, they may have been on 20 different team-based projects. If you graduate from a school like Olin, your resume looks a lot different than it would if you graduated from one of the more traditional schools, like those that I went to. It includes the specific projects that you worked on and the things that you built.

So, for instance, courses in robotics are very popular at Olin. A year ago we had a group of Olin students who competed in an international competition in robotic sailing, the SailBot competition. (I'd never heard of it either.) The teams make an autonomous robot that controls a sailboat in the ocean. It goes out three miles, goes around a buoy, and follows a prescribed course. Our kids decided they were going to compete in this contest even though they couldn't spell the word sailboat yet, and they did. They went to Vancouver, they competed, and they got second place in the international competition last year.

So, on their resumes, they can actually show you a picture of what they built. They can tell you how it competed. They can discuss how they worked on teams.

The other part of the graduate profile, which was a little bit surprising, is that about 40 percent of our graduates to date have gone back to graduate school, most of them in science and engineering. A significant percentage of them go to the Harvard business school each year. We have a string of students, of course, that are going to medical school, which is not uncommon for selective engineering schools. And 24 percent of those who go back to graduate school are going to either Harvard, Stanford, or MIT.

If you normalize for the total number of graduates in the class, Olin is one of the top producers of students who win National Science Foundation graduate research fellowships. Four times since 2006, we have been one of the top producers of Fulbright Scholars. This year we had a Gates Cambridge Scholar—but not to study engineering. She went to Cambridge to study European literature and history.

So Olin has produced an interesting group of people, and I don't know actually what future graduates are going to do. We had a graduate from the class of 2006 who is a successful film producer in southern California. We have another who's an actress in Boston and New York. They're all over the map. So how would we measure success? I think the most authentic way to measure it is to ask our alumni—after they've been out for 10 years—whether the education that they got at Olin opened doors for them in the areas that they wanted to open them, and whether it made a difference in their lives. We view our mission as educating the next generation of innovators for the country. That's a higher calling, I think, than teaching them more technology.

JE: There are a lot of engineers out there—young engineers—who were educated in the more traditional way. What advice do you give to young engineers about their careers and their lives?

RM: Well, I was trained in a very traditional way, too. Most of the faculty members we have at Olin were, as well. I think there will always be a real need for engineers who have an applied science background. But I tell our own graduates, and this applies to other students, as well, that they need to act in accordance with the reality that the world is changing. You are not educated when you leave college; you're just beginning your education. I'm old enough to remember when physics only had a few particles: electrons, protons, and neutrons—oh, and also leptons, mesons, and baryons—and that was it. We went through a stage where we had zillions of these things, and now we don't even talk about particles; we have strings instead. So the world changes, and if you don't keep up with it, you won't have a career. You shouldn't let your bachelor's degree define who you are.

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My recommendation? Every six months, for the rest of your life, read a book. Read a nonfiction book in an area outside of engineering. And once a year you should read a book by an author with whom you violently disagree, because it's becoming very hard in this world to find people who have heard opinions that are not the ones that they started with.

We engineers, through the Internet, have figured out a way to make it possible for a person to go through life without ever hearing the opinions of anybody he doesn't already agree with. We've lost something there. If you're going to move forward in your career, you need to find ways to get a broader view.

The last point I would like to make is that education is about making a positive difference in the world. It's about purpose. Some people—some lucky people—will find that purpose in their careers. Maybe if you're a physician in an emergency room in the pediatrics ward and you save lives every day, you will find deep meaning in your work. But most of us aren't going to have that kind of a career.

You still have a deep personal need to find a way to make a positive difference in the lives of others, even if your contribution has nothing to do with engineering. You have talents and skills that nobody else has. Be involved in the school board in your local district. Help people build new playgrounds in the community. Think about ways that you can contribute to policy debates; so many of the laws we're going to have to make in the next few years have technology and science at the heart of them, and yet only about a dozen members of congress have a background in engineering. They need your voice. You can make a difference.