A *D&T* Roundtable

What's Next for Microelectronics Education?

D&T: Most of us realize the education system must change to more closely align with industry needs. But is there consensus on what industry wants? Who are they hiring and why?

Feinsmith: Most of the companies in the Silicon Valley, including ours, are hiring at the master's level. Grads at that level bring a good combination of practicality and knowledge. Five years ago a bachelor's level was good enough, but with today's specializations, grads at that level no longer have the skill sets we're looking for. And PhDs tend to be very specific and expensive.

With funding for services like MOSIS shrinking and industry demanding more diverse skills, the microelectronics education infrastructure—indeed that of engineering education in general—is under intense pressure to change. But change without organization and a concrete implementation plan could be disastrous. Participants from academia, government, and industry met to discuss the best way for change to take place and just what is required to make it happen.

D&T thanks participants James Aylor (University of Virginia), Joseph Cavallaro (Rice University), Bernard Courtois (CMP), Jason Feinsmith (Xilinx), Robert Hodson (Christopher Newport University), John Hines (US Air Force Wright Laboratories), Cesar Pina, (the MOSIS Service), and Michael Smith (University of Hawaii). We also thank moderator Don Bouldin (University of Tennessee), *D&T* associate editor Kaushik Roy (Purdue) who organized the event, and the Microelectronic Systems Education Conference, which sponsored it.

Aylor: Companies may prefer master's students, but they seem to be hiring anyone they can get their hands on. We're finding it hard to keep good students—master's students especially—in the graduate program. If students have some HDL experience or have done some IC design with commercial CAD tools, they can pretty much pick where they want to be.

Hodson: Industry wants students with both a multidisciplinary background and good communication skills.

D&T: We're already overwhelmed with material to cover in four years. How realistic is it to provide this multidisciplined grad? How do we do it?

Courtois: It will be hard. Technology is too dynamic, and the program isn't built to handle rapid change. Take the transition to the deep-submicron process. How can we get our hands on everything we need to educate students about it? Frequency is going to shoot up, which means you're going to have more analog behavior. I don't see a lot of resources to support that. In Europe, we lack not only tools, but knowledgeable staff to teach these concepts. The power density will also increase with deep submicron. This means our staff must be able to deal with multidisciplinary facets like thermal, electrical, mechanical, and cooling. Cooling is

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becoming much more important. We're looking at increases to 50 or 60 watts.

Feinsmith: The curriculum needs restructuring. Industry wants grads who know how to do system-level design, say, 100,000 gates. They've got to know not just schematics, but design languages like VHDL and Verilog. Only 25 percent of all designs are currently done in VHDL, but in three to four years—when it counts—that's likely to be more like 60 percent or more.

D&T: So what specifically is wrong with the curriculum and what are the challenges associated with changing it?

Cavallaro: It still reflects the 1980s generation design— when we all learned VLSI and custom chips. Industry is now worried about higher-level issues.

Hines: People want to put complex systems on a chip, so we have to go beyond a single discipline like VLSI or logic design. But we learned, and it's still true, that change doesn't happen in zero time. Universities must very quickly put into place mechanisms and curricula to address the problems, and they've got to do it collaboratively. How do we get the mechanical engineers to work with the electrical engineers and computer scientists with the thermal people to do the analog design?

Cavallaro: This multidisciplinary approach is even more important as we transition from VLSI to microelectromechanical systems. But it might be too early to worry about MEMS. The tools aren't there yet.

Courtois: We already have a VLSI-MEMS split even without the tools. The tools may not be completely there, but they're close, and we've been able to move some microelectronics people to design MEMS. We're beginning to overcome the split using CAD.

Pina: What about rapid prototyping skills? The designs that come from NSF-sponsored VLSI classes are about 70 percent analog, which you can't really simulate.

Aylor: Achieving a multidisciplined graduate is not just a microelectronics problem. I'm sure chemical engineers worry about what they're going to do in electronics. It's really a school of engineering problem. People are trying to break down the stovepipes of chemical, electrical, and mechanical. The problem I see is how to define a core curriculum. Until we know exactly what it is we have to teach in four years, we can't possibly expect to organize anything across disciplines.

Hines: Engineers come out at a master's level specialized in some way, which is why industry hires them. We need to figure out how to provide the balance of training for engineers within the current ground rules and guidelines for the basic 120 to 124 credit hour curriculum and provide additional materials to integrate these engineers across disciplines. We should work with the ABET community to see how we can fit the right pieces and snippets of material into the existing structure.

D&T: Ours is one of the most rapidly changing technologies at the moment, so industry is hiring our guys right at the bachelor's level. I almost wish they wouldn't because they're not ready yet. If we could get everyone, especially students, to think along the lines of six years, we could be as broad and general in the four years as we'd like and then spend the next two being specialized. Students could pick up a lit-

tle practical experience during their summers or on their master's project. But of course that's not realistic.

Feinsmith: A project-oriented course can teach a lot of practical stuff about system-level design, like logic, memory, and thermal design. You can also do testing and simulation all the way through. Students can now get industry-standard software packages. You can now do rapid prototyping to give students hands-on experience. Having more students with a PC opens a lot of doors.

Pina: There's a place for both programmable logic and VLSI design. In analog design, for example, you can't always use programmable logic. If you're doing something with PLDs, you need VLSI design. I also believe students need fundamental design knowledge like the physics of the transistor, which you don't get from PLDs. If we focus on very high level concepts without teaching what makes the circuit go, we will produce students with only half the picture. They could make some serious errors.

Courtois: When you say "microsystem," I envision a really big system. In Europe, we have set up a new initiative to provide designers with very high level design cores like ARM cores or microcontroller cores, and cache memories so that they can design systems.

Smith: As I see it, a core curriculum split is probably inevitable because the students don't use everything. Some go to work for a company like Cisco to do routing or system-level design. They really don't need to know how to lay out a transistor. Others go to companies like Applied Materials, where understanding transistor-level logic is crucial. So I see an ASICs testing course becoming a kind of ASICs/PLDs course. The complexities of what we must teach dictate that we can't teach everything in the time we're given. It makes sense to have a dual path through core courses.

Hodson: It depends on how many layers of abstraction you want. Maybe people don't always need to look down to the very bottom. Maybe some people just need to know VHDL.

Aylor: It may just be a question of repackaging. Some universities are trying courses like "Chemistry of Materials," where they look at the atomic levels of materials and then at various types of materials and then at properties of materials and so on. We could use that model in circuits courses. We may want to rethink standard second- and third-year circuits courses and get some of the fabrication stuff into the circuits courses, and not talk about things like op amps and standard-package op amps. Facultywise, it may mean we coteach courses in modules. We've done this with thermodynamics. We wanted the

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heat-transfer stuff, but not the rest of it, so we just deleted what we didn't need and used the snippets we found useful.

D&T: How would we organize ourselves to share tutorials and teaching modules? What about incentives?

Hines: The RASSP program's aim was to incorporate course modules and laboratories into existing structures as painlessly as possible. The laboratories could be integrated into the existing curricula as one- to three-hour segments, and each had supporting material that was ready to incorporate into the existing curriculum. The mechanism was successful as a noninvasive change agent, and we could probably use it to broaden the curricula base to meet our needs.

Smith: Maybe the repackaging Jim suggested is more a "repurposing." I proposed this at the last VLSI education conference, and it hasn't really happened. I tried to do some of that in my latest book on ASICs, but there's too much to cover. You mentioned op amps. That's a painful example. We tried to delete some of the op amp material at my school so that we could fit in some fabrication and basics needed for VLSI design. I could not convince the rest of the faculty that we should not be teaching op amp fundamentals.

Hodson: It's not as bad in my school, perhaps because it's smaller. Faculty already teach across many courses, so they tend not to lock into a particular one. By our insisting on cross-training the faculty, people can move between courses and drop and add material as needed. Also, although certain areas of electronics have been static, others are very much dynamic. I typically introduce one-third new material into senior-level courses each year. So if I have to change my curriculum, it's no big deal. Our faculty is younger than in most institutions, so that may also make a difference.

Smith:

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D&T: What have you deleted specifically?

Hodson: We don't teach assembly language anymore in our computer engineering curriculum. It's become obsolete in my opinion. That raises the larger question of who gets to decide what an institution teaches. You can't teach everything to every student—analog, VLSI design, FPGAs, digital VLSI design. So maybe you focus on what's best for your institution's programs. Our school does a pretty good job in systems microelectronics, but not in analog VLSI design. But the point is that we don't care if we don't teach analog VLSI design.

D&T: What would you suggest as a first step for larger institutions that are not already oriented toward multidisciplinary faculty or curricula?

Hodson: I'd look first at a single department. It might have several tracks. You could focus those tracks and then work at combining them. The administration has to step in sometimes and cross into departmental boundaries and say, "You have to create some logic courses that involve multiple departments." When the administration says you have to do something, it gets done.

Smith: ABET doesn't give us the luxury to say, "Our school

Getting involved

For those who would like more information on how to be part of the movement to change the curricula and infrastructure or are just looking for resources, these URLs are a good place to start:

Accreditation Board for Engineering and Technology. Monitors, evaluates, and certifies the quality of engineering technology and related education in US colleges and universities. Initiates and sponsors studies, conferences, and seminars and cosponsors projects.—http://www.abet.org

CMP. The service part of the TIMA-CMP Laboratory, CMP is a broker in integrated circuits and systems fabrication for various technologies that involve prototyping and low-cost production.—http://www.tima-cmp.imag.fr

Microelectronic Systems News. Formerly the MOSIS Users' Group Newsletter, includes items of interest—conferences, course listings, files—to those designing ICs for prototyping via MOSIS, as well as those designing, prototyping, and producing microelectronic systems. Broadcast quarterly at no charge.—http://microsys6.engr.utk.edu/ece/msn

The MOSIS Service. Low-cost prototyping and small volume production service for custom and semicustom VLSI circuit development.—http://www.mosis.org

National Science Foundation. Invests more than $3.3 billion per year in nearly 20,000 research and education projects. Site includes pointers to funding opportunities, contract information, and awards.—http://www.nsf.gov

The Rapid Prototyping of Application-Specific Signal Processors Program. A DARPA tri-service program to improve the design process for complex digital systems, particularly embedded digital signal processors.—http://web-ext2.darpa.mil/ETO/RASSP/index.html

Semiconductor Industry Association. Tasked with coordinating industry activities to address common concerns and develop unified responses to challenges and opportunities facing the semiconductor industry. Affiliate organizations include the Semiconductor Research Corporation and Sematech.—http://www.semichips.org

US Defense Advanced Research Projects Agency. Central research and development organization for the US Department of Defense. Manages and directs selected basic and applied R&D projects for the DoD and pursues research and technology where "risk and payoff are both very high and success may provide dramatic advances for traditional military roles and missions and dual-use applications."—http://www.darpa.mil

Xilinx University Program. Chartered with enabling engineering schools worldwide to integrate Xilinx programmable logic in curricula and research. Provides donations, discounts, course examples, student edition software, and training.—http://www.xilinx.com/programs/univ.htm

doesn't do analog IC design. We don't have the resources or the staff, there's too much other stuff that we do." ABET, at least currently, insists that every school try to cover everything. It is a tremendous waste of time. All these professors are basically concocting the same course in their own way all over the country. How do you get around that?

Hodson: ABET doesn't say that everybody has to teach analog design. Maybe there are some core Circuits I and II classes, but if your institution elects to specialize in ASICs, analog, or VLSI design—that's your choice. ABET prescribes some core courses, but you're allowed more flexibility than you think. And ABET 2000 is going to be even more flexible. As long as you can prove you're producing engineers who are valuable to the workplace, you'll keep your flexibility and maybe get more. In fact, I just came back from an ABET meeting a few weeks ago. People have been getting the clear message that there's too much prescription, that schools need more flexibility.

Smith: But if the core courses take four years, where does specialization come in?

Hodson: A final year's worth of design projects, a two-semester sequence, will let you integrate disciplines and really polish the student's skills into something productive to the engineering community. If you want to get more, you'll have to do it at the master's level. You have to constantly look at what's realistic. A six-year program isn't going to happen.

D&T: Let's move from the program to the infrastructure to support change. The challenges there are probably just as great if not greater. Funding for things like a MOSIS fabrication facility is shrinking. If I didn't have the research program, I'd never be able to keep the infrastructure I use for the undergraduate level.

Smith: Collaboration with industry is imperative. We said we have the largest industry in the world right now. There's got to be tremendous motivation for people in industry to work with us. But it's our responsibility as universities to be a little more united in seeking collaboration. Unfortunately, we're going to end up being forced to do it.

Feinsmith: I strongly agree. We've had a university program for 12 years or so, and it's expanding. On a scale of one to five, with five being the highest degree of industry-university collaboration, the US, is probably a three, maybe even a two and a half. Europe is probably a three and a half. In some Southeast Asia countries, collaboration is a five, with universities clearly leading industry. The US would benefit tremendously from level-five collaboration. Students are look-

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ing for projects beyond making a UART, and industry would save untold amounts on training. But to reap the benefits, there's got to be some infrastructure for communication. I see professors putting courses on the Web. It would be nice to have some catalog of courses at various schools.

D&T: How effectively are we exploiting the Internet as a resource? There are lots of individual hot spots, but can the Internet support something like a wide-scale collaboration? Can it hold down expenses?

Cavallaro: It's less a question of technology and more one of motivation. How do we keep the community involved and interested in hardware design issues?

Hines: The government is facing a big reduction in R&D funding to universities. To compensate for that, we are starting cooperative research agreements and research programs. These programs don't cost a lot because the government just adds focus and structure in certain areas. We're also attempting to put together a Web-based collaborative engineering environment to solve some communication and management problems. It's a bit too early to tell where this is going. We have lots of technical issues to work out, but if we can get some mechanism like this for working collaboratively in a virtual space, we could make a lot of progress on infrastructure problems inexpensively and hopefully relatively painlessly.

Smith: Jason, what must we professors do to organize ourselves and present a proposal that industry would be prepared to invest in?

Feinsmith: That depends on whether you look at collaboration with an individual company or an industry. If you ask for help to put together a course, I can tell you to pull the

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Feinsmith:

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donation form off the Web, and we'll look at your request. But asking for help from multiple computing companies makes things more complicated. There has to be some formal agreement from universities about what they need, and there has to be some kind of payback to industry. The payback has to be enough to where each industry player can say, "This makes sense to my company."

D&T: What are industry's motivations for collaboration?

Feinsmith: First—and this one is purely selfish—companies want future engineers to further the use of their technology, which is likely to happen if they've been trained with it. Second, a lot of research turns into commercial products eventually. Third, students come already trained in particular areas, which saves the costs of ramping up and ineffective designs. The last reason is touchy-feely but very relevant. Companies are basically interested in doing good things for the community. On another point, an important first step is to agree on a set of companies to target.

Aylor: I wonder if we could solicit the support of the SRC companies so that more money goes directly to education. Education is part of their needs. The things we've talked about doing don't involve only IC fabrication or x-ray lithography. We want to support multidisciplinary design, so we might say to the board of the SRC Design Sciences group, for example, "Let's talk about how money is being spent at SRC. Will it ever be possible to channel more of that money to education directives or initiatives?"

Cavallaro: I was at NSF this last year when a lot of these changes began to occur, and some in the government feel that this industry has done quite well. MOSIS was started at a rather risky time, and there was definitely a need to help

as much as possible. Now things are a little more stable. The technologies, companies, and curricula are there. And like most other NSF-funded programs, after a certain period, universities and industry are expected to keep things going on their own. The government encourages taking limited government dollars and moving to the next new product area to invest in the next new, risky technology area, so the best approach is to put in transition funding in the current year for the upcoming year. But not so much that the year after that becomes difficult. We've talked with the Semiconductor Industry Association and the Semiconductor Research Corporation to try to do something within the next year so that the effects will be minimal.

Hines: We're looking at a trillion-plus dollar industry by 2000, so it seems logical that industry should pick up some of these things. Regarding SRC, much depends on how you define research and education, which is something the Design Science Technical Activities Board can do. If we work smartly, we can accomplish both research and education objectives without adding too much additional funding.

Cavallaro: When it became clear that some funding was decreasing, I talked with SRC's vice president of research. He was concerned because he has used MOSIS while at NC State. Unfortunately, my timing wasn't great because DARPA is also terminating a design program. The SIA is struggling to make up the shortfall from another DARPA research program. Both the SIA and SRC are concerned that government funding is reducing at a time when industry is doing well. They don't feel they have the resources to take up the slack, that it would take a lot of work to get enough companies to respond. They need feedback from their member companies to make any policy changes. There's just no cushion for them to redirect funds at this point.

D&T: Did you go beyond SRC and SIA?

Cavallaro: Yes, the Semiconductor Equipment Manufacturers Institute might be interested, but their companies are suppliers, so they're much more diffuse. It's not quite as dramatic as an Intel doing a processor. SEMI finds it difficult to recruit well-trained VLSI designers because those folks would rather work for a design firm. SEMI wants to be sure that whatever it gave would help channel more people to the industries that make equipment. The Electronic Industries Association is interested in some of the systems issues, but it does a broader range of large components. There's also the American Electronics Association and the President's Semiconductor Technology Council, but the SRC and SIA are the most appropriate organizations for VLSI education.

D&T: So let's assume we have zero outside support, except maybe volunteers. What happens now? What can we accomplish? We talked about maybe having some kind of peer review for lab tutorials and some kind of module sharing.

Smith: The first thing we have to do, outside support or not, is get organized. That's going to be a tremendous challenge in itself. It's the herd of cats syndrome. You can't get cats or professors to work together. Traditionally, professors have followed Stanford's steeples of excellence principle, proposed by Terman: Every professor shall be his own steeple of excellence, and therefore there's really no need to talk to the other steeples. Collaboration is fighting against that philosophy. Maybe we can get a small core group within a discipline to get a dialog going through e-mail, and it will expand.

Feinsmith: Yes, there's definitely got to be a culture change. We'll have to go to labs to access specialized equipment, which we haven't had to do because we've had MOSIS. We might look at other specialties to see how they've addressed these kinds of problems.

Smith: Maybe we should pick a project that will force people to collaborate.

Hines: I agree that we need organization. The academic community needs to sit down and define some well-structured projects and do them. It costs nothing and can be done within the existing framework.

Feinsmith: But change doesn't just happen. Usually you need both a push and a pull. Right now things are fairly peaceful. The economy's going well. There's no Cold War. The push has got to come from leaders who are brave enough to say this is what we're doing and who wants to be part of it?

Cavallaro:

"A multidisciplinary approach is even more important as we transition from VLSI to microelectro-mechanical systems."

Cavallaro: It's also vital to agree on some mechanism to disseminate information. We might distribute material like teaching modules through a publisher-based system.

Feinsmith: One way you can cause change is to publish articles in high-circulation publications. Or you can get big keynote speakers to make controversial statements.

Smith: Maybe we need to get the word out. Funding hasn't exactly diminished gradually. In some cases, organizations have gone fairly quickly from more money than they knew what to do with to the point where they don't know where the next dollar is coming from. I don't think a lot of people outside the community realize that.

Feinsmith: I agree we need to bring the problem to a higher level; we might even be able to change funding policy. Maybe we could coordinate with sister societies like the ACM to survey the courses and how people plan to react and update in the next couple years. If we could start some communitywide mechanism, we might see some change.

D&T: I agree we should be doing everything possible electronically to evolve a core group. We should also try to have a conference every year.

Aylor: But first we've got to define some objectives. If the objective is to do X, how do we do that? Is it Web stuff? Is it meeting at DAC?

Pina: At one time or another, 190 universities used MOSIS. You want to organize 190 different universities and professors?

Aylor: You don't need all of them, just a few to form a core

Hines:

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group. Remember how we started the VLSI effort five years ago? If you get the core group doing the basic stuff, the rest of the group will come forward.

Smith: Look at the way things were before MOSIS. Everyone whined that they wanted their own curriculum and no one could do that for them. But when MOSIS came along, everybody followed lockstep in teaching the offered curriculum. Why? Because it was there, packaged and ready. They loved it. It was free, and they used it.

Aylor: If we can get people to recognize that we have the support for HDL entry and FPGA prototyping from FPGA and EDA companies, we could start talking about how we could share resources like software to make that support more widespread and less expensive.

Cavallaro: Maintenance fees in the CAD industry are almost on the order of the MOSIS budget for a medium-size university. Small universities still use public-domain VLSI CAD tools like Magic because they really can't afford anything else. To help them, maybe we could do more with the CAD industry to develop a standard package. I know CAD companies are smaller and have fewer resources than semiconductor companies, but the semiconductor industry uses commercial CAD tools. The CAD companies would benefit a great deal from having more students who can use their tools.

Aylor: It's not that people aren't interested in the material and how to deliver it. We had educator's seminars that drew capacity crowds. Maybe we could evolve a core group from efforts like that and try to define what's needed in system-level design or hardware-software codesign. Then when we get these materials, we could provide opportunities for faculty to come and see how to present them.

Hines: Most universities tell us they would like to have totally free tools and no infrastructure costs, so we're trying to repackage some of the advanced university tools we've funded and make them available over a Web environment. We could offer things like free VHDL simulators. We haven't incurred any new costs. We've just repackaged stuff.

D&T: I agree that we have plenty of material out there. We need a way to point people to it and get them to use it. We could start recruiting a core group from the people who attended this conference. Out of the hundred people who came, surely we could get fifteen to start looking into things like a Web site. If the roundtable accomplishes that, it will be time well spent. ◁D&T▷

About the participants

Don Bouldin, our moderator, is a professor of electrical engineering at the University of Tennessee, Knoxville, and was general chair of the 1997 Microelectronics Systems Education Conference.

James H. Aylor is chair of electrical engineering at the University of Virginia. He has been involved in VLSI and computer design engineering for more than 15 years.

Joseph R. Cavallaro is an associate professor of electrical and computer engineering at Rice University. He was director of the National Science Foundation's Prototyping Tools and Methodology Program.

Bernard Courtois is the director of CMP, a service that performs chip prototyping.

Jason Feinsmith manages Xilinx's University Program,

which is chartered with helping nearly 1,000 colleges worldwide incorporate programmable logic technology into their curricula and research.

John Hines is technical director for the System Concepts and Simulation Division of the US Air Force Research Laboratory Avionics Directorate.

Robert Hodson, the director of computer engineering at Christopher Newport University, has been involved in design and instruction of microelectronic systems for 15 years.

Cesar Pina, the director of the MOSIS Service, has been involved in microelectronic design and fabrication since 1958.

Michael Smith divides his time between teaching at the University of Hawaii and consulting on ASIC design in Palo Alto, California.