

## **Delivery of a common microelectronics technology curriculum at several degree levels**

**John Robertson, Lakshmi Munukutla and Richard Newman**  
**College of Technology and Applied Sciences**  
**Arizona State University East**  
**Mesa, Arizona, 85212**

### Abstract

In an integrated circuit (IC) manufacturing company, the workforce has many skill and education levels but everyone has to work together and communicate effectively on complex technology issues. The microelectronics technology curriculum at ASU has therefore taken on the same challenge - to present a common set of device and process concepts to classes at different educational levels in an integrated teaching factory environment.

This experiment in education delivery has the familiar broad range of parameters – students from diverse backgrounds, several degree levels and the gamut of content treatments that constitute technology. We present conclusions from many of the delivery combinations. Our experience is that we can indeed manage common concepts at many degree levels in an integrated environment. The biggest obstacles are concerned with student communication skills, their management of ambiguity, numerical fluency and troubleshooting.

### 1. Challenges

The microelectronics industry has grown to become a major force in the economy. For 30 years, revenues have increased at an average of 14% annually and semiconductor products have delivered productivity improvements at twice that rate. Success, however, brings its own new challenges and some of the most formidable are in the provision of education services to this sector.

The driver behind revenue growth is a technology solution that delivers a new operational “node” – with 4 times the number of transistors on a chip – every 2-3 years. This is Moore’s law<sup>1</sup> and we see the results in ubiquitous computing, both stand-alone and embedded. However, fast compound growth quickly transforms any environment, so the first challenge is to recognize that we are not preparing students for past career patterns

and skills. It is tempting to wait to see what demands arise but the historical evidence is not comforting for companies (or countries) that fall behind.

Fortunately, the prospective evolution of the semiconductor industry is fully documented in the International Technology Roadmap for Semiconductors (ITRS)<sup>2</sup>. This review has been steadily extended both in detail and scope and is now about the best estimate of what can be expected *through fast incremental progress* over the next 15 years. For our purposes, there are 2 critical features:

- The driver part of the industry is very capital-intensive. This means that continued business success depends on a relatively small number of people using increasingly sophisticated tools.
- The cycle time for evolution is very short, so everyone involved – including the providers of educational services - has to plan proactively and adapt quickly.

The capital features of the industry are illustrated in figure 1. A lithography tool is one of the more expensive examples and there may be 20-30 in a factory. A \$2B factory employs about 1000 people and the general skill level is rising steadily.

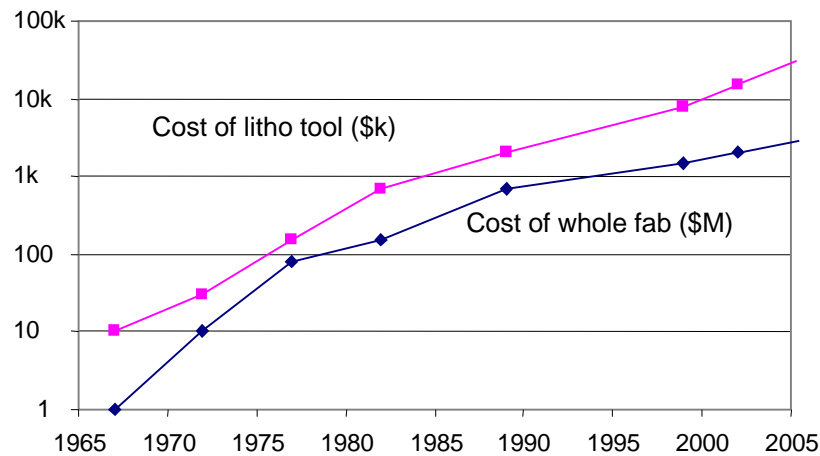


Figure 1

The implications from an educational perspective are:

- Investments on this scale require all-round technology business strength. Good ideas, designs, processes or occasional winning products are not enough. The organization must be world-class in every department and maintain that standing against escalating benchmarks. We are fortunate in having a number of such companies in Arizona.

- The scale of the investment is clearly beyond the scope of any academic organization. The traditional self-contained research – teaching interaction can therefore no longer provide the academic stimulus for change and relevance. The new stimulus is figure 1 and we have elected to partner with the industry to bridge the ever-increasing gap between university and industry technology capabilities.
- A \$12M tool is a formidable combination of hardware and software. However, it has to be designed, used and maintained by people who were educated for much less complex tasks. Our academic team has a role to raise the skills of the existing workforce. That experience also provides vital feedback that serves as our guideline for further curriculum development.

The ITRS<sup>2</sup> introduction timetable for new technology is shown in figure 2. Development takes about 2 years and as the production phase of one product starts, development of its successor (with 20-40% new technology) is initiated. It is a punishing schedule and one function of the industry-wide roadmap is to integrate the diverse efforts of many contributors. We have elected to use the roadmap to define the pace and direction of our curriculum development.

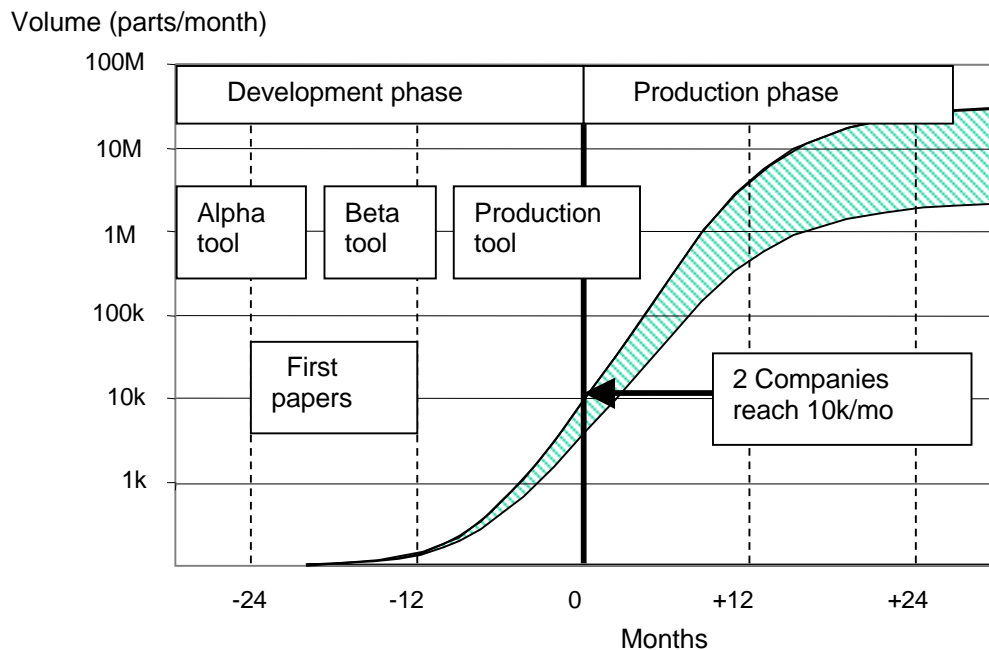


Figure 2

The simplest way to assimilate the challenge implied by this graph is to superimpose the timetable for development of an academic research program or even the approval process for curriculum change. A more constructive view is that the ITRS gives us the bigger picture so we can separate concepts and principles from their tactical implementation.

## 2. Parameters for curriculum development

The most significant external curriculum influences are implied in figures 1 and 2. The other major factor is local market conditions which help but also threaten to overwhelm a balanced response. In our case, Arizona has a wide range of semiconductor businesses - from materials and tool suppliers through major IC makers to product and systems companies. They provide us with a valuable source of experts, a very strong Industry Advisory Board (IAB) and of course, a steady supply of students at all levels.

The establishment of a new campus at ASU East has led to a new approach to technology education<sup>3</sup> with a new curriculum and a Teaching Factory for microelectronics. As a result, we have been able to use the local conditions to our advantage by adding the following operational parameters:

- Course materials are flexible enough to be readily adapted to teaching at many academic levels – MS, BS, BAS, AAS. The AAS stream is an important feeder to the Arizona universities as well as industry and we collaborate closely with local community colleges and the Maricopa Advanced Technology Education Center (MATEC)<sup>4</sup>. MATEC is an NSF-funded center that develops course modules and support materials for community college faculty throughout the country. The driver for a common educational language is that all graduates from will eventually work together in industry. Each has different skills to offer but there is also a common thread of understanding and communication that should be captured in the different degree curricula.
- Provision of realistic educational facilities is an ongoing boundary condition. Our approach has been to establish a Microelectronics Teaching Factory (MTF) that is about half way (on a log scale) between a billion dollar factory and a traditional university lab. The 15000 sq ft clean room has a wide range of 150 mm tools, mostly donated by the sponsoring companies. The MTF allows us to demonstrate process principles and clean-room operations in conditions that have the same “look and feel” as a semiconductor company. It is a broad community resource and is used for experimental work by university and community college students. We bridge the gap from the MTF to state-of-the-art industry practice with adjuncts and guest contributors from the local companies.
- We have taken on a challenge to define “Technology” as a distinct educational discipline in its own right. It goes well beyond the engineering of semiconductor devices to encompass many economic, managerial and marketing activities. The MTF provides a realistic environment to illustrate the total package for product definition and delivery as well as decision-making under uncertain conditions.
- None of the challenges or goals could be met without establishing a very clear customer-focused outlook to our provision of educational services. It is easily said but probably the most difficult behavior to implement.

### 3. Curriculum implementation

With the familiar constraints on budgets, faculty time and technical support, implementation of the new curriculum has been dictated mostly by expediency. The industry contribution has been vital – at a strategy level through the IAB and in the provision of expertise and resources for lab execution. The approach has been very pragmatic with no proprietary agendas; just deliver the product, learn from the experience and move on quickly to an improved version.

The most important – and simplest – structural change we made was to break all courses into 1-credit modules. Fortunately, microelectronics is a subject that is very structured. Although it spreads across many conventional educational disciplines, the technology scope can be easily broken down into about 30-40 topics. Examples are diffusion, chemical vapor deposition, lithography, etching, device parameter extraction and assembly. With one module each, this conveniently fits the coverage and depth needed for a typical BS-level treatment. About half the topics are completely new; the others are existing courses that are being incrementally adapted to feed the new courses.

We elected to start at the middle (BS) level and then selectively extend some topics to MS and AAS courses. In the latter case, we have focused on three levels of interaction. We support MATEC in their development of new course materials for community colleges. The faculty who deliver these courses have access to our BS programs for personal development. Finally, AAS students can do lab classes in the MTF. The classes are being jointly developed but are run by the community college faculty with support from the MTF professional staff. The shorthand guidelines for the different degree treatments are:

AAS	Explain what happens
BS	Add why it happens
MS	Add methodology to optimize

The MATEC courses provide a sound overview of the physical features of semiconductor processing tools and how they are used. Our BS program starts from the MATEC benchmark and adds device mechanisms, process and tool design and operational sensitivities. Optimization largely occurs in industry but the University MS-level programs provide the overview, methodology and common technology to link many independent (and proprietary) programs. In that sense, the MS program goals are closely aligned with those of a typical MBA program.

So far, we can report on experience with 18 credit-hours of new course materials. In 2002/3, another 18 new modules will be added to round out the preliminary phase of development. The classification of delivered courses (by module credit-hours for each delivery category) is:

A	B	C	D	E	F	G
Class with book	Class with web assist	Web with class assist	Web only	Class with web assist & lab demo	Lab with class assist	Lab with web assist
0	6	4	3	4	0	1

The delivery selection was largely determined by the location of information sources and the degree of explanation what was considered appropriate for the topic. The absence of any offering in the conventional category A was not deliberate but it does reflect that state-of-the-art descriptions exist largely on web sites and general information is spread across many books or in expensive compendiums<sup>5</sup>. Most effort has been devoted to web delivery in various formats. We have proved to our own satisfaction that we have no magic formula to avoid the high preparation effort by faculty. However, the benefits in more thorough course design and a platform for future adaptations are also very real and worthwhile. Web access for students is through a common My.ASU portal which gives access to Blackboard software. For the web-based courses, categories B and C represent levels of emphasis and both worked well from faculty and student perspectives. By comparison, full web delivery (D) was less satisfactory, mainly because the student body is very inhomogeneous in its experience and they regretted not having face to face dialog. We may be able to rely on future web-only courses for background revision and preparation but our experience points to more suitability for training than education.

Our experience with lab classes is being built up more slowly. By dividing the curriculum into 1-credit modules, we were able to start with classes that only needed short lab demonstrations. We are now in the process of extending to full clean room practical course modules where significant parts of a device are fabricated by the students. Progress is determined by the rate at which equipment is commissioned and safety training is rigorously established. With students from a diverse range of backgrounds, their range of incoming lab skills varies from zero to proficient. We have therefore adopted a competency based qualification process for all users. The standards that are the same as those in industry and use the same audit process for certification. In this we have the total support of our Industry Advisory Board.

As we planned the new curriculum, we naturally focused on new topics - the complex tools and processes associated with high technology operations. We fully expected to have to redefine the content of feeder courses and that is now happening. However, the close dialog with industry and our increased focus on learner-centered education has led to much more sharply articulated needs for communication, team-working and trouble-shooting skills. In a factory-like environment, data is never in short supply but it usually has intrinsic constraints and rarely points to an unambiguous conclusion. Few students are adequately prepared to handle that uncertainty either personally or with their fellows. It is an issue that vexes our industry partners and we have their strong support to extend the curriculum to give more prominence to the personal skills needed in the manufacturing environment.

#### 4. Conclusions

We have set up a process to develop a microelectronics curriculum that has good industry support and which addresses the pressing needs of the local community. The web delivery component has been productive but we have added 2 operational constraints based on our experience to date:

- Use web delivery only where it is proven effective – to give students a wide range of material that is relatively easily understood and where some sort of customization to personal interests and deficiencies can be made by each student. The serious dialog and lab components of instruction still need direct contact.
- Students need very systematic help on how to study using web tools and apply them in a technology context. We have to find more effective ways to link our preparatory courses in communications and trouble-shooting more closely to their applications context. This is a familiar debate with math teaching but for our technology requirements, it becomes more pervasive.

On the plus side, we have established a process for course delivery that combines effective treatment of the most complex semiconductor technology with more flexibility for both faculty and students. It can also be readily extended to distance learning with short concentrated sessions in the MTF. We shall test that paradigm over the next 2 years thorough our partnership with industry and with community college faculty.

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## Biographical information

### JOHN ROBERTSON

John Robertson is a professor in the Department of Electronic and Computer Technology at ASU's East campus in Mesa, Arizona. From 1993 to 2001, he held a number of senior R & D positions in Motorola's Semiconductor Products Sector. His earlier academic experience was as Lothian Professor of Microelectronics in Edinburgh University, UK where he managed a national research center and developed continuing interests in process control and the global economics of semiconductor technology.

### LAKSHMI V. MUNUKUTLA

Lakshmi Munukutla received her Ph.D. degree in Solid State Physics from Ohio University, Athens, Ohio and M.Sc and B.Sc degrees from Andhra University, India. L.V. Munukutla developed an interest in semiconductor device processing technology and characterization while she was working at Motorola Inc. She has been active in research and published several journal articles. She holds an Associate Dean position in the College of Technology and Applied Sciences at Arizona State University East.

### RICHARD L. NEWMAN

Richard L. Newman joined Arizona State University East (ASUE) in August of 2001 and currently serves as Director of Training Operations for the Microelectronics Teaching Factory. In this position Mr. Newman is responsible for the identification, development and delivery of education and training for the semiconductor manufacturing industry. Prior to joining Arizona State University, Richard served twenty years as a faculty member and administrator within the Division of Technology and Applied Sciences at Arizona Western College and the University of Arizona. He most recently held the position of Associate Director at the Maricopa Advanced Technology Education Center (MATEC). MATEC is a national center of excellence funded by the National Science Foundation (NSF) that focuses on workforce development for the semiconductor manufacturing industry.