AC 2008-1021: THE TECHNOLOGY WORLD IS CHANGING RAPIDLY - CAN HIGHER EDUCATION MATCH THE PACE?

John Robertson, Arizona State University

John Robertson is a Professor in the Electronic Systems Department at Arizona State University Polytechnic. He was formerly an executive with Motorola and now participates in many senior technical training programs with the JACMET consortium.

Louis Frenzel, Electronic Design Magazine

Louis Frenzel has wide experience of higher education and is currently editor of Electronics Design Magazine.

James Hyder, Intel

James Hyder is an expert in ion implantation technology. He is currently responsible for technology training activities in Intel Fab 11X, Albuquerque, NM.

Michael Lesiecki, MCCCD

Michael Lesiecki is Director of the MATEC organization - a national center devoted to educational technology development for community colleges.

Thomas McGlew, Maricopa Advanced Technology Education Center

Tom McGlew is Project manager for the ESYST program which has been funded by the NSF to develop systems-oriented educational programs for use in community colleges.

© American Society for Engineering Education, 2008

The Technology World is Changing Rapidly.
Can Higher Education Match the Pace?

Abstract

New electronics technology has been the driver for huge changes in all sectors of business over the past three decades. As more functions have been integrated on silicon, the amount of component-level design, assembly and test has decreased and with it the need for large numbers of engineers and technicians with these manual skills. Instead, low-cost assemblies are now produced in relatively few locations but they feed a rapidly developing global market for electronic systems applications. The paper considers the new skills that the higher educational system has to deliver for future jobs. The changes impact all engineering education sectors but the two-year schools are in the front line. A new NSF-funded program has been launched to address the issues.

Pittsburgh, We Have a Problem

If a group of 1988 graduates were to sit in an introductory electronics class in many higher education establishments today, they would find that very little had changed. Students still learn manual circuit analysis and how to solder discrete components, op amps and logic gates on simple circuit boards to create basic electronic functions. Bipolar transistors are given more emphasis than MOS and any computer-aided design and analysis of circuits is very much linked to examples that can also be done manually. If challenged, the justification is that these hallowed courses are vital to provide students with “the fundamentals” of the subject. Commercial products and their applications may change but the fundamentals never will. Hence there is no need for curriculum change. There are always good intentions to treat current (ie 1990s) technology in the later courses if there is time – and of course, there never is enough time. This outlook prevails across all higher education but the implications are most severe in two-year schools since they don’t have the luxury of using upper division and graduate-level classes to introduce current technology and its associated skills.

The purpose of this paper is to examine the validity of this line of argument. It is the starting point for a new NSF-funded curriculum development initiative that will be discussed later in the paper. However, the underlying causation factors are sufficiently profound to justify their presentation as a stand-alone paper. They have massive implications for changes in program content and structure so the intent of this paper is to layout the issues and promote wide-ranging discussion that will lead to a community of interest to support all relevant program change initiatives. The authors represent a range of academic, publishing and industry interests but they have a common commitment to understanding the change agents that should drive curriculum planning. It has been a recurring theme at past ASEE conferences [1, 2] and this paper is intended to further stimulate the dialog but more from the perspective of 2-year colleges.

There are two commonly used techniques that can help. The first is root cause analysis (RCA) - a process that is routinely used in companies to ferret out deep interactions that have fundamental implications for behaviors and responses to external challenges. Once the root causes of change have been determined, the second technique, road-mapping, can be used. A technical roadmap shows leading indicators and decision points. The combination of these two techniques can help the curriculum planning process.

Root Cause Analysis Process

In making any analysis of the factors that determine change, it is always important to identify root causes. If only the symptoms are treated, the responses may keep changing but the problems will continue.

The process for root cause analysis is shown in Figure 1 [3].

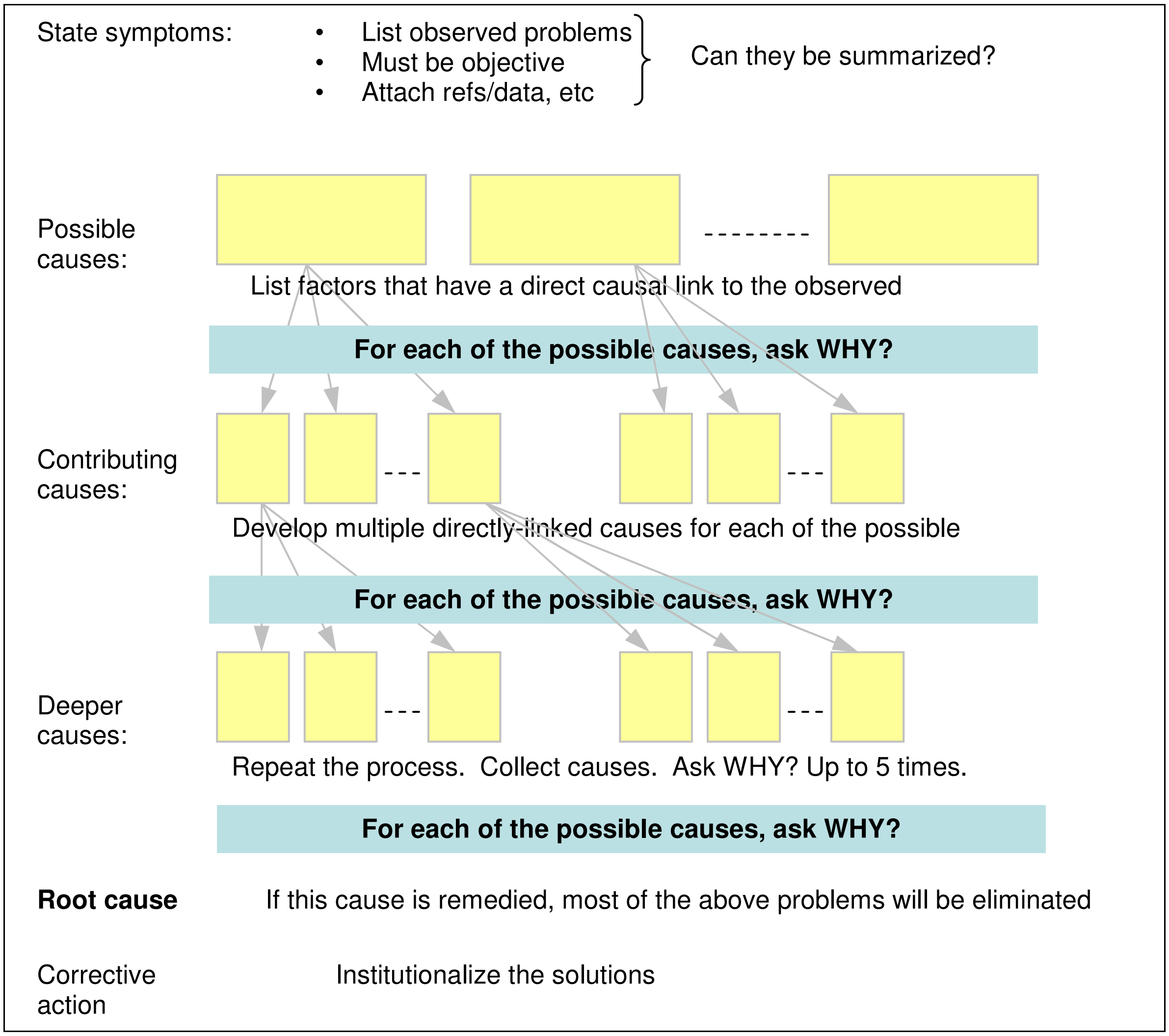

Figure 1. Root cause analysis process

In any process like this that develops branching chains (especially to 5 levels) the representation quickly becomes unmanageably large and some priority selections have to be made. This is an inherent risk, but it is counterbalanced by the simple structure of RCA and its supporting documentation. It should always be possible to go back to the process, reconsider each step and add new paths. The acid test is whether reconsideration has any effect on the derived root cause. A stable root cause is the best indicator of its validity.

Symptoms: How Industry Operates Today

The treatment of technical subjects in most academic courses invariably only deals with the materials, physical and electronic behaviors of inanimate objects. Little (if any) attention is given to the sort of company that successfully produces the products or where the job is done. The prevailing assumption is that everything is done within a single organization. When the foundations of today's technology were being formed in the 1950s, 60s and 70s, that was a valid picture. New tools, processes and materials were required and the only option was to develop them in-house. It was very effective and was successfully applied across almost all business sectors from aerospace to semiconductors. Economists call this style of business operations 'vertical integration' and it is represented in Figure 2.

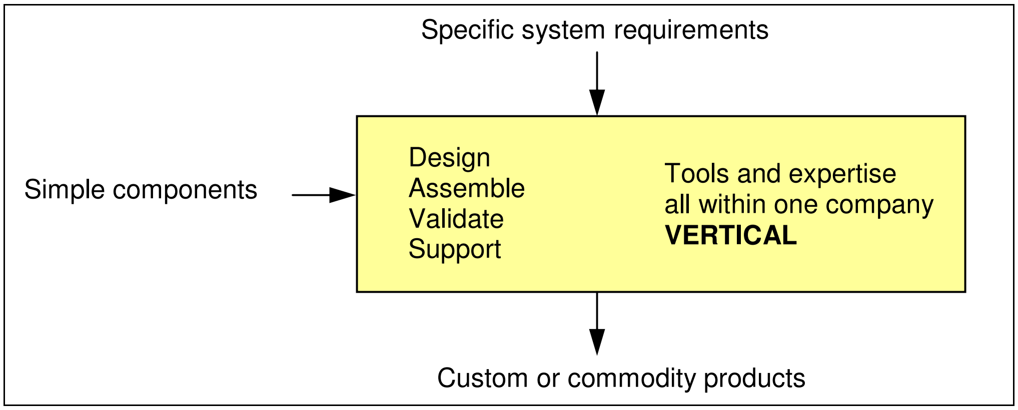

Figure 2. Vertically integrated operations

A vertically integrated business has two characteristics that are important to this paper. First, it takes in simple raw materials and components and delivers complete products. The value-added is therefore high. Second, it can have a very hierarchical organization. With manual design and assembly, large numbers of operators, technicians, engineers and managers are needed, all with clearly demarcated functions and supporting qualifications. The skills requirements become the requirements for the feeder educational system and that structure of degrees and qualifications is still in place today.

In the past 20-30 years, there has been a profound change in the way that high-technology companies are structured and operate. Functions that were once considered strategic and essential to have in-house have been sold or spun off as separate entities and in their turn, they have merged with others performing similar functions or disappeared. The business style is called 'horizontal integration' and it has profound implications for the skills and distribution of people in the whole industry. A good example is Motorola. Once the company had the capacity to grow its own silicon, make the semiconductors and incorporate them into cell phones. Now these functions are in separate companies located around the world. The changes are summarized in Figure 3.

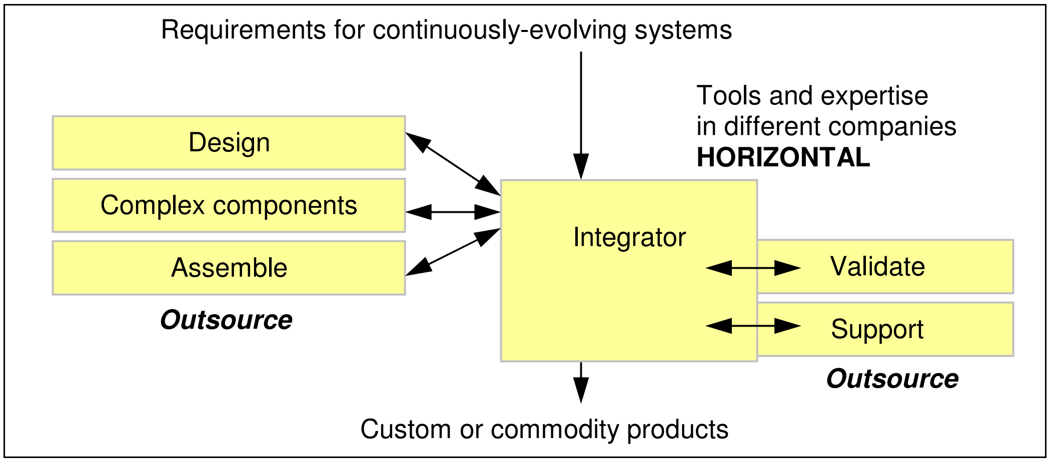

Figure 3. Horizontally integrated operations

The primary driver for horizontal integration is the complexity, capital requirements and focused skills that are inherent in the production of today's electronics and computers. A company can only attain the necessary mastery of its selected area of technology by focusing on its core competency and then competing in the global market as part of a massive and interlinked supply chain. Four immediate consequences that impact the education of professionals for this industry sector are:

- All operations have to be viewed in a global competitive context.
- New categories of specialist skills have evolved.
- The system integrators must be able to interact with many specialists.
- Since complexity and technical challenges have increased, educational requirements, skills and expectations have increased too.

These are profound issues. They affect all current technical jobs and they will determine the pattern of recruitment and career progression for future technologists. Unfortunately, the educational sector has not changed at the same pace as industry and it is still delivering skills and qualifications appropriate for vertically integrated organizations. The immediate question is therefore how the educational world should respond to the conditions represented in Figure 3 (and the future requirements as it evolves further). Root cause analysis can update and redefine the "fundamentals" for the next generation. The roadmap process then provides the path to a productive solution while recognizing the many options and priorities that have to be managed.

From Primary Causes to Root Cause

The previous section illustrated many of the operational features that characterize today's high-tech industry. It is a worldwide phenomenon. Although laws and government influence vary considerably, the trends are truly global. Educational responses and solutions must therefore also be set in the context of international competitiveness [4]. Following the reasoning process of Figure 1, the much-simplified trace-back sequence is:

Why has the structure of industry changed so much?

> It reflects an evolutionary process that pays off in earnings and market growth. Specialization on core competencies allows fast technology development.

Why specialize?

> Advanced technology requires massive investment to achieve low unit costs for large production runs. That means it is now better to be an independent supplier to the world than a limited in-house activity.

Why is it more possible now than 30 years ago?

> Cheap communications, open international trading standards and the capability to manage the complex networks allow the supply chain to work efficiently on a global scale. These are today's operational tools.

Why has it been possible to create these operational tools?

> There is massive and effective interaction between the "7 Cs" of modern technology - components, computing, communication, control, complexity, customer-focus and cost. These are the capabilities and factors within a company that determine the competencies required in the workforce.

Why? What enables these capabilities?

> The technology to integrate more electronic functions on silicon every year and at the same time, reduce size and cost and increase reliability.
> *This is the Root Cause.*

Many other analysis paths can be followed but all point back to the same root cause: to put ever-larger numbers of transistors on silicon for no additional total cost. This phenomenon is often called Moore's Law [5] but it has gone much further and lasted much longer than its author ever imagined. One useful outcome from a long-lasting change–driver is that it is possible to generate a model that describes the likely outcomes and project its results forward in time to create a technology roadmap.

Roadmap Process

The purpose of a technology roadmap is to provide quantitative targets for future capabilities. The International Technology Roadmap for Semiconductors (ITRS) [6] is an excellent example that is built on the principles that Gordon Moore laid out in 1965. It started life as a number of small-scale parallel speculations but has now grown into a major international collaboration with annual updates. It only addresses materials, tools and technology; not the products or costs that will be realized using the results. The ITRS therefore remains pre-competitive so companies and institutions worldwide can contribute to it. It is also openly available so the whole international community of providers and users can see what is coming.

Figure 4 illustrates some positive and negative features of a roadmap. The diagram shows two of the most important trends in semiconductor technology development. The reduction in minimum feature size leads to higher packing densities of functions on a chip while clock speed is a direct measure of computer performance. The time data refers to the starting point for production of commercial products.

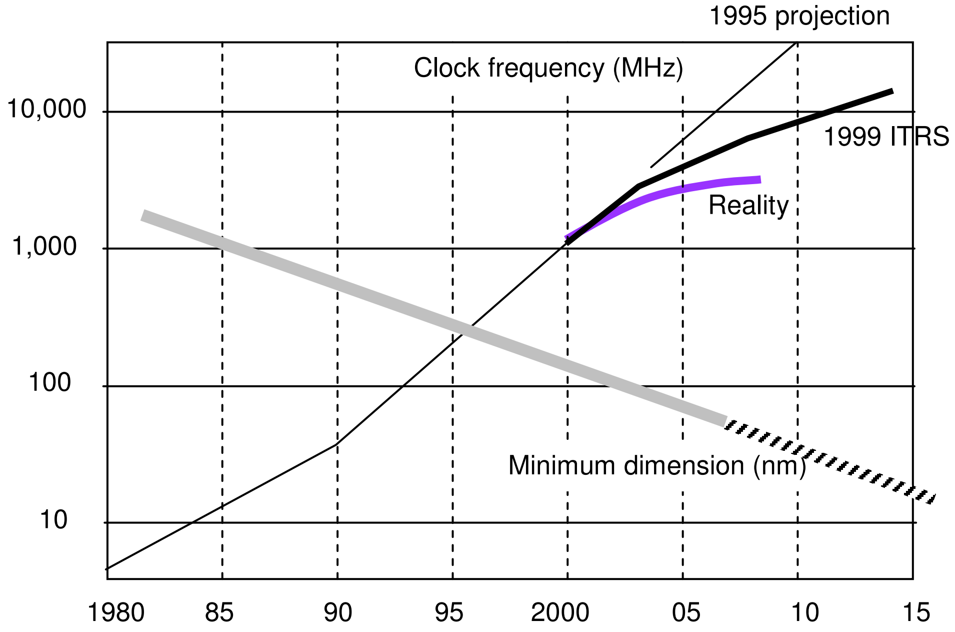

Figure 4. ITRS projections

The reduction in minimum dimensions of transistors has been steady and the projections show the process continuing. Much smaller devices are currently in the development stage so it is likely that the shrink path will be valid for the next decade. However, all projections have risks and the graph also shows the expectations for clock frequencies. Excessive power dissipation in CMOS forced the projections to be scaled back and there has been little increase over the past three years. However, development has not stopped. As processor cores continue to decrease in size (with smaller transistors), it is possible to put two or four on a single chip for the same cost. That leads to a whole new roadmap for multi-core processors with projections for several hundred on a chip within a decade [6].

Changes in the Production and Use of Semiconductor Products

In the 43 years since Gordon Moore made his prediction, very little has changed in principle. Understanding the details of materials processing, device physics, basic circuits, computer architectures and programming have all been substantially enhanced but an engineer from 1965 would be familiar with the principles (though not the scale or cost) that apply today. Is this not therefore an argument to retain teaching these basic principles? The answer would be affirmative if the principles were used in the same way. Unfortunately, the applications (and therefore the necessary skills) have changed radically.

The inexorable increase in semiconductor packing density has several important consequences. The first is that the cost of a gate or a memory cell is now measured in nano-$[7]. True, they come millions or even billions on a chip but these are today's building blocks. The second feature is that chip fabrication and the associated board assembly process are sufficiently reliable to allow millions of samples to be made with very few failures. In the language of statistical quality process control, this is called six-sigma manufacturing. Figure 5 shows the implications of this quality imperative for high volume production.

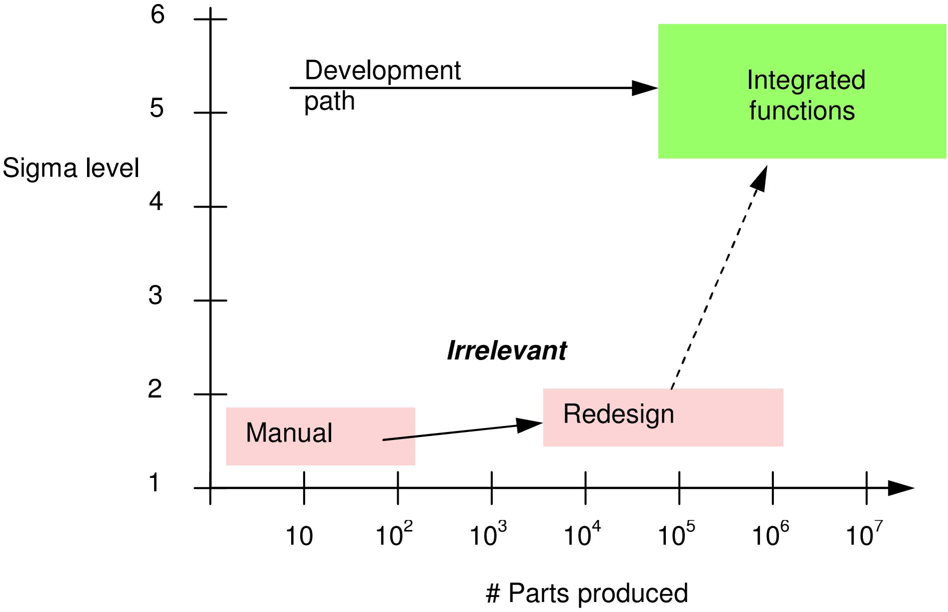

Figure 5. Paths to volume production

Most of these high quality integrated components can be obtained in small volumes for prototyping. If the concept is successful, production volumes can be readily scaled up to meet market demand. By comparison, a manual assembly process using simple circuits (of the kind that are commonly used in teaching labs) can only give quality at the level of 1 or 2 sigma. That may be enough to demonstrate a simple prototype but suppose it were to be successful? It cannot be scaled up without being redesigned to use high quality technology. As an example, TTL or CMOS gates are building blocks that are much too small for today's prototype digital circuits. A component of much greater functional capacity such as a microcontroller or programmable logic array or even software emulation is used. The point is that all these solutions can be readily scaled up for volume production if needed. This leads to the third consequence; winners are defined at the end of the production process when the big revenues materialize. Losing time to redesign with new technology is a death wish.

As a result of these trends, there are now two very different career paths in electronics.

1. Those who make the integrated circuits and boards that are now the building blocks for all electronics systems. This group has very specialized skills and is therefore composed mostly of engineers – increasingly with higher degrees. The number of people involved has been static for many years although their individual productivity has risen hugely. It is an international business with few ties to any locality.
2. Those who decompose customer requirements to generate and sustain solutions using the basic integrated building blocks. This is a relatively new requirement that is increasing rapidly in importance and in numbers employed. It has aspects that relate to design, manufacture and system support that will be considered in the next section.

What is missing from this scenario is a place for the skills that are currently being taught in introductory electronics courses. They have become history. Today's device design and circuit analysis are vastly complex and embedded within specialized design tools since they relate to specialized IC or board design. So the question we have to ask is what purpose is served by teaching obsolete technology outside a history class? Soldiers are not trained to fight with swords so they can better understand the principles of warfare. Surgeons do not practice without anesthetics nor do accountants use quill pens and legers before moving on to spreadsheets.

In every profession, there are basic principles to be learned but no one pretends that they can be most appropriately learned using obsolete technology. This conclusion does not negate the need to study history. It is important that students (as well as non-specialist faculty and administrators) realize that some subjects are more dynamic than others. The best way to emphasize that change in the educational world is by continuously upgrading the curriculum to reflect current and future practice. The stakes are high since rapid developments in electronics technology underpin most productivity gains in the economy. This is an important message that bears constant repetition and demonstration.

The 2018 Scenario

Technology education makes a bold claim that it prepares students for the workplace of the future. In order to make an assessment of the skills that might be required, the technology roadmap data can be used to construct a number of scenarios for the technical jobs of 2018 and the skills they demand. Together, they cover many of the features we can expect to see from the evolution process described above.

The route to greater (and cheaper) computing power is through parallel processing. The International Technology Roadmap for Semiconductors [6], points to the prospect of several hundred processor cores on a chip. This will be a massive headache for the computer science community where the software tools for efficient use of concurrent processing are still rudimentary and there is little prospect of a breakthrough soon. However, for many system applications of the type addressed by hardware engineers and technicians, the restrictions are less critical since systems tasks are inherently broken up and allocated to specific processors. System integrators should therefore prosper with the new multi-core technology.

The development in functionality is most marked in digital processors and memory but traditional analog and discrete components have continued to be developed. In addition, a low-key technology revolution is underway to mount multiple die in a single package. The most familiar examples are flash memory drives where the silicon has been ground down to paper thickness and 4 – 16 die are stacked to create a three-dimensional System in a Package (SIP). Another example is shown in Figure 6 where optical features have been added to give the low-cost camera module found in nearly all cell phones [8].

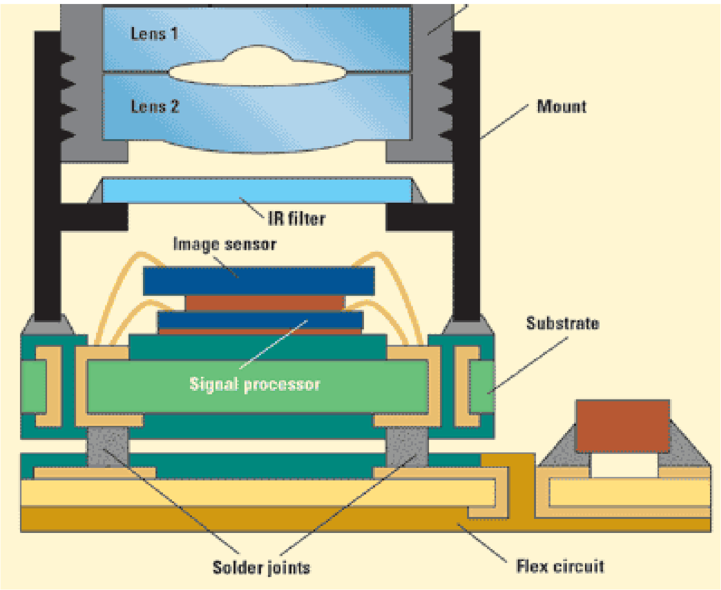

Figure 6. Stacked die cell phone camera module

The same trend in specialized, optimized and complex assembly has also been extended to multi-layer printed circuit boards. Chip-scale packages, ceramic capacitors and laser trimmed resistors allow the strip-line layouts necessary for high signal integrity at GHz speeds. The combination of SOC, SIP and automated board assembly allows devices from different product generations and suppliers to be combined at low cost and with high reliability.

The surface mount process that involves lead-free solder balls on a multi-layer circuit board does not allow any manual intervention for repair. Even probe testing for troubleshooting is difficult (assuming we can understand what the signals mean). The primary building block for electronics is therefore now the circuit board. This means that all educational programs have to rethink how sub-board topics such as circuits and component interactions are treated. However, as component-level activities are constrained, new opportunities at the board level and above open up.

Although the one-off costs for design, tooling and validation are increasing rapidly (and current technology roadmaps show no break in that trend), unit costs for functional circuit boards are low because there is a mass market for the product. This trend is expected to continue and it offers many opportunities for practical education. The low unit costs mean that very sophisticated electronic functions can be delivered on a lab budget and the whole systems world beckons. Demonstration of digital, wireless and measurement functions can be easily done using microcontroller, smart sensor and programmable gate array development kits and the range of available functions is expected to grow substantially. Over the next decade, a massive increase in systems requirements for extendibility and sustainability are projected. The functional needs will be met by using both hardware and software plug-ins. This activity requires a broad view of all aspects of system operation. It is a business sector that is growing rapidly and it requires a whole new range of skills. Technicians have to be able to match new with old technology, interpret the significance of specifications to a much greater extent than before and also have a wide range of contextual communication skills to interact with the end users and suppliers.

These skills are tightly coupled to the competitiveness of our industry and they represent the logical end-point for the calls from the National Academy of Engineering (and others) for higher technical standards in all levels of education [4]. There is therefore a great opportunity to expand and enhance the systems components of technology programs. The most immediate requirement is for a new category of technicians who can develop and manage systems in the field.

Electronics Systems Technology NSF ATE Project - ESyst

Most current electronics curricula in two-year schools still focus on preparing students for jobs as traditional engineering technicians. These positions have gradually but significantly declined in numbers over the years because of advances across the whole range of semiconductor technologies that have been laid out in this paper. Electronic technicians today are predominantly engaged in jobs involving installation, service, maintenance, repair and manufacturing. Furthermore, because of large-scale integrated circuits, technicians work less at the component level and more at the equipment and system level. However, the current curricula are still more component- and circuit-oriented, with far more detailed analysis and design that is rarely required in contemporary jobs. Fundamentals are still important, but their depth of coverage and context are different today. Therefore, traditional basic and core competencies will be examined closely in this project.

An innovative, new approach to curriculum with a systems view for electronics technology is being designed within a new NSF-ATE project [9]. It is based on the rationale developed in the preceding sections of this paper. In cooperation with an industry roundtable and faculty advisory panel, a new curriculum is being created to match anticipated industry needs. The most distinctive feature of the project is that it uses a top-down approach as shown in Figure 7.

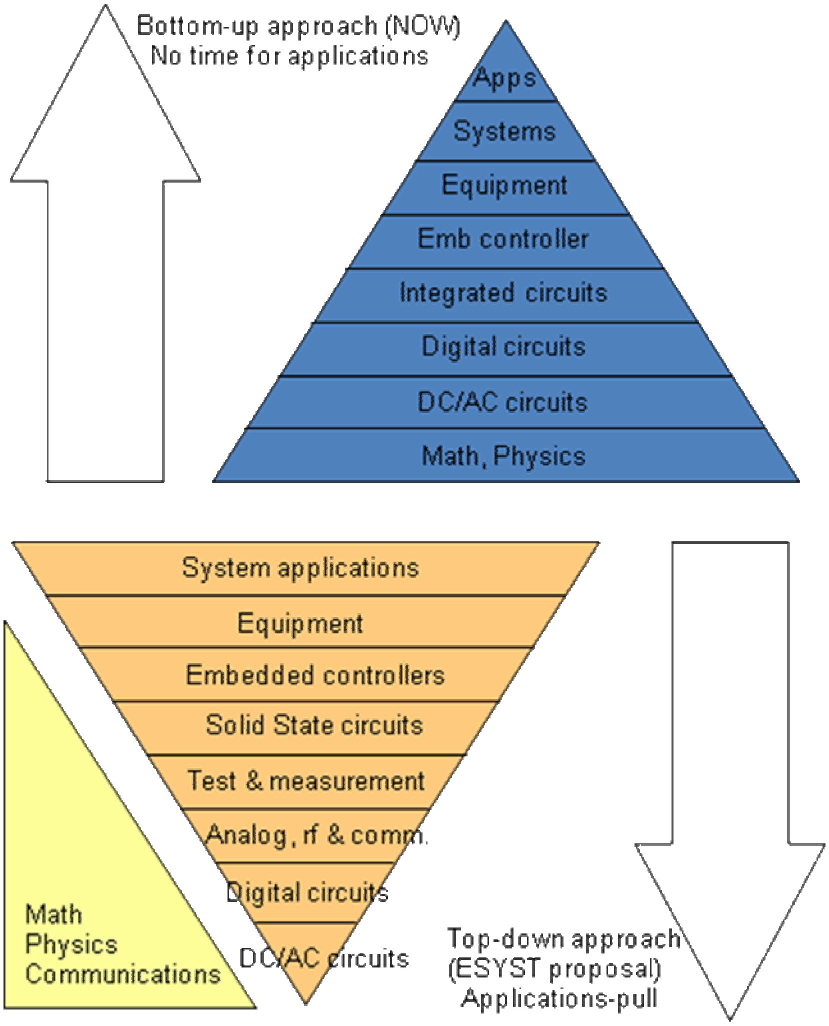

Figure 7: Approaches to systems curriculum treatment

The resulting curriculum will contain entirely new materials for incorporation as well as fresh opportunities to include systems-level concepts and learning activities. The Electronics Systems Technology (ESyst) project facilitates an alternative approach to curriculum sequencing. The current curriculum often uses a traditional or bottom-up design where the math and science background is learned first. Early DC/AC circuits courses are then followed by semiconductor fundamentals and circuits. Digital and microcomputer courses come after that, then specialty subjects that typically include equipment and systems that implement the actual applications.

The structure shown in Figure 7 allows the more exciting and interesting applications, especially system applications, to be covered first at the systems level to improve student motivation and retention. Then, as needed, the courses will dig deeper into the subject matter. Less emphasis will be placed on math where it is not necessary for technician jobs or where the mathematical analysis is built in to the equipment or system. More emphasis will be placed on math that involves data interpretation and optimization of system performance. Detailed circuit analysis and theory will be addressed to the extent needed to develop defined competencies. In many ways that will result in a higher level, more focused study of mathematics. Math and Science fundamentals are critical hiring requirements for today's technicians; these fundamental skills will be integrated throughout the curriculum. This may be considered to be an example of "Just-in-time" education.

The majority of the online laboratories and course development is expected to take place in 2008 and 2009. Pilot testing will begin in Fall 2008 and conclude at the end of the project in 2010.

Conclusions

As electronics systems technology develops, its impact is felt throughout all segments of the business and service economy. Since it is also the primary driver for higher productivity, success is a contributor to international competitiveness. These business activities require a level of technical expertise that is significantly different from the smaller scale and more manual activities that defined traditional electronics. A workforce with a new range of skills is required and the educational world has been slow to respond to the new requirements. That criticism applies to all categories of higher education but the case is particularly acute for programs that prepare technicians. A pointer to the shape of future curricula is being developed within a new NSF-ATE project and its outcomes will be fully reported later. However, the top-down systems approach can also be applied to other education sectors. It provides an effective way to prioritize course content and balance the requirements for inclusion of new technology topics within the ever-present constraints of time and resources.

Bibliography

1. G Mullett & A Smith, "Are today's Engineering Technology programs doomed to extinction or is their mission changing?" Proc ASEE Annual Conference, Honolulu, June 2007, # 2348.

2. J Mossbrucker et al, "Addressing the future: Development of an Electrical Engineering curriculum", Proc ASEE Annual Conference, Portland 2005, # 1432.

3. NASA provides a clear and simple exposition of its process at: http://process.nasa.gov/documents/RootCauseAnalysis.pdf

4. N Augustine, 'Is America falling off the flat earth ?' National Academies Press, December 2007.

5. G Moore, "Cramming more components on to integrated circuits", Electronics, vol 38,8 April 1965.

6. International Technology Roadmap for Semiconductors (ITRS) is available at : http://public.itrs.net

7. For a good overview of all exponential functions that relate to semiconductor development, see: http://www.icknowledge.com.

8. A Chowdhury, “Camera module assembly and test challenges”, Semiconductor International, February 2006.

9. NSF project, “A systems view of electronics for 2010 – ESyst”, DUE# 0702753. Details can also be found at the web site: http://www.esyst.org.