AC 2007-577: MATCHING JOB REQUIREMENTS TO DISCIPLINE SKILLS

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Introduction

A cursory glance at any electronics product is enough to show the extent to which functionality has improved and costs have been reduced in the past 30 years. It also means that in one generation, the necessary skills of an electronics industry professional have changed radically. In 1977, we were at the end of a 50 year period where every electronics engineer typically had to be able to start with simple electrical components and from them, design, assemble and evaluate circuits. It was a labor-intensive process that offered a great deal of individual choice in the selection of values and configurations. It was also a process that was easy to replicate in an academic department. Components were cheap and the design skills were well-suited to undergraduate teaching in any Electronics Technology department. However, electronics in that form has effectively disappeared so the provocative question is, "how have the discipline skills being taught in higher education institutions changed to match the new generation of job requirements?"

The technology change has been driven by the effects of increasing integration of electronic functions on silicon. The inexorable progress of Moore's law [1] has allowed a relatively small number of companies around the world to produce powerful electronic functions that deliver super-computer performance on a single chip. The product is also delivered in high volume and at low cost. The span of design extends from atomic-scale features to systems that interact with a large proportion of the population of the planet. When we add the corresponding requirements for high reliability and low cost, the task of preparing competent professionals is clearly a big – and increasing – challenge.

The change in products has also changed the skills and jobs of the professionals who deliver the products. The electronics job of 1977 has now evolved into three different but interacting functions:

1. Design and construction of integrated circuits is concerned with delivering massive functionality on a silicon chip using a very capital-intensive process. It requires contributions from every engineering discipline (and others beyond engineering) working to extend the known limits of the science and technology.
2. Applications of these commodity components; chips, boards and higher levels of electronic functionality. The role is to interpret an ever-expanding range of user-requirements, define the best way to deliver the necessary system performance and then map out the path to deliver a competitive solution.
3. The "glue" that connects the above two functions is increasingly becoming a software task that is executed on an international scale. It covers the code used to program embedded computers and the specification of hardware for logic functions.

Each job category continues to evolve rapidly with new and more powerful tools and technologies. This paper examines some of the ways an academic group has responded to these new job requirements.

Problem methodology

In order to meet our College goal to generate industry-ready graduates, we have to look more closely at the degree to which the discipline skills and competencies taught in the academic program match future job requirements. The first step is to minimize the "transition shock" that new graduates experience when they take their first professional job. Internships and co-op programs certainly help *students* in their personal development but how do we make sure that the same benefits accrue to the faculty so they can be embedded into the academic program? The faculty also has to blend that student-centric goal with a long-term objective to provide a stream of technologists who will contribute productively to the success of their enterprises – large and small – over the next 2 decades and more. Understanding job conditions is the key to new employees being able to adapt quickly to the business environment and be fast-track candidates for promotion and career advancement.

Such introspection is not new. In a 1981 review [2] of the education requirements for the next 25 years, John Fluke stated: "The entire educational system in the United States simply isn't working sufficiently well. Major system elements must be entirely rebuilt or replaced in the next 25 years. Today's teaching staffs are either inadequate, inadequately supported or both and they lack the necessary physical facilities to provide proper and sufficient training". His words still resonate today and we have probably not changed nearly enough to meet his expectations. However, there is now one significant new factor to drive change in academia. Institutions and faculty have signed up to an accreditation process that is rooted in continuous improvement and we can no longer procrastinate. This paper illustrates the outcome of an extensive and prolonged dialog between an Electronics Technology department and a number of companies from the aerospace and semiconductor industry sectors.

While the industry keeps extending the state of the art, university programs still have to start with the basics. We see no evidence that students today learn faster than in the past. Unfortunately, there is also no evidence that the faculty teach better. However, at the output side, we are committed to keep up with steadily increasing competency requirements for entry-level jobs. To manage the curriculum development process, we need to understand the industry job requirements if we are to adapt our graduate-level skills to match. In our case, it has been done through several types of dialog over the past 5 years:

- Over 60 Industry Advisory Board meetings
- Short courses for senior engineering managers given in the companies
- Feedback from graduates and interviewers
- Contributions from senior managers on loan from our industry partners

The common thread throughout these dialogs was to show what drives change in industry. At a more detailed level, we mapped the required skill sets for graduates entering both semiconductor fabrication and electronics application jobs. Finally, these features were used to adapt curriculum structure, course content and the strategy for student recruitment.

The changing technology environment

We have reduced changes in job requirements in the high-technology industry to just three root-cause factors:

> **Capital-intensive processes**. The design and production of advanced electronic components and systems requires high capital investment. An example is a semiconductor plant that represents $3B investment but that is typical of high-tech manufacturing. Since labor costs are a small percentage of the whole, there is little incentive to move the operation offshore. The complex tools and processes require a new blend of workforce skills but their cost of ownership is far beyond the budget of any academic unit.
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> **High capability processes**. Over the past two decades, there has been a systematic and intense attack on variation in manufacturing through techniques such as Design for 6-Sigma. As a result, many functions that were once manual are now embedded in the expensive tools and automated machines that characterize the capital-intensive process. The new tools (software and hardware) give outputs with much higher yield and performance uniformity. However, they can also be easily set up anywhere in the world. Paradoxically, the challenge to our position at the top of the high-tech pyramid [3, 4] is not labor costs but our capability to use and exploit the high-tech tools and processes.
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> **System complexity.** With low-cost computation, highly reliable commodity components and the capability to acquire, manage and store vast quantities of data, today's complex electronic systems are perceived to be the way forward for almost all industry sectors. Examples as diverse as medical imaging and supply chain management point to electronic systems as the key enabler to manage high complexity and at the same time offer greater productivity and better performance.

This is the environment within which our graduates must perform and deliver competitive solutions. It is therefore reasonable to ask where they learn about these features that shape their careers. If they know and understand these elemental forces for evolution, will it help the individuals with career management and make them more attractive in their job search, placement and starting salary.

It is clearly important that the three root-cause factors (capital-intensive, high capability and complexity) be addressed within the academic program. The close working relationship with the industry partners provided essential insights by making the industry workplace a virtual extension of the academic environment. Almost every course in the program now actively covers the root-cause factors or uses them as a backdrop to illustrate applications of the course topics. This has proved to be a very convenient way to meet the challenge to link job specifications to discipline skills. The methodology also illustrates a typical feature of high-tech engineering that solutions flow easily from thorough definition and analysis of the interplay between the intended outcome, root-cause for change and constraints.

Changing job activities

The diversity of job functions being done by recent graduates and by current students who are currently employed is truly bewildering. In order to get past that array of individual cases, we have considered how engineers contribute to two classes of activity: decision-making and assessment of outcomes. No matter the job they have, every technical professional has to undertake these two activities.

Every product, process or service offered by a company is the result of a series of deliberate decisions. We call these ‘decision outcomes’ and an important job skill is to contribute to their formulation or realization. Our first instinct is to assume that there are only a few decision outcomes – what to make, how to make it and what its performance should be. However, if we dig deeper, the process is much more complex. Decision outcomes can be the end-point of a vast design activity or they can be pre-defined by custom or customers. The differences are important. The list of decision outcomes given below was derived from activities undertaken in 8 iterations of a Certificate program for Chief Engineers (ie. technology executives) in the major systems companies in the State [4].

1. Performance priorities
2. Materials selection
3. Components
4. Partitioning and sub-systems
5. Whole system production and delivery
6. Physical parameters
7. Energy and services (in and out)
8. Hardware-software split
9. Suppliers and scope
10. Supply chain management
11. Validation process
12. Upgrade paths
13. Documentation
14. Maintenance and sustainability
15. Safety (EHS, OSHA specs)
16. Environment & end-life disposal
17. IP protection and system security
18. Reliability and its consequences
19. Training
20. User interfaces

Each topic could easily be sub-divided or re-classified but in this case, the goal was to generate a list that could be used generally in industry short courses and in our academic program. It was a great advantage to have the list prepared and refined by a large number of technology executives. They have personal knowledge of the details but are also committed to finding tractable tools so they limited the list to 20 topics. One useful practical outcome from the list is that it demonstrates the blend of technical and operational skills required by all engineering professionals.

In every company, the final definition of each decision outcome is only reached after a process of systematic consideration by the technical and business experts. Each decision outcome therefore represents a set of technical conclusions about how the business will operate [6].

A demonstration can be given in almost any course. As an example, consider the behavior of RC circuits. The usual steps are to derive the basic equations and perhaps couple them to a simple lab demonstration or power supply requirement. However, there are many more applications of even this simple concept. Although they may be covered in many other courses, the separation of basic theory from applications does not encourage critical thinking or good troubleshooting skills when the concepts have to be used outside the academic environment. Some cases to consider are:

- Signal propagation delay
- Ripple reduction in a power supply
- DRAM operation and refresh
- Super-capacitors in hybrid vehicles
- Optical imager stability
- Decoupling filters
- Analogies with thermal time constants

Almost all of the 20 decision outcomes can be applied to each of these RC circuits. The utility of the approach lies in its simplicity. It does not take long to demonstrate how decision outcomes are relevant. If the activity is repeated in many courses, students become familiar with the routine. More importantly it demonstrates that the outcome of an application of any discipline skill is not to crank numbers out of an equation. Numbers are an indispensable aid to decision-making and performance improvement, not an end in themselves.

There are interactions between the decision outcomes. A simple demonstration can be done with students at any level. First, they select any electronic product or system. Then randomly select any two decision outcomes and examine their interaction. The process can be repeated for any other pair, then for the different interactions between three and four outcomes. This is enough to indicate that we are dealing with a reasonably complex concept. However, a 20-minute discussion also shows how even the most basic course activities lead to issues of business competitiveness and the critical thinking that follows from a good understanding of basic principles. The evident importance of interactions leads to analysis of trade-offs and then to the idea that technical questions may have a variety of answers determined by their applications context. In this process, students have moved from simple manipulation of numbers in equations to a higher level of competency where they can use their understanding of the relationships between the variables to achieve a result that can have important business outcomes.

Appreciating the complexity of decision outcomes is the first step. There is a complementary process to make a quantitative assessment of whether the decision outcomes meet the goals. The assessment process is as rich as the design activity. Again, we used the experience of over 150 Chief Engineers in customer, process and design reviews to generate a representative list of 20 assessment criteria:

1. Fitness for purpose
2. Cost (all facets)
3. Performance against spec
4. Quality
5. Business metrics (profit, ROI)
6. Extendibility
7. Re-use, flexibility and scalability
8. EHS impact
9. Procurement flexibility
10. Delivery and support constraints
11. Field support
12. Metrics for reliability & repair
13. Availability and efficiency (OEE)
14. Continuous improvement impact
15. Risks beyond planning horizon
16. Intellectual property defense
17. Regulation and legal factors
18. Competitive position
19. Time to obsolescence
20. Conditions of sale.

Students at any level can see the rationale for these metrics. Some, such as intellectual property may be unfamiliar but they quickly see the need to understand the competitive importance of novelty [7]. Again, there are interactions between combinations of criteria and it is consider examples for any course topic. Inherent contradictions or conflicts of priorities quickly come to light and force a more rigorous re-appraisal of the decision outcomes. The good feature of this approach is that it can be used by students at any level in the program.

It is also useful to highlight the difference between the types of data used in decision outcomes and performance criteria. The former is based heavily on measured data and analytic relationships. The criteria, however, put more emphasis on attribute data (such as pass/fail or customer opinions) so it is a convenient way to demonstrate the distinctions. In all cases, the need for clear communication in expectations, specifications, performance and outcomes quickly becomes self-evident in any discussion.

The final stage of the process is to represent the decision outcomes and criteria as a 20x20 matrix and start to fill in the interactions. A simple binary yes/no review is enough to show that for almost any subject, the matrix is far from sparse and that it may change with time. The conclusion is that professional competency is about being able to have a strong intuitive understanding of the subject principles to be able to apply them in any application.

Skills required

The process described above allows typical job activities and requirements to be described in a sufficiently generic way to allow them to be linked to the content development within any electronics technology course. Once the conceptual link has been established, the next step is to identify the skills that students need to make the process work. The classification has again been based on industry-based training programs for senior engineers [5]. We use the simple expedient that if companies wish to encourage certain skills and behaviors in their technical leaders, it is a good idea to start early and incorporate the same skills into the graduate formation process.

The skills fall into the four categories shown in figure 1.

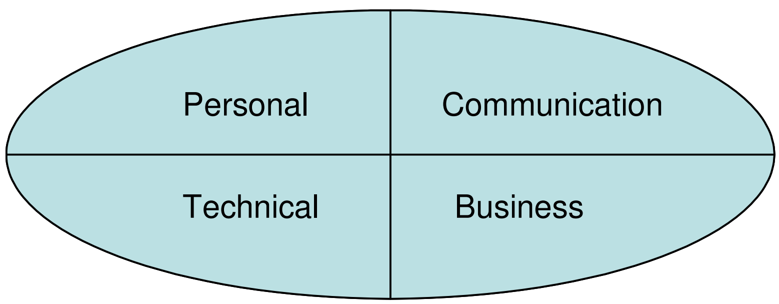

Figure 1. Skills categories

There are typically 10 – 20 skills in each category. Examples include:

Personal - time management, team working and accountability.
Communication – fluency, effective use of tools, listening and oral presentation
Technical – system architectures, data acquisition, roadmaps and constraints.
Business operations – drivers for change, safety and quality by design.

Although the whole list is long, it provides a useful checksheet and guide for course content planning. Most of the skills are used frequently in every course. It is not a major addition to explicitly highlight a skill and explain its application context. The students quickly get the message and start to develop their own dialect of that skill and thus make it their own.

Outcomes and conclusions

The work described in this paper is part of a sustained effort within the Department and College to build a culture that couples the educational process to the future workforce needs of industry. Like any attempt at culture change, we should not look for quick results. However, there have been a number of significant outcomes over the past 3 years:

- Industry case studies are used to demonstrate the applicability of the decision outcomes – assessment criteria matrix.
- In post-class student surveys, students say that their critical thinking skills have been significantly improved.
- The procedures have been incorporated into the Department’s strategic development roadmap and its measures of progress.
- The range of factors used for course planning has been widened.
- We have an objective set of criteria to help determine course priorities and to steadily reduce or eliminate obsolete topics and examples.

The process to better align job requirements with discipline skills will continue with more systematic collection of quantitative data on graduate capabilities.

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