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Dimensions in Electronics Education Change*

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Through the years, electronics engineering has been undergoing changes in a variety of aspects. An analysis of these changes is carried out, relating separately to five dimensions: (1) availability of information; (2) scope of knowledge; (3) engineering entity; (4) information handling; (5) human-machine interface. Implications of these changes on electronics education curricula are presented. The transfer of a classic Electronics Engineering Technology BS program into an Information Technology BS program (integrating electronics hardware with software) is described and its implementation issues are discussed. This illustrates the issue of dealing with change. The new programs reflect similar foundations of math and science as to conventional programs but moves students and institution in directions reflected by trends in industry.

INTRODUCTION

ENGINEERING is changing all the time. Change used to happen gradually. It is now happening in large discontinuous steps [1, 2]. This creates significant challenges in changing engineering curricula to prepare professionals to master new contents and skills. This paper will elaborate on the issue of applied versus theoretical contents and its effect on the engineering curriculum. The changes inherent within any engineering entity become apparent when the human-technology interface comes into action. Since engineering is related also to applications, the human-technology overlap is quite dominant, and it might not be enough to relate merely to the basics: the product has to operate correctly. This means that details cannot be ignored and *convenient* assumptions must meet reality-based situations and conditions. Every basic development or innovation initiated by a scientist or a research engineer, results often in a series of new applications, devised in many cases by the engineering graduate in the field. This means that the engineer is confronted with a large number of changes. This fact has serious implications on the engineering education decision-making processes, suggesting the need for continuous and substantive updating of the curriculum.

Engineering must deal with the tension between the applied and the theoretical or between details and vision. This tension stems from the fact that these two entities are a continuum, not to be treated merely as a dichotomy. Can the applied be approached without employing any theoretical means? Many theoretical topics (in an engineering curriculum) can be taught without adequate reference to practice. But applications can certainly not be adequately learned without any reference to theoretical fundamentals. This calls for a corresponding balance in the continuum dimension of theory and practice in the curriculum, which might be unique to an engineering subject in a specific social environment. Attempts to achieve such a balance have been carried out for decades in various engineering colleges. It is agreed among many engineering educators that it is vital, and becoming increasingly essential, that the graduates be educated broadly, be able to think and express themselves (orally and in writing) clearly and profoundly.

Curriculum design is often founded on non-changing contents and skills. Engineering disciplines in general and electronics programs in particular, are characterized by substantial and continuous change, so the issue is how does the electronics education community deal with these contradicting factors.

One way to overcome this contrast is to emphasize, in the electronics curriculum, long-sustaining theoretical foundations rather than applicative episodic subjects. Opponents to this approach claim that diving too much into theoretical foundations might distance the engineer from effective work in industry—so while such an approach may be appropriate for the academic-oriented graduate of engineering, it might be an impeding factor in practical engineering activities of a field engineer. Radicals claim that many engineers do not arrive to the point of using (consciously or unconsciously) most of the theoretical material (or contents based on it) acquired at university studies—we

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have not found any research evidence supporting such a claim. It is true, however, that since the release of the Grinter report in the USA in the mid-1950s that many engineering programs have emphasized a theoretical or science-based approach to engineering [3].

Perhaps another outcome of the issue of losing the linkage between theoretical science-based engineering studies and the practical world has been the emergence of applied engineering educational programs, such as engineering technology in the USA or the practical-oriented polytechnic colleges in Europe. On the other hand most of the applied engineering curricula included some theoretical engineering foundations for two main reasons: (1) the need to understand theoretical technological processes in order to carry out practical tasks; (2) the need to gain academic professional recognition (and prestige).

In any case, change is occurring in both the theoretical and practical sides of engineering, though it seems to be more apparent in the applicative portion.

There have been suggestions that the engineering or engineering technology curricula should encompass both the practical and theoretical sides of the discipline. That usually comes in the form of proposals to make engineering a five-year degree or to make graduate studies required for professional practice as is done for law and medicine. These suggestions evolve out of the constraints of the system. There are considerable economic and academic pressures on most institutions to keep engineering or engineering technology as a four-year degree. The final result of this is that curriculum changes are implemented in, effectively, a zero-sum game. Topics have to be removed to make way for new material. Removing topics from the curriculum is a difficult process, often facing strong opposition from faculty involved in those areas. Thus as technology changes, particularly in applied fields, we see new four-year disciplines evolving to fulfill new niches rather than continually extending the standard engineering curriculum to encompass the new fields.

We present and illustrate one approach to this problem. No discipline is changing faster than information technology. Several universities have moved to create programs in this area as a new discipline in its own right, with the same foundation as similar engineering or technology programs. Inherent in the creation of a program of this type is the need to base the development of such a program on an analysis of the dimensions that define modern technical curricula.

DIMENSIONS OF ENGINEERING TRENDS

Engineering change occurs in a variety of aspects. In order to analyze systematically the overall change in engineering developments and their implications on engineering education, let us first identify several dimensions of these changes. The electronics engineering domain is one of the engineering disciplines that is characterized by a remarkable rate of change, through the years. We will focus on the field of electronics.

In regard to curriculum design, the term, 'change', in a discipline like electronics refers not only to changes in subject matter contents, such as the shift from component-centered devices toward systems analysis or synthesis. It relates also to professional and thinking skills involving, for instance, the move from small-scale to large-scale integration and system thinking.

Let us analyze the unique features of change of a few dimensions of engineering in general and electronics education in particular.

Dimension 1: availability of information

Since the contents of engineering is changing rapidly, especially technically related knowledge and required skills, there is little point in loading the electronics student with vast amounts of specific knowledge and facts—most of it might be obsolete by the time he/she graduates, or shortly afterwards [1]. The engineering graduate's professional competence will be examined mainly in his/her capability to create new ideas and design their realization in highly competitive circumstances. In order to do so one should be competent in identifying, retrieving and using effectively existing information and/or knowledge required to solve engineering problems. This change in emphasis, from mastering to applying knowledge, has to be taken into account in the modern educational engineering programs—it involves a basic change in thinking patterns and professional habits.

During recent decades, the availability of information in general (including obviously masses of electronics engineering information) has improved substantially. No longer is the lecturer or paper-book the sole source of information. Electronic media sources, like the Internet, provide direct access for the student to most of the information he/she needs [2] to advance in one's studies. The information available through the Internet is more comprehensive and updated than that received from a book, due to the electronic handling of information (via hypertext means, for example).

No doubt the **information**, which can be retrieved from an electronic data base, is not necessarily professional **knowledge**, which has been traditionally conveyed by a good lecturer or professor. However, Internet sites including information and explanations in a variety of subjects and levels in electronics education (and related subjects like math, physics and computer engineering) have been available as shareware on the web since the early nineties or even late eighties [4]. Most of these websites are frequently updated. One can find tutorials on a variety of subjects and levels. The electronics educator or student is overwhelmed by a huge quantity of software, of which some is invalid, unreliable or untested. To select relevant adequate courseware for a given program might be a problem in itself. Reference [4] (and its following updates) provides a selection of tested shareware for electronics education purposes, which might assist the lecturer and student.

The fact that courseware (including tutorials) and lab simulations are available on the Web means that availability of **knowledge** is possible, not merely information. One should bear in mind that effective e-learning, synchronous and asynchronous [5, 6], involve great efforts of curriculum design on the part of the lecturer and/or the educational institution—just exposing the student to information and even knowledge is far from being enough for an effective learning process to occur. Most learning theorists in this field promote cognitive or constructivist learning over acquisition of knowledge [7, 8].

Dimension 2: scope of knowledge

During recent decades, the nature of the electronics professionals' activities became more interdisciplinary. This trend is reaching professional domains far beyond electronics: it might include mechanics (for example 'Mechatronics') and aeronautics, not to mention computers, information technology and bioengineering. Technological systems in reality are interdisciplinary in nature. Learning many subjects (breadth) in any content area comes usually on the account of depth-learning in a specific area. However, more complete understanding is mainly achieved by depth in a selected area. Going too far in expanding the scope of disciplines carries the danger of getting to know very little in a lot of disciplines, namely, shallowness. This might result in professional incapability. On the other hand, too narrow expertise may have similar negative results. The problem is actually to find an optimal balance of disciplinary and interdisciplinary contents to be included in an educational program. The engineering graduate has to possess mastery in a wide range of disciplines with in-depth knowledge in at least one specific domain that they might use as a professional anchor—illustrating an example of in-depth engineering thinking patterns. When the electronics domain is considered the interdisciplinary nature takes place across subjects that were once treated under the umbrella called electronics, i.e., interdisciplinary character of the electronics domain itself. Until World War II (WWII) electrical engineering focused on electrical power generation (high current/voltage installations) and its distribution among customers, and the low current was linked mostly to radio engineers. Other communication techniques (e.g., telephony, telegraph and even transmitters) were barely considered in a regular electrical engineering curriculum. After WWII new content domains appeared. To mention just a few electronics branches: control, communication, digital (besides analog electronics) computers, microelectronics, neural networks and bioelectronics. In addition to the expanding borders of the 'within-electronics content scope' one finds also the expansion of electronics beyond its own borders, namely into other disciplines like mechanical engineering (e.g., electronics in the motor-car industry, machine control, robotics) and software engineering. Similar interdisciplinary issues exist within other engineering fields. For example mechanical engineering encompasses manufacturing, aerodynamics, thermodynamics, computational simulation and many other sub-disciplines.

In this section we relate merely to quantitative aspects of the scope of electronics. This huge expansion of the electronics discipline carries substantial effects on the contents and skills to be acquired in electronics education programs. One outcome of this development was the specialization within electronics curricula, i.e., after studying science, mathematics and engineering foundations during the two first years of an undergraduate program, there were options of specialization (e.g., microelectronics, control, computer engineering and telecommunications) in the following two years toward the B.Sc. degree. The question in this regard of fundamentals versus specifics, a dilemma remains: how to construct, run and update a well-balanced curriculum in electronics, in order to meet modern educational and professional goals.

We have seen in this section that the range dimension of electronics education has expanded enormously during the years, as a result of scientific and technology developments. Its impact on electronics curricula design must be taken into account.

Dimension 3: engineering entity

For decades the classical method of teaching electronics has been characterized by starting with general theoretical fundamentals such as electricity, electromagnetic fields principles and discrete components such as resistors, capacitors, inductors, diodes and transistors. The physical structure of the component was emphasized. Thus the resistance of a wire has been expressed through the wire's physical properties such as specific resistivity ρ and its physical dimensions (length l and cross-section A) yielding its resistance $R = (\rho l)/A$. A similar approach has been used when a two-plate capacitor was concerned ($C = (\varepsilon A)/d$). As larger scale integration in technological setups has become more commonplace, the functional definition of a system's block and even component (like a transistor for example) has been employed. Thus the internal resistance of an electronic system or block/module, is being more commonly approached as the ratio between the voltage supplied between its terminals and the current it causes. In reality, where larger-scale integration prevails, the input-output electrical behavior of an electronic system or block is more relevant than its discrete components. This development has a far-reaching effect on how electronics should be taught: the component-to-system approach should perhaps be replaced by the system-to-component orientation. This means, to start explaining how an electronic system operates using input-output electrical behavior of the system or its blocks and only afterwards get into the block and refer to the discrete components, if needed.

In the preceding section we mentioned the expanded quantitative scope of the electronics discipline (e.g., communication, digital, computer, microelectronics, neural networks, and bioelectronics). It is not only a question of expanding the quantity of contents, i.e., '*more of the same*'. The characteristics of the subject matter have changed, be it the required scientific background (e.g., need for discrete mathematics, numerical analysis, using more statistical analysis tools). This means a change in the identity of engineering contents, the *engineering entity* has changed. One may look at it as a unique dimension of change, worthy of paying attention to in new engineering curricula developments.

One of the most dramatic changes occurring in the electronics professional arena in recent decades is the transition from the analog towards the digital domain. Amplifiers and radio transmitters and receivers circuitry that operated mainly in the linear region dominated the early days of electronics (especially before World War II). In the late forties, as more industrial applications used electronic devices, particularly in control systems, switching and pulse circuits became more common. The great shift towards digital electronics began with the appearance of computers and microprocessors. More and more digital-related electronics systems, circuits and devices in telecommunication, control and home appliances, have been applied in a vast variety of applications. The situation today is that digital electronic circuitry is replacing analog circuits such as audio amplifiers and radios.

This dimension of movement towards the digital domain has reached a point that calls for introducing drastic changes in electronics curricula. It is no longer a matter of altering some electronics courses in the educational program—it challenges the whole structure and relevance of the existing programs. We will treat this issue later in this article.

Radicals amongst electronics educators may claim that there exists also a change in thinking patterns, not only in contents. Digital thinking patterns are not exactly the same as analytical/analog patterns of thinking. It is known that some engineers feel more comfortable dealing with digital systems, while others prefer analytical analyses of analog networks.

Dimension 4: information handling

Initial applications of electricity related mainly to handling energy. For example, converting energy stored in coal or fuel, at the power station, into electrical energy, transferring it via long-distance power lines and distributing it among consumers. At the consumer's premises the electrical energy is converted into another form of energy, be it thermal, mechanical or light. Over the years, as electronics evolved from the electricity supply domain, information was also handled by electronics. As a result, telecommunication entities such as telephone, radio and television evolved. Their effects on human life are known. The main change that substantially affected the nature of the electronics profession was the appearance of computers. Information handling—creating, processing, transmitting and receiving huge quantities of information, is the principle focus of computer systems. The dominance of information issues is so great that they become a primary domain of electronics. The information era, information systems and information technology are the new terms that illustrate the dominance of information in the hierarchy of modern technological systems. Is this an episode, which will diminish with time? The impression one gets is that information-matters will occupy humans' mind for the foreseeable future at least.

In regard to the electronics profession, this phenomenon of the empowerment of the information entity is illustrated explicitly by the hardware-software interrelationship. With the appearance of computers and microprocessor devices there has been a continuous shift from hardware concerns towards software ones. Problems that could in the past be solved only by hardware means, are now being handled by software, reliably and efficiently. Developments in the hardware-software dimension call for substantial changes in the electronics curriculum. We realize that this dimension of change (i.e., information handling) reaches beyond the issue of information availability factors discussed earlier.

Dimension 5: human-machine interface

Consider the electronics graduate professional practice. In the past, his/her activities related mainly to hardware. The interface was with electronic components, devices and instruments. With the appearance of computers and microcontrollers, professional activities became more and more software-related. At present, the professional user of computer-intensive equipment operates virtual buttons on the computer screen, which represent physical components such as a volume control in an on-line MP3 audio amplifier. Such graphical interfaces, called widgets [9], stand for a real object—a combination of an on-screen graphic symbol and some program code to perform a specific function.

Though the shift from hardware to software in the human-machine interface relates mainly to users, it has substantial effects on the nature of professional activities of an electronics graduate. The curriculum has to take this dimension of change (going from physical towards icon interface), into account. Human-machine interfaces have always been an issue but analogue or electromechanical equipment provided visual, tactile and other clues to users while icon interfaces do not. The icon that saves your document could look exactly like the one that deletes the entire computer hard drive. User interface issues are far more important to modern designers. Consumer electronics has led to great advances in human-machine interfaces.

In the light of the above-mentioned trends in electronics education, changes in curricula are clearly necessary, and many are indeed taking place. Furthermore, some engineering educators claim that the required changes are so dominant in the electronics discipline, that even the degree title of a 4-year electronics program graduate should be altered to **Information Engineering** or **Information Technology**. It is obvious that many electronics educators wouldn't agree with this dismantling of electronics discipline—electronics reaches beyond information handling matters (control, power handling, bioelectronics, microelectronics, etc.). This issue is open for discussion in the electronics education community. It is interesting to note that the impact of change is perceived more in the engineering technology applied-oriented programs than in the engineering programs, which put more emphasis on theoretical foundations. So, in order to illustrate the change issue we will refer to the engineering technology case.

NEW 4-YEAR UNIVERSITY PROGRAMS REFLECTING TECHNOLOGICAL CHANGE

The exponential growth of the number of people using the Internet is accompanied by huge efforts and investments of software enterprises in developing user-friendly human-computer interfacing working possibilities. Thus the typical computer user does not need to know much of the computer system's technicalities or how it works, he/she desperately needs help in deciding which technology is appropriate for specific needs and assistance in deploying and using that technology. This situation not only calls for introducing substantial changes in existing engineering technology educational programs, especially in the electronics field, it caused the emergence of new professional technologists, such as the Information Technologist.

Computer and information-related baccalaureate engineering technology programs [10] are already running in certain universities in the US. Consider some of the following examples. Rochester Institute of Technology [11] has offered, for some years, information technology 4-year programs instead of the 4-year electronics engineering technology studies. Their program started in the late 1990's and now numbers in excess of 1000 undergraduate students. Other major universities have developed similar programs in recent years; Georgia Southern, Purdue University, Brigham Young University, Macon State College and the University of Houston, to mention just a few. Such new programs do not always replace electronics studies, nor are they all necessarily named 'information technology'. Some of these programs have evolved from computer science programs or information systems programs. However they share a common core of topics based on math, science, various digital core topics, as well as a commitment to applied technical education based on a firm theoretical foundation. They also all accept the concept that information technology is an integrative discipline and that the users' needs are an important factor. They all award 4-year BS degrees. They attract many potential students of the classical electronics engineering programs. Representatives from these programs are working together nationally (in the US) to agree on curricular and accreditation standards for this emerging discipline. Various national and international bodies, such as the Accreditation Board for Engineering and Technology (ABET) and the Association for Computing Machinery (ACM) have officially recognized these efforts. A new interest group of the ACM called SIGITE (Special Interest Group: Information Technology Education) has been formed. The group has held.

Let us concentrate on one recent example illustrating the transfer of an electronics engineering technology program to an Information Technology (IT) program as it took place recently in the School of Technology at Brigham Young University [12].

AN INFORMATION TECHNOLOGY (IT) PROGRAM

Brigham Young University offered a program in Electronics Engineering Technology (EET) for about three decades. This program always had an emphasis in computer applications. In recent years, many of the graduates found jobs in IT fields as network designers, system administers and also as software interface designers and related fields. Enrollments in EET declined slowly from 1984 to 2000 as they did for most similar programs in the USA. In 2000 it was decided to recognize the trend in technology and to convert the program to an information technology emphasis. Many of the circuit design courses were eliminated or de-emphasized and were replaced with courses in software, computer hardware and system integration. The guiding principles behind the development were that graduates needed certain types of skills and that many students and employers favored a particular approach to education. The program was thus designed around principles of:

- Technological competence: the students should be able to design, implement and manage information systems.
- System level design and integration rather than component level.

- Human communication (oral, written, leadership, user advocacy).
- Experiential learning.
- Life-long learning; essential in a rapidly changing field.
- Critical thinking.

These principles were written up as the objectives of the BYU program [12].

Research and collaboration with similar developing programs at other universities helped to develop the core technical topics of the curriculum. The curriculum now includes basic analogue and digital electronics, design of digital systems, software coding, operating systems, networking databases, electronic communications and human-computer interfacing. This is combined with courses in mathematics, (calculus and discrete mathematics), physics, statistics, human communications, and other general education support classes. All technical classes include a significant laboratory component and most of the third year and above classes include projects. All students are required to select, design, implement, present and document a project in the discipline as a capstone experience in the fourth year. Concepts such as teamwork, project management, system-level thinking, life-long learning and enterprise-wide integration are formerly taught and applied in projects and classes. The principles mentioned above are not necessarily taught as specific classes but are incorporated into classes in the major.

The above curriculum was announced early in 2001 and offered formally in fall 2001. Student acceptance has been excellent. With almost no publicity and no formal recruiting efforts student enrollment has increased about 30% in one year and the growth has been sustained for three enrollment years so far. Enrollment in the program is now being capped due to limited teaching resources. Similar increases in enrollment have been seen at other campuses offering IT or related degrees. Much work remains to be done.

The relevance of the new program in information technology can also be illustrated by its comparison to other similar programs offered at BYU and at many similar institutions. In addition to information technology BYU has programs in computer science, computer engineering and information systems. The information systems program is hosted by the School of Business and is characterized, in this context, by required courses in accounting, business management and related business oriented courses. The remaining three programs all share a core of advanced mathematics, physics, and modern computer programming techniques. Computer Science is characterized by its emphasis on software algorithm design. Studies in this program include software effectiveness, discrete mathematical analysis and management of small and large software design projects. Computer Engineering is a classic engineering program with an emphasis on design grounded in scientific and mathematical principles. Students focus on computer hardware design and are also competent in software. In contrast to these disciplines the Information Technology program is housed in the School of Technology. It has an emphasis on system design at the macroscopic level. While students are competent users and writers of software they will spend a greater portion of their time configuring systems comprising hardware, servers, networks, databases and the like. The program is also characterized by its emphasis on human-computer interfacing and on project management and written and oral communication. Being housed in a technology school with its traditions in the fields of engineering technology the program requires extensive project and lab work. By the time the students reach their fourth year of study they will have completed several projects independently and are well prepared for their capstone senior project experience.

FACTORS AFFECTING THE IMPLEMENTATION OF THE IT PROGRAM

In his keynote address at the 2nd Global Congress on Engineering Education the Editor-in-Chief of the *International Journal of Engineering Education*, Dr. M. S. Wald [13], claimed that the traditional approach to curriculum change (plan; prototype; assess; modify and adopt) at a university is focused on the curriculum itself. One of the main drawbacks of this traditional approach is that the changes are dictated from above, without enough active cooperation (and motivation) of the practitioners that are directly involved in implementing the curriculum changes, especially the relevant faculty members. In many cases '. . . their only real involvement was trying to guess how this change would affect them, and in the absence of this information, they would opt for no change'.

A new Curriculum Change Model (CCM), to which Wald refers, has been developed and applied recently by a team at Texas A&M University [14]. The focus of this new model is on changing the behavior of people, rather than changing the curriculum itself. The main component for motivating change is to foster cognitive commitment from those involved in introducing and maintaining the change (including the decision makers). This model is based on five general stages:

1. identify the subjects whose behavior needs change;
2. act to neutralize the objection to change;
3. implement changes;
4. evaluate outcomes and reward participants;
5. stabilize changes.

So far only the first three changes have been implemented in the new Information Technology program in the BYU case. Evaluation and stabilization of the curricular changes are forthcoming steps, which are in progress.

The new curriculum at BYU was developed in the full knowledge that concepts such as outcomes-oriented education and continuous improvement would be expected of them. These concepts have been built into the design of the curriculum. The program has now been through a couple of cycles of update and improvement and the faculty are finding what mechanisms to keep the program current and relevant, while maintaining standards according to basic goals, are effective so far. However this must still be considered early days and further evaluation is required. Findings relating to these stages will start to be available after the autumn of 2003 [15].

CONCLUSION

We have analyzed the trends of changes required to be introduced into the Electronics Engineering Technology curriculum, as a result of recent (and ongoing) technological developments, especially in the fields of computers and information technology. These changes are characterized by multi-dimensional factors, which some of them have their roots back in the seventies, with the spreading of personal computers. These trend factors relate to changes in a variety of dimensions such as going digital (from analog), interdisciplinary (from specialized), software (from hardware) and relating more to systems rather than to components.

We have surveyed some engineering technology educational programs already running in several universities in the USA, and presented a unique program for BS studies in Information Technology (IT), prepared in the School of Technology at BYU. Though the IT program relates to the existing Electronics Engineering Technology (EET) it is substantially different, in the sense of the above-mentioned dimensions of technological trends (particularly in the computing domain). Therefore it was decided to replace the existing EET curriculum by the IT program, starting Fall 2001. The main feature that distinguishes the proposed IT program from other IT programs is the robust integration of hardware and software; aiming at imparting to majors a certain extent of 'technical autonomy' so the graduate will be able to fulfill the role of the technology and computer authority/leader at the workplace. This program also offers options for minor studies for students of non engineering disciplines.

The engineering education literature shows that preparing a new curriculum such as the one presented in this paper is merely one step in introducing and managing curriculum change. This stage comprises merely the 'What' (contents) of the changes. Unless the other component of the curriculum change is taken care of, namely the 'How' component, the chances for introducing the curriculum changes are slim. Furthermore, these two components might even be interdependent. In introducing a new program, such as the IT, one should focus on people: cooperate with the decision makers and instructors from the start (as has been the case at BYU).

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