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II-2 THE IMPACT OF TECHNOLOGY ON ELECTRICAL ENGINEERING EDUCATION, PARTICULARLY IN ELECTRONICS AND INSTRUMENTATION

by

K. C. Smith
Department of Electrical Engineering
University of Toronto

The Pervasiveness of Electronics

The possibilities of providing power, measurement and control account for the ascendancy of Electrical Engineering over other engineering disciplines. These possibilities are in turn only manifestations of a single subdiscipline, namely Electronics. It is Electronics which makes possible all of the important technological change we see. Without instrumentation and measurement, control and the need to power would vanish.

In terms of the traditional power and communications divisions of Electrical Engineering it is Electronics which lies at the fore-front of technological change. Spectacular specifications of new products appear almost daily: In power applications one sees kilovolt, ampere, nanosecond switching transistors and 1000 volt 1000 amp, 10 kHz SCR switches and 3 inch diameter, 10 Megawatt rectifiers. In communication one sees Impatt oscillators at tens of gigahertz or amplifiers providing 5 watts of output at 5 gigahertz with 10% band width. The mind boggles! But what of education?

Mechanics for Impact on Education

While motivating a need for change in education, Electronics provides the means as well. It is through the advances in Electronic technology that many things undreamed of a few decades ago are now economically possible. Through Electronics, we, as educators, are provided with a host of devices and tools which make our job at once more easy and yet more difficult. The existence of ideal building block modules: op amps, logic, phaselocked loops, etc., allows us to deal easily with complex concepts unfettered by details of implementation. Yet, at the same time, we need not, and perhaps may not, occupy our time teaching the perhaps easily taught detail. We must face the challenge of identifying what is globally most important.

The advent of the zero-cost microprocessor technology will surely revolutionize the world. Interestingly enough, it tends to invert its environment. A major cost of its use is the labour to program it. The major shortage its presence identifies is one of ideas. It may be responsible for a return to a labour intensive society, or at least provide, at low cost, games for the idle to play.

In our view of impacts we should not fail to identify the real source of impact of what is thought of as computer technology. Computing, per se, is only a special and degenerately simple application of the real basis of the technology, namely digital memory. It is memory and its relatively low cost* which has been, and will be, the major driving force in information technology.

* complete systems at .001 to 1 cent per bit.

The Operational Amplifier as a Vehicle for Teaching all of Electronics

This section, which might be also called "Analog Computing Revisited", will address the possibility of using the op amp to invert the traditional view of the educational sequence in Electronics. The traditional view, for those of you who have already abandoned it, is "fundamentals first, frills finally".

I wish to suggest that the op amp can be used in a first course subtitled "Ideas that Work", and that this course may be logically followed by others subtitled "Why?".

Such a course should itself be taught in a spiral of increasing complexity. It begins with the general concepts of characterization and modelling using a simple view of the op amp as implemented by controlled sources or as an implementor of them, then proceeds to real, realistic and realizable applications, both linear and nonlinear. Amplifier configurations based on simple Kirchoff arguments can be used to inspire simultaneously an interest in themselves as well as formalism which is, and is described to be, basic feedback theory. Positive feedback as well as negative is automatically produced. Two-state digital devices and Kirchoff logic automatically follow to motivate other principles.

In a similar way oscillator principles follow as do filters. The need for power supplies and ways to make them naturally occur.

On a later loop of the spiral, characterization is expanded to include the fact that the effective utilization of a hierarchy of models is the key to successful engineering and that second and third order properties of the op amp can be described, understood, and even used. Frequency effects, feedback compensation, etc., automatically follow at some degree of intensity. And so on, and on, and on in a widening spiral capturing more and more of reality while having captured and maintaining the imagination.

The Basis for Change - Trends in Industry

But what should we be doing? Self serving introspection is at least suspect if not wrong. One may rightly explore the direction indicated by industry. Data for one such industry, Bell Telephone Laboratories, a traditional bell-weather for the Electronics business, is shown in Table 1. This Table lists in the major four segments of the particular industry, numbers of attendees in a course program given to about 3,000 candidate employee engineers in each of six years.

What might one conclude? Apparently, there is either very little need for classical network theory or it is being taught adequately in the schools from which these employers emerged. I suspect that it is a combination, with a bias to the latter. Perhaps more to the point of

TABLE 1*

THE BASIS - TRENDS IN "INDUSTRY"

Bell Telephone Laboratories

	70/71	71/72	72/73	73/74	74/75	75/76	TOTAL
Classical Network Theory		12			16		28
Digital Filters	112	105	131	48	57	6	460
Active Filters	44	0	0	37	15	19	115
Circuit Design	146	177	194	281	166	320	1393

≈ 3000 candidate employees

TABLE 11*

CIRCUIT DESIGN - BREAKDOWN

Integrated Circuits		
	General	334
	Analog	361
	Digital	39
	Microwave	23
Circuits - Technique		
	General	184
	Feedback	148
	Logic	50
	Phase Lock	116
Computer Aided Design		138

* Tables 1, 11 presented on slides at the 1976 International Symposium on Circuits and Systems, Munich, Germany, April 29, 1976, by Frank Witt

this presentation is the emphasis on Circuit design. The detail of this effort is exposed in Table ii, which expands the total attendance (1400) for Circuit design into subdisciplines. There is a wealth of interesting conjecture available in this data. For example, in an organization where digital technique is very important, why are there so few course takers in digital circuit design? Is it because schools do such a good job in teaching this? Unlikely. Is it because it is fundamentally so simple and/or learned automatically if one learns something else, say analog circuit design? Probably, but this shows my bias.

The Broader Perspectives of Electrical Engineering Education

What are the goals of the process? Clearly there are many. One must distinguish the scientist from the engineer, and the engineer from the technologist.

One must bear in mind that our real goal is to teach students to solve real problems as well as the implied perception of what is real. Yet more than today's tools are needed. Our need to teach basics is identically our need to provide tools to do the job. Thus, for the future of our students, one of our major goals must also be to teach tool making.

To Engineer is to examine, to synthesize, to implement, and then to test. Each is equally important.

With apology to G. Sinclair for a potential misquote, "Engineering is a vocation requiring knowledge of engineering science and judgement based on experience, concerned with creating the means for man to deal with his environment".

It is probably clear to us all that Engineering Method is equally as applicable to economics, education or political science. It is our challenge as educators, to use Electrical Engineering as an example of the approach, the Method, in effective use. The rapidity of change in technology makes this all the more interesting and possible. But how?

A Philosophy for Engineering Education in an Expanding World

As technology expands, so also appears the need to teach about more and more. As we stretch finite minds in finite time with more and more material, an inevitable superficiality appears. As the basic product of the TV age enters our halls, so does he leave. He is, by past standards, well educated, his perspectives are broad. He knows about more things than any of us at his age. But his depth of perception is lacking. There is a glibness and superficiality to his knowledge. It has rarely been tested, never tried, and lacking a depth basic and fundamental to the process we identify as synthesis. Faced with a real problem, unstructured, underconstrained or overconstrained, this mind is muddled.

The difficulty is that we in general do little about this lack of depth. We do not identify it, and more seriously, while we are the victims of it, we propagate it. What we need is a serious effort to rethink the process.

If we are basic, we are not relevant. If we are relevant, we tend to be superficial. If we are basic and relevant, we are not broad. What is the answer?

Clearly, we must deal with basics at some level, let us call it mathematics, science and communication. We must also deal with technique: problem capture, problem solving, learning to learn and interpersonal skills. It is this package which is called Engineering.

The issue is one of breadth versus depth in a learning space whose total area is beyond the comprehension of most students. Thus we are forced to a sampling process on the assumption of the existence of some proximity measures in this learning space, and the hope that the goal of education might be to maximize a collection of such measures.

As I see it, our challenge as technology changes around us, is not as great as it might otherwise appear. It consists only of the continuous process of selecting, in the single dimension of breadth, the essential components of a core program which, by sampling, stretches the mind over the subject space. The only complexity beyond implied uniform coverage is to represent all of the extremes as well as provide at least one example of close proximity or potential for inter-relation of subjects.

In the proposed scheme, breadth sampling is not optional. Only the depth at which a subject is taken is optional. A student must demonstrate depth, but he is given a choice of the areas in which he will do this. To demonstrate it in one area may be adequate but it is probably safer to require two orthogonalized choices by some standard means.

What does depth consist of? The choices are many and a collection of approaches should be used. One is facilitated by the inverted (basics last) approach to education which I favour. Clearly depth may be achieved by taking a more basic or fundamental course. Often a course with some intensity in a cognate area may legitimately be a measure of depth and accommodates some aspects of the specialty courses common in current curricula.

There are of course many other approaches. One offering simplicity and economy is simply the possibility of writing a second "honours exam" in selected subjects. The only resource necessitated by this process is in the mind of the participant. Perhaps it would be humane to provide additional tutorial/problem/laboratory experience as a prelude to this particular measure of depth, but it is not necessary!