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A Circuits Course Family for Technology Students Using Just-in-Time Techniques

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Introduction

The teaching of electronics to students of other disciplines and majors is becoming more prevalent in technology curricula. “Non-electrical” majors are often turned off by a non-major subject. Also, many electrical/electronic faculty members have difficulty teaching “watered-down” fundamentals to non-electrical/electronic majors. Yet the demands of industry for multi-disciplined B.S. graduates are increasing as more high-technology firms strive to become increasingly effective and efficient in the global marketplace.

This paper describes the development of a multidisciplinary instructional package for teaching a circuit and system-design sequence. It includes a:

(1) theory-oriented text that emphasizes the connection of engineering-technology technical material to the physics,
(2) companion laboratory-experiments text required to reinforce the theory, and
(3) technical-communications text to assist students in learning and tying written and verbal communications to their newly-found knowledge.

More than ten years ago, the authors developed the concept of Just-In-Time Education™ (JITE). It follows many of the principles of Just-in-Time (JIT) Manufacturing. A brief history of JIT education is summarized to provide an overview of the approach.

The JITE objectives were converted into chapter outlines. These outlines are being converted into theory, laboratory, and technical-communications text material. Each of the resulting texts is being designed so it can be used separately or as a package. Finally, an instructor’s manual is being developed that will contain strategies for presenting all or a portion of the instruction-material package in part and also as an entity.

A trial offering of this course is planned for the Fall of 2004. (Interested faculty and administrators should contact the authors.) Results of developments to date are included in this paper; an update of additional development work will be presented at the conference.

Just In-Time Education™

As noted above, JITE was developed from the concept of JIT manufacturing. In the manufacturing environment, parts, pieces, and subsystems are delivered to the assembly process as needed, when needed. In curriculum design, the mathematics and physics are the "parts" (topics) that need to be delivered to the student just as that student begins to study technical material. The material is first divided into learning objectives that have measurable inputs and outputs. These objectives are connected in a precedence diagram. See Figure 1 for an example.

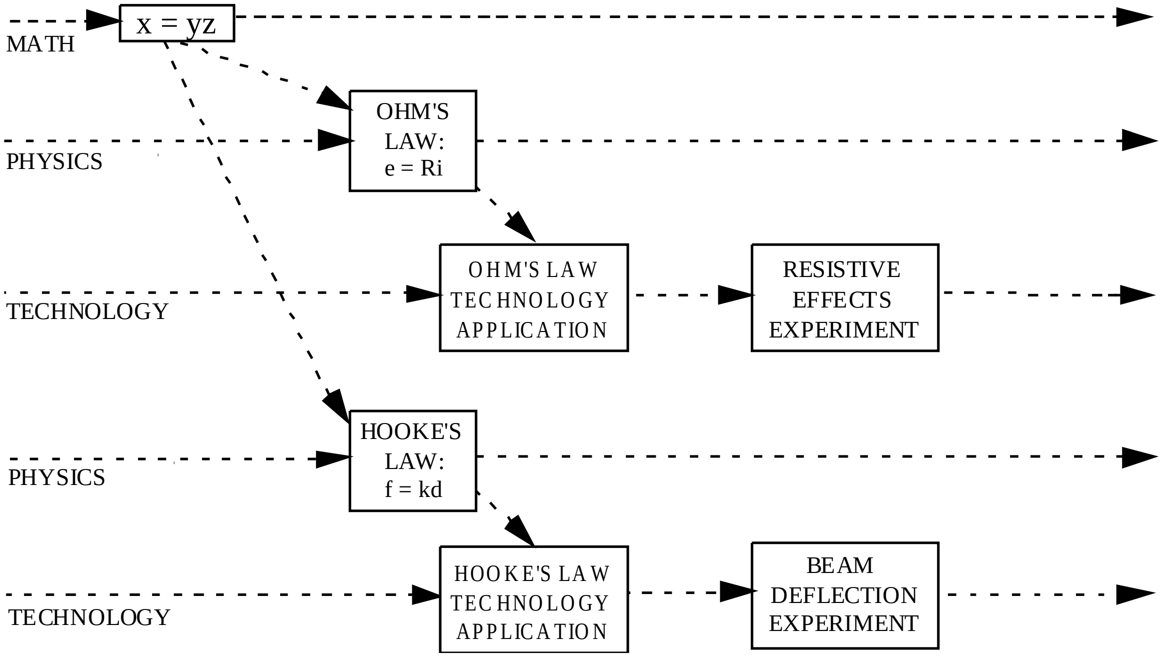

Figure 1 – Partial Precedence Diagram

The above diagram visually shows the sequence (precedence) in which the mathematics, physics, and technology information is required for learning. Greater comprehension and retention occurs. Just-In-Time Education includes all aspects of educational practice: curriculum, instruction, and assessment.

Prior to examining Ohm's Law and Hooke's Law, the student is tested to see if x = yz is known and that it can be manipulated correctly to solve for y and z. That fact is ascertained first. Once the answer is "yes", then the physics, whose math parallels the two laws (Ohm's and Hooke's), is presented and tested. The next mathematical concept (after x = yz) is presented and tested; the companion physics/technology sequence is then presented.

After the information in the above seven blocks has been presented and verified, the next mathematical topic is presented. An example is the solution of two simultaneous equations. After verification testing, then Kirchhoff's Laws can be presented. Next a simple circuit solved for two unknown voltages and/or currents is analyzed. For the mechanical field, a one-dimensional combination of forces upon a body, such as a beam, or the interaction of pulleys and forces, can be presented. The complexity of each technology problem can be extended as the simultaneous solution of equations leads from simple substitution to determinants to matrices. Later, the geometry of two-dimensional forces and the geometry of interacting sine-shaped waves are introduced as parallel topics to the mathematics of geometry.

Tests are given on a continuing basis. These tests, because of their design, are known as diagnostic tests. The various diagnostic tests are used to determine where a student should enter the precedence diagram. They also provide specific remedial guidance for each student. See the example of Figure 2.

Mathematics Diagnostics Test

Problem:

Solve for i where e = Ri.

Answer:

a: i = e/R
b: i = R/e
c: i = Re

Solution:

The answer is: a

Error:

If b or c were chosen,
then go to (the school's
designated math text),
page 21 and solve
problems 3-21 odd.

Figure 2 – Sample Diagnostic Test Problem

The various diagnostic tests will be included in each section, allowing the instructor to be an overall guide for many students. Thus the remediation details are left to individual students supported, where necessary, by teaching assistants. The diagnostic-test concept was initiated more than thirty years ago in classrooms at the University of Massachusetts in Lowell and at the Northeastern University School of Engineering Technology. The first published application of diagnostic tests can be found in Math at Work[1].

The Goal

The goal is to devise text and chapter outlines. Then hard-copy and software texts will be written to allow student education for integrated fields. These fields include electrical, electronic, mechanical, fluid, and thermal "circuit" design. Circuits and devices are examined separately initially; then they are then brought (integrated) together. The authors, in conjunction with a few publishers, have been working on this problem for more than two years. The encouragement of many senior and retired faculty has been extensive. Present teaching faculty and publishers seem to be resistant to such significant changes.

From the JIT analysis, the mathematics and physics level required for each new electrical-engineering concept is established. JIT techniques are then used to review and, if necessary, re-teach the applicable mathematics and physics. (Our approach in developing these texts is primarily to re-teach or review the material.) Both the mathematics and physics are adapted so each student can ease readily into the design and analysis of components and devices. (These components and devices are discipline-integrated in a modern circuit and system design approach.)

Timelines are included within the theory text to provide historical perspective relative to today's technology. They assist students in connecting the evolution of mathematics and science. Much of the mathematics came from bookkeeping and astronomy. The sciences led to the present-day electrical and electronics fundamentals. Our hope is that students will also realize how chemical and industrial research and experimentation led to today's components and devices, and vice-versa.

Inclusion of early-on written and verbal technical communications education should be included with any family of technical texts. Knowledge learned and understood, without having the ability to communicate that information to others, is almost useless as has been noted many times by the Accreditation Board for Engineering and Technology (ABET) and its predecessor (ECPD) for more than a decade. Recent changes in the ABET evaluation criteria require that both oral and written communications are woven into the technical courses. Its impact upon most educational institutions has had a modest effect. Industry representatives cringe when interviewing many final-year students who are looking forward to working in industry and making a useful contribution rather quickly. Much mentoring and additional training/education is required on-the-job, particularly where practical applications and technical communications are concerned.

Existing Problems

There are few introductory texts in the circuits and design fields that integrate theory, practice, and communication. The design and analysis techniques applicable to integrated-field systems are directly applicable from introductory electrical/electronics texts. Most of these texts assume that students can recall, and immediately apply, the applicable mathematics and physics to modern-day design and analysis problems. These disciplines include electrical, electronic, mechanical, fluid, and thermal interactions. Most introductory electrical/electronics texts also avoid any involvement of non-electrical components and devices.

Faculty members seldom want to face the problem of including laboratory experiments whose student documentation is more than a repeat of the data obtained while performing the experiments. Administrators trying to lower laboratory-equipment costs are moving to the inclusion of more simulated (virtual) software packages, such as the Multisim Electronic Workbench™. Administrators are reluctant to negotiate the inclusion of non-technical faculty costs required in the areas of technical communication. Why? Because the allocation of these costs among the various colleges and departments can be difficult.

Most institutions that educate liberal-arts students in the areas of information communication and presentation are extremely uninterested in becoming a supporter of the technical departments. They often do not comprehend, and do not wish to acquire, the technical language. At university-oriented faculty meetings, they often feel like outcasts. The attitudes of the engineering, technology, and business-administration faculty that also attend these meetings do not help either.

The Challenge

There are five groups that must interact in moving electronic circuit theory to engineering "circuit" and system design and analysis, including standardization of terms, symbols, and nomenclature. They are:

- The electrical-engineering circuit teaching faculty and administrators
- The professional societies for all the engineering fields
- The students, and those from industry who hire them
- The authors and reviewers of textbooks related to the general subject
- The publishers of texts that encompass the overall material

The Faculty and Administrators – As an example, many electrical/electronics faculty are attached to continuing the use of "v" for the voltage notation, such as in $v = R \cdot i$ (Ohm's Law). However, for integrated-field analysis, the "e" as in electromotive force, would be better because it would not conflict with the "v" for mechanical velocity. There is much opposition to this change because of historical usage. Another example is that some administrators and professional-society executives propose the addition of a fifth year in engineering programs, not counting co-operative experience, before the receipt of a B.S. degree. Better integration of introductory technical material, including mathematics, physics, and systems-design concepts, should eliminate the need for an additional undergraduate year.

The Societies – There is much to be examined and accomplished in the areas of diagram, nomenclature, and symbol standardization. Perhaps leverage via the American National Standards Institute (ANSI) as an overall technical coordinator of standards would be of benefit. Also, ANSI personnel have excellent contacts with the International Standards Organization (ISO) which would be involved in any consideration of new or revised standards.

Students and Industry – One of the significant complaints from both students and industry is the length of time required to train multi-disciplinary engineering-technology students. In 1994, ASEE summarized the challenges as: "… accommodation of a greater diversity of students, as well as the need to shift to a technological policy strongly focused on national security to one aimed more diffusely at international economic competitiveness, communications, and sustainable development."[3] This transition has had an impact on the academic community. "Academia is now on the defensive – not absolutely certain of what we need to help create; [they have] to react to a reality that defies its very approach to thinking. Change, often orchestrated by committee, as may be expected is not often a change and when it is, however slow it may be, needs other such committees to engineer the said change."[4]

The Authors and Reviewers – Our interactions with some authors and reviewers have led us to realize that many of them have not kept up with the proposed and accepted changes in technical standards. Authors (and faculty) should strongly consider monitoring and/or joining their professional-society standards committees and subcommittees.

The Publishers – We have some sympathy for those publishers who are given no access or minimal access except at great expense, to standards for the diagrams, nomenclature, and symbols that have been proposed by the professional societies. Our contact with the IEEE standards group has resulted in their not even answering some of our inquiries regarding their components and notation, and their willingness to assist publishers with reasonable-cost standards and symbols. Also, the publishers are under great strain to achieve profits so their corporate stock will continue to grow in value. Thus they are often less than willing to experiment with new concepts that may take awhile to be accepted and eventually lead to greater book sales. One publisher indicated that integrating technical information with communication skills and with technical materials makes conceptual sense. However, because this integrated approach is not practiced widely today; this limits the degree to which a publisher could support the text proposal described below.

Perhaps a professional coordination group could be formed. It would consist of educational faculty and administrators and industrial employees that would work to devise standards regarding circuit, device, and system diagrams. This group would be interdisciplinary and will hopefully be acceptable to the various professional societies – both nationally and internationally. Funding would be necessary so the group could meet periodically rather than correspond only via e-mail and snail mail.

The need is great as we try to accomplish at least two standards:

- standard diagrams for multi-field components and devices
- analysis techniques that apply advanced mathematics, such as the Laplace transforms

These integrated diagrams and their accompanying analyses would then easily lead to multi-field servo-system design and analysis. A copy of our recommended standard diagrams, nomenclature, and symbols will be provided to those persons who are interested in its status. Some of you may wish to assist us in formulating an overall engineering standard for our proposed diagrams, nomenclature, and symbols. (Contact bobangus@tiac.net with a postal mailing address.) Included are the symbols and notations for electrical resistors, capacitors, and inductors; mechanical friction, springs, and mass; fluid friction, inertia, and mass; and thermal resistance and capacitance interactions.

Our Plans

A number of related charts have been prepared that develop and review the mathematics and physics as related to a family of circuits-course texts. As noted above, this family of texts includes:

- a just-in-time, integrated-theory text,
- a laboratory manual, including both actual and virtual equipment, and
- a written/verbal technical communications text

Interested reviewers have examined and commented upon the present outlines for the above materials, both as stand-alone texts and as an integrated family. We have contacted two publishers whose interest will depend upon later surveys of the potential market. Conference attendees and readers of this paper are encouraged to provide feedback. Please evaluate this plan with respect to your personal feelings and also with respect to the folks within your department and/or institution. Send your comments to the e-mail address above.

Status

The theory text is approximately 70% complete and has been reviewed by supportive faculty. Their suggested changes have been incorporated. One publisher selected several electrical-electronics faculty to review the first eleven chapters of the theory text. Their comments include suggestions for improvement, most of which are being incorporated into the latest drafts. Some of the more fascinating comments are:

- … this text did not “turn me on”; maybe it was the comparison to mechanical systems, the conservation of power …
- I don’t like the negative-power concept (load power is +, source power can be + or -)
- text uses a physicists’ point of view to address engineering/technology concerns
- don’t like timelines that include astronomy, physics because it is not circuit theory
- the first “g” in giga (10^9) is <u>not</u> pronounced “jiga”
- charge is electrical force
- why describe mechanical, fluid, and thermal effects in a “circuits” book?
- amplifier (op amp) equivalent circuits belong in an electronics text
- is generally more explicit on issues that I would expect students to deduce on their own

Many of these and other comments indicate the (understandable) attitude of the teachers of just electricity and electronics; they do not want to learn and teach how these topics fit with other topics that seem unrelated to them. They just want to teach electricity/electronics; not teach those technology students who want to broaden their education to encompass today’s needs. One publisher-chosen reviewer noted that he was using a text that was in its “nth” edition and did not want to consider a new text that was “different” although interesting. We view the above comments as somewhat discouraging as they indicate the mind-sets of present-day faculty.

Summary

In this paper the authors have shown how the concept of JIT education can be used for developing instructional material. The materials being written and evaluated use an innovative approach. It combines the learning of theory, the applications of that theory to practice, and the communication of that knowledge to others. Just-in-Time learning is more effective and should lead to better retention of that material.

References

1. Angus, R. B., and Clark, C. A., Math at Work, Prentice-Hall, 1999.
2. Angus, R. B., and Hulbert, T. E., Objectives to Outcomes and Back, Flexible Automation & Intelligent Manufacturing (FAIM) Conference, Dublin, Ireland, 2001.
3. Engineering Education for a Changing World, American Society of Engineering Education, 1994.
4. Karim, M. A., Engineering: Diversity of Disciplines and of Students, The Interface (IEEE Education and ASEE Electrical and Computer Engineering Division), Nov 2001.

Biographies

ROBERT B. ANGUS is a Senior Lecturer at Northeastern University with 55 years of part-time and full-time teaching experience that includes mathematics, physics, and electrical-engineering courses. He has also been a design engineer, engineering manager, and senior engineering specialist for more than 20 years. For the past 20 years, he has been an engineering consultant specializing in circuit and system design, curriculum development, and technical-manual writing.

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