Retention Through a Coordinated Spiral Curriculum

Robert J. Herrick, James Michael Jacob, Jeffrey J. Richardson

Electrical and Computer Engineering Technology Department
Purdue University

Abstract

The Electrical Engineering Technology (EET) Program of Purdue University at West Lafayette, Indiana implemented significant curriculum change in the fall of 1996. The focus of the change was to produce a relevant coordinated curriculum to optimize the students' learning process and provide a curriculum path that retained qualified students rather than filtering them out. This paper describes the characteristics of the innovations introduced, the successful retention outcomes achieved as a result of these changes, and a national textbook series that was generated from this spiral curriculum.

Introduction

The faculty of the EET Program, after just completing a highly successful national accreditation evaluation in 1992, decided to review and revise as needed their curriculum. Rather than resting on their laurels of their recent accreditation success, the faculty spent an intense two years developing a new curriculum. The challenge was to re-think and re-design the entire curriculum, *tabla rosa*. The fundamental goal was to create a curriculum for optimum learning of relevant curriculum content without being shackled to old traditional pedagogy and methodologies that were aimed more at delivery than they were at learning. Another overarching goal was to create a coordinated curriculum that facilitated the success of our students rather impede their progress with built-in snares that filtered out qualified students. After two years of meetings, seminars, and workshops, forty faculty came to 93% consensus of a new curriculum that was focused on a *coordinated curriculum*, an integrated *analog electronics* course series utilizing helical or spiral education, innovative pedagogy to stimulate and excite the learner, and teaching techniques to engage the learner as an active learner. Helical or spiral education is an educational technique or curriculum structure that introduces something at a very elementary level but then continues to spiral back to that topic teaching it (and thus learning) at deeper levels of understanding with each cycle. Jerome Bruner, a leading national educational psychologist, made a strong case for spiral curriculum and education[1, 2]. "*The Process of Education* (1960) was a landmark text. It had a direct impact on policy formation in the United States and influenced the thinking and orientation of a wide group of teachers and scholars. Its view of children as active problem-solvers who are ready to explore 'difficult' subjects while being out of step with the dominant view in education at that time, struck a chord...".[3] "Jerome Bruner is not merely one of the foremost educational thinkers of the era; he is also an inspired learner and teacher. … To those who know him, Bruner remains the Compleat Educator in the flesh…".[4] The spiral curriculum approach is very effective but very difficult to implement, especially if multiple faculty are involved. After 8 years of evolution, the Purdue ECET program has been very successful in meeting its fundamental objectives utilizing a coordinated spiral educational approach, primarily focused on its analog electronics curriculum.

Coordinated Spiral Curriculum

Although the curriculum had just passed a rigorous review by its accrediting agency, the faculty believed that there was always room for improvement. The faculty decided to step back and examine the entire curriculum with fresh eyes. The faculty threw off the shackles of mundane mentality and looked afresh at curriculum. If we the faculty could start with a clean slate, what would we create? The faculty determined that the curriculum must have the following key features:

- Satisfy accreditation criteria
- Provide breadth and depth of curriculum content
- Include a projects thread through the program to develop professional skills
- Incorporate a just-in-time curriculum content flow
- Produce streamlined relevant curriculum content
- Create a coordinated, integrated, and spiral curriculum as appropriate
- Develop a curriculum driven naturally by meaningful content as opposed to following an off-the-shelf textbook

Accreditation is a choice that can be made; however, as a service to our students and our graduates, accreditation by practice is a necessity. Professionally accredited degrees are frequently required by employers. Accreditation facilitates transferability of courses between educational institutions and provides additional opportunities for graduates to continue their education into graduate school. And, ultimately, it is a statement of quality in terms of meeting a professional criterion that is accepted nationally.

The Purdue EET curriculum produces national as well as regional graduates and must therefore provide breadth and depth of subject matter. Breadth is also needed to provide a solid foundation in the first two years to allow for selection and specialization by students at the junior and senior level. The size of the program permits the opportunity to provide a diverse offering of upper division specialties: analog electronics, digital electronics, embedded microprocessor control, electrical power and energy, industrial and process control, analog and digital signal processing, RF communications and telecommunications, and industrial networking. Also, the program must have the flexibility to incorporate emerging technologies while maintaining a strong foundational base.

The graduate must not only be knowledgeable in their academic discipline but must be prepared to apply their knowledge and to seamlessly join the engineering workforce. Project management, work ethos, professional etiquette, team membership, and team leadership are primary ingredients for professional success. Projects threaded throughout the curriculum are utilized to develop a professional skill set, both individually and as team members and team leaders.

Curriculum content and flow is critical to the success of the student and their education. A curriculum must be coordinated in its use of subject matter and supporting curriculum such as mathematics and the sciences. One of the fundamental changes implemented in this program was spreading algebra and trigonometry from one semester out to a full year. This was a major shackle. Many faculty initially *perceived* this change as a weakening of the program. However, after significant discussion, this change was looked upon as a major enhancement that allowed greater flexibility in the curriculum. In looking at the data, on average our students were not being successful in the one-semester algebra-trig course and the curriculum was attempting to force what the faculty ideally wanted (not reality). A revelation discovered later is that students now have algebra II in their sophomore year of high school so it is no wonder their algebra skills need to be re-tooled when starting the program. The mathematics sequence was revised from algebra-trig, calculus I, and calculus II over three semesters to algebra, trigonometry, calculus I, and calculus II over four semesters. In conjunction, the standard circuits-electronics curriculum was then revised into the *analog electronics* curriculum bolstered by the new mathematics sequence (a just-in-time tools approach). Table 1 and Figure 1 demonstrate this transformation. The first two courses in the *analog electronics* sequence are algebra based. The third course in Advanced AC Electronics, utilizes trigonometry, complex numbers, and phasors, which are covered in the previous semester's mathematics course (just-in-time mathematics timing). The fourth course in Power and RF Electronics requires the use of Calculus I, which again is taken the semester before (just-in-time mathematics timing again). This creates an additional year of maturation during their mathematical development; mathematics has been significantly reduced as a stumbling block for our students and has become a much more reliable tool for them.

Table 1 Typical circuits-electronics sequence and corresponding mathematics

Passive Circuits I	Algebra-Trig
Passive Circuits II	Calculus I
Analog Electronics I	Calculus II
Analog Electronics II	

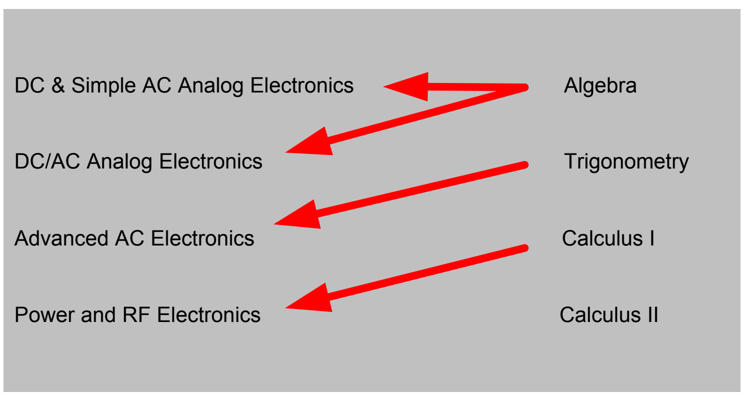

Figure 1 Just-in-time mathematics in *analog electronics* sequence

Ideal active devices such as op amps (operational amplifiers), BJTs (bipolar junction transistors), and MOSFETs (metal-oxide semiconductor field-effect transistors) can be used to create a first-semester active circuits course that teaches fundamentals using popular electronics circuits. This foundational change transformed the traditional circuits-electronics curriculum into the *analog electronics* series of courses as shown in Figure 2. This *analog electronics* curriculum immediately engages the students in exciting and interesting electronic circuits (the reason they selected this major area of study). The student is immersed in active circuits throughout the first two years instead of only the 2nd year. By the fourth semester, students are studying and working with electronic circuits far beyond the possibilities of the traditional EET program.

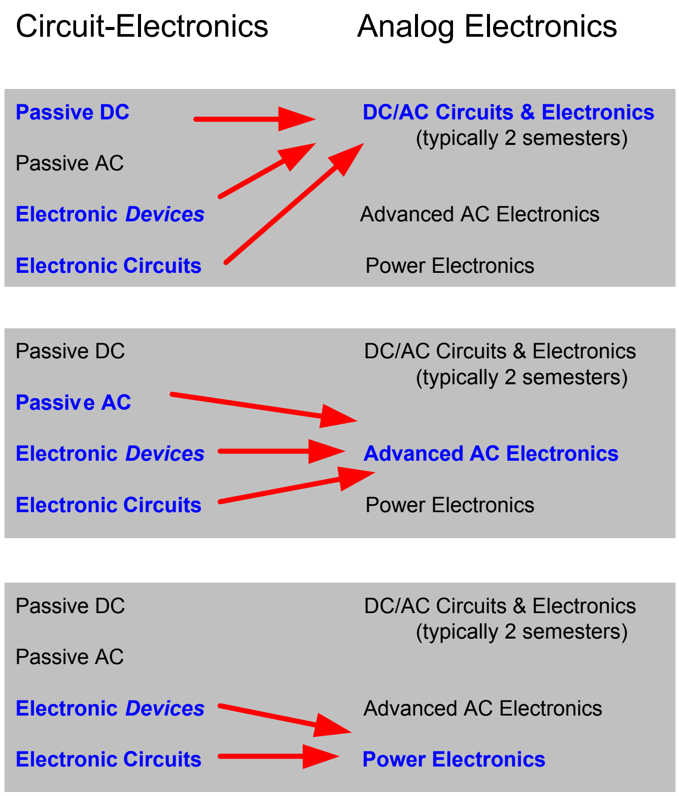

Figure 2 *Analog Electronics* Equivalent

Retention

Retention trends for the Electrical and Computer Engineering Technology at Purdue University's main campus are shown in Figure 3. The university registrar's office counts a student as retained in the department if he/she started in that department and if that student takes a class *somewhere* at Purdue the following semester, regardless of the department of the subsequent courses. So, if a student starts in ECET, and then transfers to Computer Science, or English, or Recreational Studies, that student is counted as retained by the ECET department. This is the upper line. It only indicates that 95% of the students that started in ECET in 2002 continued *somewhere* at Purdue. This places an upper boundary on the actual retention rate.

The department retention rate is obtained by tracking every student that took the first course in the analog sequence to see if they took the second course. If they did, they are counted as retained. Since there are always some non-majors in the first analog course, this calculation presents a value that is too low, forming the lower boundary.

The math SAT scores of entering students varied from a low of 534, in 1991, to a high of 566 in 2001. To compensate for this variation, the department retention rate for each semester has been divided by the SAT score of students entering that semester, and then multiplied by 534. This normalizes the data for variations in math SAT scores to that of the 1991 scores.

The change from the traditional curriculum of (DC Circuits, AC Circuits, Electronics I or Electronic Devices, Electronics II or Electronic Circuits) to an integrated spiral analog curriculum began in the fall of 1995. It was then phased in, as those students moved through their plan of study. This transition is shown by the vertical dotted line. It is suggested the reason the department retention *appears* to exceed the university retention that semester is that students transferring into ECET that semester were required to begin with the very first course. So they were counted as retained by the department, but were counted by the university as retained elsewhere. In both previous and subsequent semesters, most transfer students were allowed to start in a later analog course.

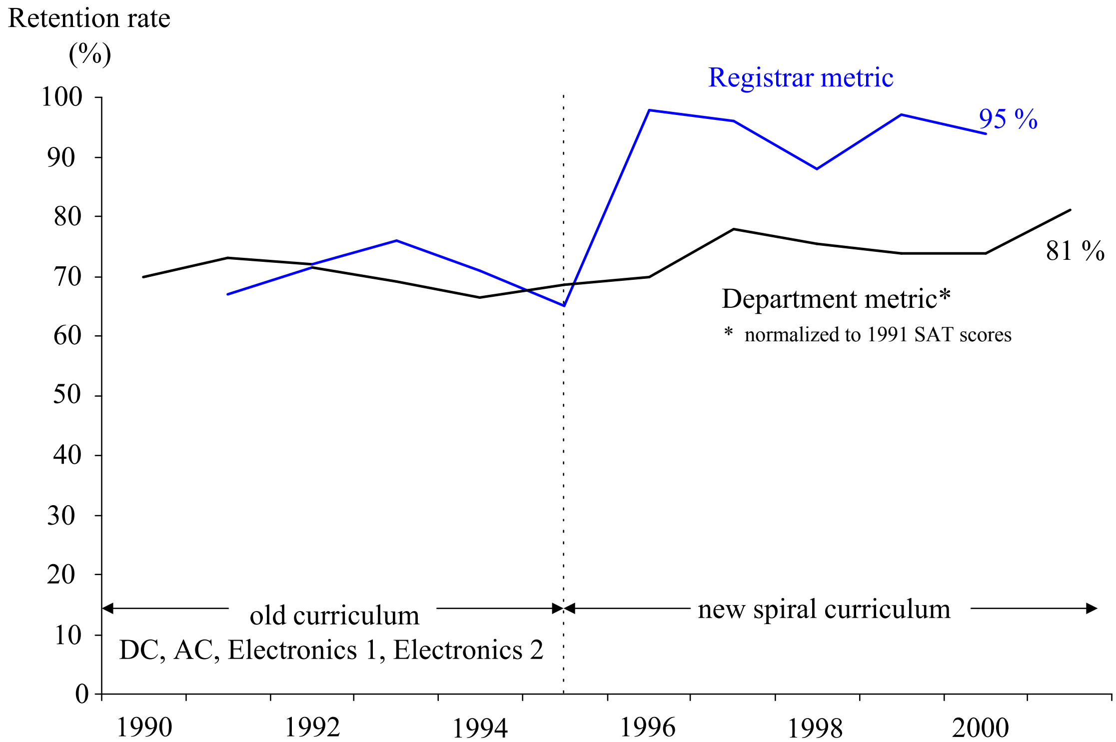

Figure 3 Retention rate trends for Purdue University's ECET Department

Under the old curriculum, retention was about 70%, only slightly better than the national norm. However, *immediately* after the implementation of the spiral curriculum, retention rose significantly to somewhere between 30 % and 50 % better than the national norm. Figure 3 strongly suggests a causal relationship.

However, *if* the first course was simplified to the point where everyone passed, retention may increase, as would the grades in the first course. However, such a strategy would leave the students poorly prepared for subsequent courses. These courses would have to cover less material, re-teaching what was missed in the first course, and would display poorer success rates.

Figure 4 is a display of the success rates of the four courses in the analog sequence. As in Figure 3, the transition to the spiral curriculum is marked with a dotted vertical line. Success is defined as the % of students completing the course with a passing grade. With the exception of one semester in 1998 in EET 157, there is *no* significant drop in success. In fact, for the last four semesters, the rate in all four courses has been above 80 %. The spiral curriculum has *not* delayed failure to subsequent semesters. If there is any effect, it has been to improve performance in *all* courses.

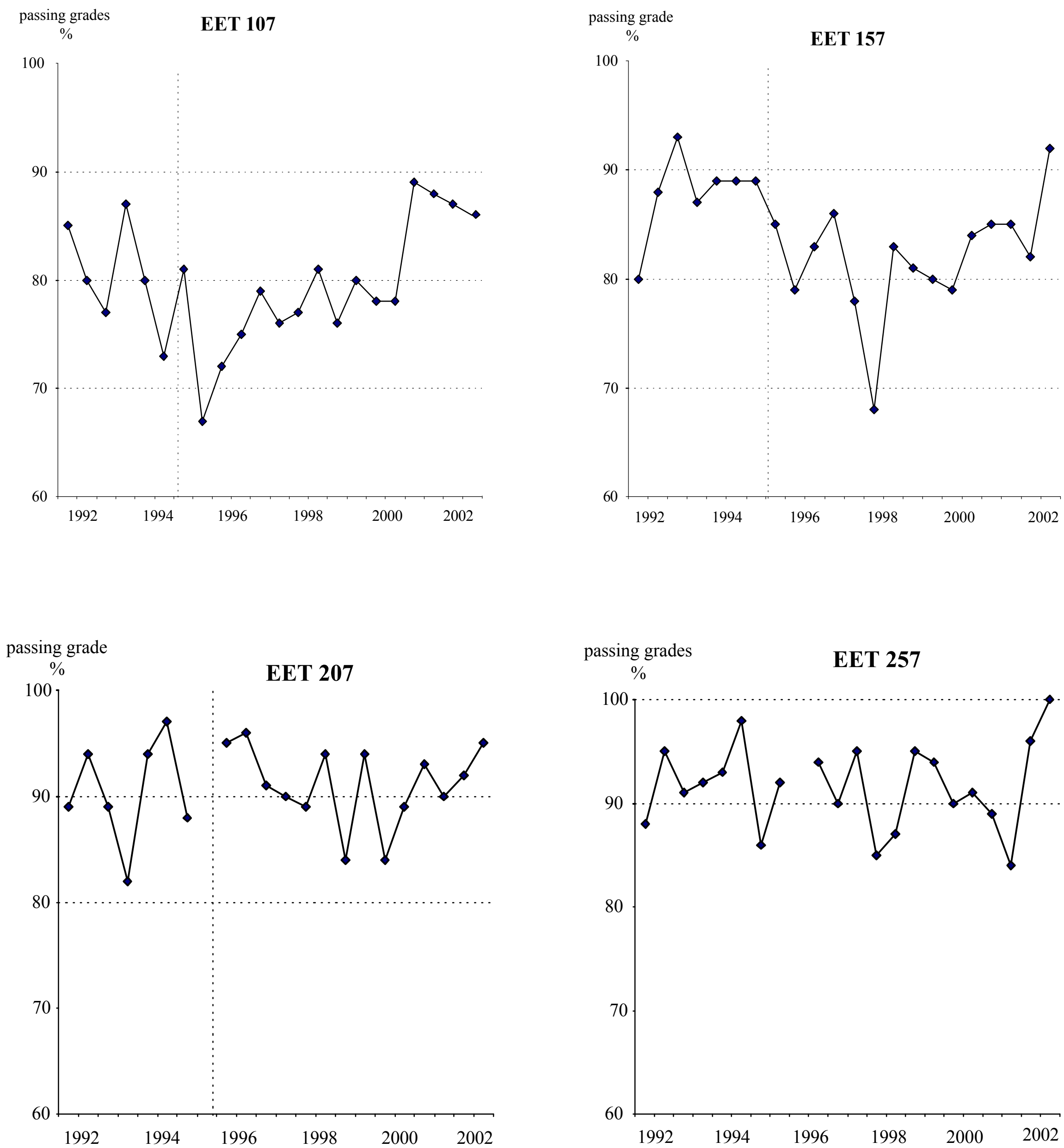

Figure 4 Success rates in the four *analog electronics* courses

Below are the catalog descriptions of the four analog sequence courses in the spiral curriculum. *More*, not less is being covered, with more success, and better retention than was possible in the traditional DC Circuits, AC Circuits, Electronics I, Electronics II approach.

Courses

107 Introduction to Circuit Analysis Class 3, Lab 3, cr. 4.
Corequisite: Math 153 (algebra).

Voltage, current, power, and resistance; and Ohm's law, Kirchhoff's circuit laws, and network theorems are studied. Circuit analyses cover ideal or first approximation electronic devices: diodes, transistors, and operational amplifiers, to enhance the understanding of basic circuit laws and theorems. Physical features of capacitance and its effects in transient circuits and in ac circuits are covered.

157 Electronics Circuit Analysis Class 3, lab 3, cr. 4.
Prerequisite: EET 107, and MA 153,

Capacitors, inductors, switching circuits, transformers, rectifiers, linear regulators, dependent sources, operational amplifiers, BJT & MOSFET based small signal amplifiers, waveform generation, and programmable analog devices are studied. Circuit fundamentals such as Kirchhoff's laws are utilized in analysis and design circuits. Computer simulation is used.

207 AC Electronics Circuits Analysis Class 3, lab. 3, cr. 4.
Prerequisite: EET 157, MA 151 or 154 (trig)

AC circuits including the j operator, phasors, reactance and impedance are studied. Circuit laws, network theorems, and the fundamental concepts of Fourier analysis are applied and used in the study of topics such as passive filters, IC filters, amplifiers, resonant circuits, single phase and three phase circuits. Computer aided analysis of circuits is used.

257 Power and RF Electronics Class 3, lab. 3, cr. 4.
Prerequisite: EET 207 and MA 221 (calculus I)

This course is a study of the application of circuit analysis techniques to amplifiers used in power and RF electronics, including bipolar junction transistors, power MOSFETs, thyristors, RF amplifiers, phase lock loops, switching power supplies, and appropriate applications. Computer aided analysis of circuits is used.

Circuits and Electronics Integration

Over time the Purdue faculty developed textbooks and laboratory procedures to match this new curricular approach. The curriculum drove the process of creating the textbooks, not vice versa. The Herrick-Jacob textbook series from Delmar Learning a Thomson Company became the next evolutionary step to match this very successful curriculum development. The next section of this paper is taken from the preface of the textbook series[5, 6, 7] and re-printed here with the permission of Delmar Learning a Thomson Company.

"The traditional approach to teaching fundamentals in Electronics Engineering Technology begins with a course for freshmen in DC Circuit Theory and Analysis. The underlying laws of the discipline are introduced and a host of tools are presented and applied to very simple resistive circuits. This is usually followed by an AC Circuit Theory and Analysis course. All of the topics, rules, and tools of the dc course are revisited, but this time using trigonometry and complex (i.e., real and imaginary) math. Again, applications are limited to passive (simple) resistor, capacitor, and inductor circuits. It is during this second semester, but often not until the third semester, that students are finally introduced to the world of *electronics* in a separate course or two. At this point they find what they have been looking for: amplifiers, power supplies, waveform generation, feedback to make everything behave, power amps, and radio frequency with communications examples. This approach has been in place for *decades*, and is the national model."

"So what is wrong with this approach? Obviously, it has been made to work by many people. Currently, during the dc and ac courses students are told not to worry about why they are learning the material, only that they will have to remember and apply it later (provided they survive). These two courses (dc and ac) have become tools courses. A whole host of techniques are taught one after the other, with the expectation (often in vain) that eventually when (or if) they are ever needed, the student will simply *remember*. Even for the most gifted teachers and the most dedicated students these two courses have become "weed out" classes, where the message seems to be one of "if you show enough perseverance, talent, and faith we will eventually (later) show you the *good* stuff (i.e., the electronics)." Conversely, the electronics courses are taught separately from the circuit analysis classes. It is expected that the student will quickly recall the needed circuit analysis tool (learned in the dc and ac courses) taken several semesters before when it is needed to understand how an amplifier works or a regulator is designed. This leads to several results, all of which have a negative effect. First, the student sees no connection between dc and ac circuit theory and electronics. Each is treated as a separate body of knowledge, to be memorized. If the students hang on long enough, they will eventually get to the electronics courses where the circuits do something useful. Second, the teachers are frustrated because students are bored and uninterested in the first courses, where they are supposed to learn all of the fundamentals they will need. But when the students need the information in the later electronics courses, they do not remember. The result is a situation with which we have struggled for decades. This new series has been developed to address and solve this problem."

"The Herrick & Jacob series offers a different approach. It integrates circuit theory tools with electronics, interleaving the topics as needed. Circuit analysis tools are taught on a *just-in-time* basis to support the development of the electronics circuits. Electronics are taught as applications of fundamental circuit analysis techniques, not as unique magical things with their own rules and incantations. Topics are visited and revisited in a helical fashion throughout the series, first on a simple, first approximation level. Later, as the students develop more sophistication and stronger mathematical underpinnings, the complex ac response and then the nonsinusoidal response of these same electronics circuits are investigated. Next, at the end of their two years of study, students probe these central electronic blocks more deeply, looking into their nonideal behavior, nonlinearity, responses to temperature, high power, and performance at radio frequencies, with many of the parasitic effects now understood. Finally, in the Advanced Analog Signal Processing book Laplace transforms are applied to amplifiers, multistage filters, and other closed-loop processes. Their steady state, and transient responses as well as their stability are investigated."

"The pervading attitude is "Let's do interesting and useful things right from the start. We will develop and use the circuit theory as we need it. Electronics is *not* magic; it only requires the rigorous use of a few fundamental laws. As you (the student) learn more, we will enlarge the envelope of performance for these electronic circuits as you become ready." Learn and learn again. Teach and teach again. Around and around we go, ever spiraling upwards."

Summary

Eight years ago Purdue University's Electrical Engineering Technology program redesigned their entire curriculum. There are two key elements. The first was the rearrangement of the mathematics sequence to deliver tools just-in-time for their applications in the circuits and the electronics courses. The second, and more sweeping change, was to merge the topics of passive circuits and analog electronics into a spiral. Instead of teaching passive dc, then ac circuits followed by basic, then advanced electronics, the first *analog electronics* course teaches Ohm's law, and Kirchhoff's laws and immediately applies them to resistor, diode, op amp, and transistor circuits. The second course travels the spiral again, this time adding simple capacitors, inductors, and sinusoids to build power supplies, amplifiers, and signal generators. In the third semester, *after* the students have spent a semester reviewing trigonometry, the spiral is traveled again in *Advanced AC Electronics*. Complex math, and phasors are used to restudy passive RLC circuits, passive and active filters, op amp frequency response, Fourier analysis, Mesh analysis, and three phase systems. The capstone, fourth semester course takes one final turn around the spiral. Supported by the Calculus I course completed the third semester, power, thermal characteristics, high speed transients and parasitics, and the foundations of rf electronics are investigated. Amplifiers running to 400 MHz, phase locked loops, semiconductor switching circuits capable of controlling over 500 W, switching power supplies, thyristor-based power converters, and 100 W audio class AB and class D amplifiers are designed, built, and tested.

A study of department's retention trends over this same time shows that before the change to a spiraled *analog electronics* approach, retention was flat at about 70%. Immediately following the institution of the new approach, retention rose to between 80% and 95% (depending on the metrics), and has stayed at that level over the last three years. Success rates (% passing) for *all* four of the courses in the sequence have either been constant at about 80%, or have gradually *risen* to nearly 100%.

The spiral approach to circuits-electronics as incorporated into the *analog electronics* sequence at Purdue University's EET program *works*. More students go further, faster, and more successfully.

Often the biggest hurdle to implementing a new curriculum is the lack of available learning materials. Once the *analog electronics* sequence had been proven to work in the Purdue classroom, the authors wrote a series of texts[5, 6, 7], optimized to this spiral approach of threading electronics throughout the circuits-electronics courses. Texts, lab manuals, instructors' guides, simulation software, automated homework, and Power Point slides are all available from a national publisher.

Bibliography

1. Brunner, J. (1960) *The Process of Education*, Cambridge, Mass.: Harvard University Press.
2. Gardner, H. (2001) 'Jerome S. Bruner' in J.A. Palmer (ed.) *Fifty Modern Thinkers on Education. From Piaget to the present*, London: Routledge.

3. Smith, M.K. (2002) 'Jerome S. Bruner and the process of education', *the encyclopedia of informal education*
4. Gardner 2001:94
5. Herrick, R.J. (2003) *DC/AC Circuits & Electronics: Principles and Applications*. Delmar Learning a Thomson Company.
6. Jacob, J.M. (in review, summer 2003 publication) *Advanced AC Electronics: Principles and Applications*. Delmar Learning a Thomson Company.
7. Jacob, J.M. (2002) *Power Electronics: Principles and Applications*. Delmar Learning a Thomson Company.

Biographical Information

Robert J. Herrick is Purdue University's Robert A. Hoffer Distinguished Professor of Electrical Engineering Technology and Teaching. He has been recognized with national, regional, university, school, and department awards for outstanding teaching and professional service. He has been active in promoting outstanding teaching and education through his leadership in ASEE, IEEE, and the Frontiers in International Education Conference; his teaching-the-teachers workshops at national conferences and special workshops, his leadership in the Purdue University Teaching Academy; and publications on education. Herrick is a professor and department head of Electrical and Computer Engineering Technology at Purdue University where he has taught circuits and analog electronics for the thirteen years. His former experience includes nine years of teaching and faculty leadership with the University of Toledo while also serving as a consulting engineer for major industry; thirteen years as a full-time design and development engineer with AT&T's Bell Telephone Laboratories and with ITT's Advanced International Technology Center; and service in the U.S. Air Force in navigational aides electronics technology. Herrick combines his rich engineering and technical experiences with an educational approach to education that engages students in an active learning process that has been extraordinarily successful with his students.

James Michael Jacob, the current George W. McNelly Professor of Technology, is an award-winning teacher. He has received the CTS Microelectronics Outstanding Undergraduate Teaching award as the best teacher in the Electrical Engineering Technology Department seven times. He has won the Dwyer Undergraduate Teaching Award as the top teacher in the School of Technology three times, and was first runner up twice. He also received the Purdue University's undergraduate teaching award (the Amoco award), the Paradigm Award from the Minority Technology Association and the Joint Services Commendation Medal (for excellence in instruction) from the Secretary of Defense. In 1999 he was listed in Purdue University's Book of Great Teachers, which holds the top 225 faculty ever to teach at Purdue University. He was selected by the faculty of his department and of the School of Technology as the Outstanding Tenured Faculty member in 1995. He has taught at Purdue for 20 years and at a community college in South Carolina for seven years. Professor Jacob's contributions in scholarly endeavor and service include writing and holding workshops. He has published several internationally popular texts on analog integrated circuits and industrial control electronics, as well as a variety of papers and conference presentations on the art and technology of teaching. Mike has lead over forty workshops on a variety of ways to improve teaching. He has six years of industrial experience as a test engineer in the automotive and aerospace industries.

Jeffrey J. Richardson is a Graduate Teaching Assistant for Electrical and Computer Engineering Technology at Purdue University where he has taught the introductory microcontroller course and worked with the troubleshooting and senior project courses. He has been nominated for the Outstanding Graduate Student Award for the School of Technology at Purdue University in 2003. His industrial experience includes three years in industrial controls and two years as a development engineer. Jeff is also listed as a co-inventory on a pending U.S. patent application. He has also worked as an engineering consultant for industry.