Session 1532

Forty Years of Teaching Circuits I: A Tribute to Dr. Hayt

R. William Graff

LeTourneau University

Abstract

The author has had the experience of teaching Circuits I for forty years, using Dr. William H. Hayt's book, Engineering Circuit Analysis, in all six of its editions. Certain teaching principles have been developed to give consistency to the grading and teaching of the material, so that some trends in student performance can be traced over that time. Some of these trends are reflected in the paper, as well as comments concerning ways to communicate the material most effectively. Historical data concerning the author's experience is also included. The author's ADD and poor study habits as an undergraduate give him a good platform from which to encourage students to study, and thus to avoid the pitfalls that he, himself encountered. He is thus able to teach effective study methods from personal experience.

Introduction: Dr. William H. Hayt

Although I have never officially taken a course from Dr. Hayt, I sat in a class as an instructor under his tutelage and watched him teach the lectures on closed-circuit television in the fall of 1962. I therefore had the privilege of being mentored in my original teaching of circuits by Dr. William H. Hayt, himself. My personal contacts with him were few, but memorable. I don't think I've ever seen him when he was not smiling; he seemed to always be thinking of a joke. Often, the joke was on me, as when my finger got stuck in the teacup handle at the party in his home. His subtle humor erupted in his textbooks in such a way that students have told me they were reading them simply to find more of his quips. I cannot prove it, but I suspect that he invented the daraf, the yrneh, and the jiffy[1] (a defining unit of time). Almost every semester since 1962, I have taught a course from either his circuits book, his fields book, or both. He has had a profound influence on my life.

My story

After receiving my BSEE from Purdue University in 1960, having had a poor start in the undergraduate curriculum, I continued studying toward a Master's degree there, barely passing due to the fact that my understanding of the basic principles, upon which the higher-level courses were based, was full of gaps. Thus, I had what might be termed a "Swiss Cheese Base". At the Master's degree oral exam Dr. Hayt was present, and after having pushed me through a circuits problem, advised that I continue on and get the Ph.D., with the provision that I be required to teach circuits, and thereby *learn* it. Dr. Hayt added the comment that it would be unfair to release me to the public with my (then) present knowledge of Circuits. Thus began my career in teaching Circuits, in the fall of 1962.

The procedure for teaching Circuits at Purdue at that time was to break the class into groups of about 25, with each group or section having a graduate student teacher to work problems in recitation periods; Dr. Hayt taught two lecture periods each week to the total Circuits class. At that time Hayt and Kemmerly's first edition of Engineering Circuit Analysis[2] was being used. Tests were prepared by Drs. Hayt and Kemmerly, using test problems submitted by the graduate teaching assistants. There were four one-hour tests each semester.

I began my teaching career at Purdue as an instructor, and then continued at Drexel as an asstant professor, then at Wilkes for 2 years, and, finally at LeTourneau for the past 28 years, becoming a full professor there. This gives 10 years of experience at secular schools and 28 at a private, Christian school. In almost all semesters, the same circuits book was used: Engineering Circuit Analysis, by Hayt & Kemmerly.

Evolution of the circuits course

While teaching at Drexel, I picked up some new (to me) teaching techniques, such as consistent grading styles (thanks to Dr. Ed Gerber) and the use of 10 minute quizzes on a weekly basis (thanks to Dr. Richard Klafter, although Drs. Hayt and Lindenlaub had suggested it in the beginning of my career) in order to defeat the students' tendencies to put off intense study of the subject until just before the test. Hourly testing was reduced to one hourly test at midterm and a final two-hour exam at the end of the course. Point awards were based on six test-equivalents; one being the midterm, the final counting as two, the weekly ten minute quizzes counting as two, and homework, pop quizzes, and, later on, design, being the other test equivalent. A single design problem is now given each semester with an optional make-up design for those who do poorly on the first one. The addition of the design component was made in 1986 due to ABET (then ECPD) requirements. LeTourneau University became ECPD accredited in 1981. This increased the work load for students in the course; there was no decrease in the amount of material covered at that time, however.

Pop quizzes

"Pop Quizzes" are given in the first five minutes of class , in almost every class in which there is not a test or ten-minute quiz. The purpose is twofold: first, to build the discipline of coming to class on time; second, to insure that those things which should be "second nature" to an engineer are in place – the fundamental concepts, on which they build later. These are the voltage-current relationships for resistance, inductance and capacitance, current and voltage division, the fact that current and voltage sources are open and short, respectively, when turned off, power and energy definitions, etc. My answer to the question, "Is that not just rote memorization?" is "Yes". Engineers must have a certain amount of information memorized. They would be embarrassed to be asked one of these things by a potential employer (as I was), and to have to respond by "I think that is in my calculator" (calculators didn't exist when I was asked; I simply had to admit ignorance). Potential embarrassment is a great motivator.

Trends in Circuits I

Over the last ten years or so, it has been observed that students have become less familiar with basic algebra and trigonometry. This change has been coincident with their heightened usage of calculators – for such things as multiplying 6 by 8. Some quizzes are now given with no calculator allowed. An attitude change has been observed, also; increasingly, the instructor is seen to be at fault, rather than the student, when understanding has not occurred.

The students were having trouble understanding the basic concepts of current and voltage at the beginning of Circuits I, so a set of "Mini-Labs" was added to the course. These were designed so that they could be performed in their rooms, using only a breadboard, DVM, 9-volt battery, and a handful of components. This strongly increased the motivation of students to learn. Now, time has been scheduled specifically for these labs, all done in a classroom, and the students are given a problem to solve when the Mini-Lab has been finished, which must be worked before they leave the room. I have an undergraduate assistant to help me as I circulate around the room to help them work the problem. In this way, I find the problem areas my students have. In recent years, I have found these problem areas are primarily in the understanding of fundamental math principles – algebra, trigonometry, and calculus.

For the past 27 years, the students have been required to submit, with each homework set, the number of minutes it took to work each problem. These data have been tabulated and taken into consideration in subsequent years' assignments. The goal has been to assign 2 to 3 hours of homework for each hour of lecture. These data are also provided to the students in subsequent homework assignments. They are given the average time, number of students averaged over, and minimum and maximum times to do each problem. I rarely get a complaint that "the homework took too long".

Grading is teaching. I presently have 6 grader-helpers working for me to take care of about 60 students. One gives a weekly help session, three grade homework, one helps in lab, and one is for backup when any of the others is temporarily overloaded. I personally grade the 10-minute quizzes and the major tests. I have strongly resisted a transition to multiple-guess tests, because I am able to determine difficulties the students are having, as I grade them. My graders also report to me any topics which I need to re-emphasize.

During the traumatic years when design was being newly emphasized by ABET (then ECPD), I developed some design problems to be used with the circuits course. This added a new category to my "Blooms Taxonomy for engineering". The first and most elementary step is rote memory: memorization of the most basic formulas to be used. This is accomplished by my "Standard Pop Quizzes", which I give almost every class period at the beginning of the class. The second step is to learn how to work specific types of problems, such as mesh analysis, Thevenization, current division, etc. This is accomplished through the "10 Minute Quiz", given once a week over a pre-specified topic. The third step is to learn how to choose the appropriate analysis for a given problem, having learned the various analysis tools. This is accomplished by the hourly and final exams. The final category is creativity, which is tested by the design problems.

Statistical design

In working with students in a more advanced laboratory situation, I find that they have found a way to bypass the problem of designing a circuit through proper insight into how it should function. This new technique, which should not really be called "design", will be termed "Statistical Design".

An example of Statistical Design would be as follows: Suppose we are to design a resistive circuit to match a given source to another given load. One could choose some random circuit to place between the source and load, and then randomly vary all the resistors in the matching circuit until a match was found. This would require no insights as to how the match was achieved, such as "when a resistor is added in parallel, the overall resistance is reduced". I first encountered this type of analysis in a higher level lab course about seven years ago, and the technique has become increasingly common. There is an increasingly common tendency to use a calculator as a "magic box" to give numerical answers, and a decreasing tendency to ask "Why?"

Lectures

I learned early in my career that, in order to be relevant to all the students in a class lecture, I had to gradually increase the difficulty of the material through the lecture session. An ideal situation would be as follows. Suppose I have a class with the fastest learners sitting in the front, average learners in the middle, and slowest in the back. Suppose further that I have three examples to present. I would give the easiest example first, so that the students in the back would be attentive, the middle group would be interested, and the fast learners would be bored. The second example would challenge the slow learners, the middle group would begin taking notes, and the faster learners would become interested. The third example would have the slow learners in despair, the middle group frantically taking notes, and the fast learners eagerly following.

The point is this: learning is uncomfortable. "In-class-learning" is inefficient. Students need to learn that class time is for gathering data, which must be digested later by doing homework.

Modern teaching methods favor adapting the teaching style to the learning style of the student, however inefficient that style may be. The basic idea behind classroom learning is, however, to efficiently teach a large number of people at once. I agree that the best possible teaching venue is one teacher interacting with one student, using the technique most acceptable to that student, but to *teach* a person means to *change* that person. When that student gets into the real world he will have to absorb information in whatever form it is given to him; and in an industrial situation he will not succeed if he refuses to accept instruction from his boss because it is in the wrong format. "I'm sorry, I'm tactile; would you give me a hands-on explanation of what you just said?" That excuse would probably not impress the boss favorably.

In our rush to be trendy, we have overlooked the main point: when we try to teach our students *how* to learn, we forget the fact that you learn *how* to learn by *learning.*

Grading

I wrestled with the bell curve for many years, and finally concluded that there needed to be a more absolute standard for comparison than "what everybody else in the class did". It was becoming more evident that there was a lack of consistency from one semester to the next. I once asked Dr. Hayt what he thought of an absolute grading system, which I was contemplating at the time. I asked, "If the students are all getting the material and understanding it very well, shouldn't they all get an A?" His answer was a hesitant "Yes", to which he added "What do the students get in practice when you apply the theory?" I answered that it was sort of a bell shaped curve – he seemed relieved and said, "Well then, I guess that would be okay."

For awhile, I used a complicated scheme in which all the students' total grade points were indicated along a line, and the breaks between A, B, C, etc. were determined by the average of the individual letter grades for tests. In this scheme, A's cancelled F's, B's cancelled D's and I agonized over the break totals, usually looking for some large break between groups so that I could defend my result when borderline students came in to dispute their grades. This was the method I used in Fields I in 1968, at Drexel; I found it unsatisfying.

My conclusion was to use the old A=90-100, B=80-90, C=70-80 and D= 60-70 scheme that I was familiar with from high school. The equivalence of the numbers with the letters also made it easier to decide on partial credit as I graded individual problems. This decision produced an unforeseen benefit; I was no longer at fault when a student got a low grade! At least, this is how the student *perceived* the situation. The "Black Hat" was transferred from *me* to the *number*. I could henceforth emote with the student, and even help him look for some mistake in my grading which would raise his overall grade – and, by virtue of my grading keys, I could defend all but legitimate *mistakes* I might have made in grading, and cheerfully raise the grade if I had misread his work. I noted that not many came to make me aware of grading mistakes which would lower their grades, but a few did (they may not have realized that such candor produced future letters of recommendation for them that were quite positive).

I occasionally receive the criticism that you can't grade problems accurate to 5 or 6 significant figures (89.9999 is a B, 90.0000 is an A). It is true, however, that if you take enough data, the number of significant figures increases (you can determine pi to any number of significant figures if you take enough statistical data). I reply to this argument that we would have the following alternative: A is 91.0000 to 100, B is 89.0000, and if the number is in the middle interval, say 90.5, we flip a coin to get the grade. *Every* student, to whom I propose this alternative, prefers the previous scheme.

Another unanticipated result of this policy is that the students are more motivated to do homework, even though it counts very little in the final grade, because "every little point counts", and the "close calls" become famous to future generations. I have heard upper classmen tell neophyte circuits students "I could have gotten a B if I had just done one more homework set."

Measured trends

I have chosen to use as my data set some of the Circuits I courses taught each fall from 1993 to 2000. By that time my grading policies had become standard, and I was teaching two sections each fall, each section containing 19 to 48 students. In 1998, 1999, and 2000, the classes were at 8:20 and 9:25 am, back-to-back, so I could use the same quizzes and tests for both sections. In 1993, one section was at 9:25am and the other at 3:00pm, so that different tests and quizzes were used. In these eight classes, the final grades were compared to the homework grades for 254 students. The most important predictor of success in Circuits I turns out to be the homework grade. This grade is found by combining the set of grades for homework turned in at each class period (usually 42 sets) with the grades for the Standard Pop Quizzes (usually about 20), and dropping the lowest 5. The rest are averaged to a maximum of 100.
For this set of data we obtain, citing the final grade for the course and the homework grade in succession: A, 89.55; B, 80.92; C, 64.69; D, 52.56; F, 44.50; and W, 24.98, where "W" indicates withdrawals from the course.

There are, of course, cases for which a student doesn't do much homework, and yet gets a high grade, and there are a few who do homework diligently (or copy someone else's) and still fail the course; but I have found that when a student obtains a D, F, or W grade, his homework grade is less than 70 in 86.9% of the cases. This means, in the case of 127 students who got D, F, or W in Circuits I in courses between 1993 and 2000, only eight had homework scores greater than 70.

During the interval used for these data the drop date for withdrawal from a course was about one week before the end of the semester. This is the reason for classifying F and W similarly, since many students see they will fail and withdraw instead. This was not always the case here, and it may presently be giving the students a false sense of security. In the earlier years, pass rates were higher; in fall of '79, two sections of Circuits I had pass rates of 70% and 48.5% (I believe the lower one was due to its being after lunch). In the fall of '85 the pass rate was 66.7%; in fall '93, 70.4% in one section and 31.6% in a late afternoon section (I conclude that the time of day at which the class is offered has a major impact on the performance in the class. The optimum time of offering seems to be 9:30am). Here, we define the pass rate to be the per cent ratio of A, B and C to the total number taking the course, including withdrawals.

As I review the trends of grades over the past few years, however, I observe an alarming trend. The pass rates become lower, in spite of lowering standards and reducing the amount of material covered in a semester. In 1993, the average homework set took an average student 2.05 hours to complete; one set was done for each class meeting, giving three per week. In the fall 2000 semester, this was reduced to 1.80 hours. The C-D break was lowered from 70 to 68, and the D-F break from 60 to 58; some of the material was moved from Circuits I to Circuits II, and the pass rates were, for the two back-to-back morning sections (so that the after-lunch-syndrome was avoided), 39.6% and 42.9% in Fall '98, 56.3% and 44.8% in Fall '99 (when the new grading scale was begun), and 55% and 55.3% in Fall 2000. This is a significant drop in the pass rate.

Some conclusions and tips gleaned from forty years of experience

1. In order to get students to turn in homework on time, one should set deadlines, and not budge past the deadline for any reason. "My alarm clock didn't wake me" is never an adequate excuse for lateness or absence.

2. Make up a key for grading each problem in a test before you grade it; assign a certain fraction of the grade to each part, and make notes on the key as to how many points should be subtracted for each type of error. Keep the key for future reference. If the student has a question about his grade later, refer to the key. You can then say to him, "I'm so sorry; this is how much I took off for that particular mistake". He can see the tear in your eye, and know that the fault for losing the points was his own, not yours. In this way, the "Black Hat" is on the numbers, instead of on the instructor.

3. I have found it convenient, and also edifying to the students, to divide the material into subgroups which cover certain concepts, with associated problems, examples, and handouts; these are given a code number. These subgroups are called "canned lectures," and form the basis for the course; they are revised as needed.

4. Most students are weak in the use of algebra and calculus. They tend to rely too heavily on the calculator to do their thinking for them. Careful choice of problems to use in "No-Calculator-Quizzes" can help to wean them off of this bad tendency.

5. I do not believe the old urban legend that "the half-life of an engineer is about three years and is constantly decreasing" is true. For the past forty years, the basic material to be taught in circuits courses has remained constant; the only change has been in what could be called "fluff"; mainly, new computer programs which change regularly enough to produce an aggravating drain on one's time to relearn them (for this reason, a portion of Circuits I was used to teach the students Pspice for a couple of semesters, but it was later omitted from the course). The basic concepts on which engineering is founded remains constant; the *details* change. It is most important to emphasize basic concepts, not details.

6. Students need to learn some concepts "by heart". Pop Quizzes are valuable instruments to test these basic concepts.

7. Tallying the times to do each homework problem reveals to the students their actual active effort.

8. Learning can be spread out more evenly through the course by giving fewer hourly tests and replacing them by weekly 10-minute quizzes.

9. Today's students cannot endure long lectures. The first few minutes of a lecture are absorbed, but they generally have short attention spans (probably a habit acquired by watching too much television). Instructors often tout "in-class learning" as the solution to the problem, but this is inefficient. Rather than adapting our teaching methods to their deficiencies, we need to wean them from this deficiency. The practice of taking notes in class, and, later, studying those notes,

serves to keep the students attentive; it also builds a habit which will help them to learn more efficiently later. I have found that in order to produce a polished one hour lecture on a subject which I know nothing about, it takes me eight hours of research, study, and rewriting to produce that lecture; thus, if a student attends that lecture, takes notes, and studies them, he has had the benefit of eight hours of study imparted to him in a much shorter time.

10. Two hour-and-a-half sessions per week are not equal to three one-hour sessions. The time of day at which a course is offered is significant. Avoid just-after-lunch and late afternoon offerings.

11. "Mini-Labs", consisting of experiments which can be done on a breadboard in a regular classroom, or in a dorm room, motivate students and help them to understand basic principles.

12. In general, students are more adept at the use of calculators and computers, and are much less adept at math skills; they are unable to visualize mathematical consequences. For example, they find it difficult to determine limits and asymptotes as functions approach zero or infinity – without the use of a calculator.

The two *main* conclusions

1. Students must do homework after every lecture session, in order to "tamp down" the information presented. The homework grade must not be weighted too heavily, to reduce the temptation to copy another student's work in order to simply turn it in for a grade; but it should count *something*, or there will not be enough incentive to do it. I explain that students are encouraged to work in groups, but to avoid being a parasite; each member should contribute homework eventually. Learning is uncomfortable, and there are no short cuts. Cramming before the exam does not produce lasting results.

2. Grading is teaching. I taught four sections in the fall of 2003, a total of 80 students. I gave weekly 10-minute quizzes in each, two hourly tests in the two Circuits I sections, a midterm in the Fields and Power Systems classes, and a final exam in all four courses. I also assigned design problems in the circuits and fields courses. I graded almost all of these myself; my grading team took care of the homework and pop quizzes. All this grading cost me an average of 7.88 hours per week. I admit that this is costly, and grading is my most distasteful job; but it is worth it in teaching value. Emphasize to the students that partial credit is a gift, not a right.

Bibliography

1. Hayt, William H., Jr., Engineering Electromagnetics, McGraw-Hill, York, PA, 1958, p. 319.

2. Hayt, William H., Jr. and Kemmerly, Jack E., Engineering Circuit Analysis, McGraw-Hill, New York, 1962.

R. WILLIAM GRAFF is a professor in the School of Engineering and Engineering Technology at LeTourneau University, where he has taught since 1975. He received his B.S., M.S., and Ph.D. degrees from Purdue University in electrical engineering. Prior to joining the faculty at LeTourneau, he was assistant professor of electrical engineering at Drexel University for six years, and at Wilkes College for two years. His professional interests include antennas, microwaves, plasmas, and ethics.