Teaching Design with Behavior Modification Techniques in a Pseudocorporate Environment

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***Abstract*—This paper describes a strategy which was developed to effect desired behavioral change in a junior year electronics design laboratory course, corequisite to a second electronics course. Since any such strategy requires a schedule of reinforcement, the setting of the course was changed to that of a new employee orientation and probationary program with the instructor serving as Manager of Engineering and the Teaching Assistants serving as staff engineer-mentors. A pseudocorporate philosophy was adopted and rigorously implemented, including standards for written and oral communications, corporate e-mail, and performance evaluations. Open-ended design projects were assigned by memos giving customer needs including electrical power and cost constraints. Initial student feedback indicates that, despite time constraints, this approach not only forces students to face open-ended design problems and professional communications in a new way, but also confronts them with the need to achieve a certain of intuitive understanding of the subject as opposed to the memorization of equations and problem unique solution patterns.**

***Index Terms*—Behavior modification, education, electronic design, laboratory.**

I. INTRODUCTION

A SERIOUS deficiency observed by many faculty who teach upper division courses with major design content is the fact that the design process and associated student behaviors are not sufficiently addressed in sophomore and junior core courses by either the instructors or the associated textbooks. A major problem for the students who must make the transition from a conventional basic analysis-based electronics course to a design-based laboratory or capstone experience is the lack of appreciation for these behaviors as well as a lack of knowledge of the synthesis or design process. Making the situation worse is the fact that many faculty who teach electronics courses have little appreciation for the nature of this problem and become one of the causal factors. Many students adopt a learning behavior in which they memorize sets of equations for each major electronic circuit configuration and thus approach the subject as one wherein they must know or look up equations for each situation and then solve them to obtain a unique answer. Many well-known and popular electronics textbooks have perpetuated this type of behavior; not only are design techniques and constraints not covered in them, but they include only token and limited design-oriented homework problems and exercises. Fortunately, some of the newer texts are beginning to address this problem. Software [1], [2] used for tutorial and simulation purposes, however, does not generally address these concerns. Certainly extensive, open-ended, and complete design problems, leading up to multistage direct-coupled circuits, have been conspicuous by their absence!

Design is a *process*, a process of utilizing the results of analysis in a methodical synthesis to solve a multifaceted problem. The solution may be quite open ended, but is always subject to the constraints of the technical specifications, economic factors (including the time and resources available to work on the design), and component availability. All these factors should be included when constructing a set of meaningful design exercises for students. But the need to systematically modify student behaviors must also be addressed at the same time. This paper describes an electronic laboratory course which not only addresses these points, but also includes professional communication skills in a broad sense. It is hoped that this example may provide a vehicle for less-experienced faculty to improve both their own design behaviors and the professionalism of their students.

II. THE COURSE VEHICLE: OYSTER RIVER ENTERPRISES, INC.

Koen [3] has stated: “To teach engineering design is to develop a strategy for changing the repertoire of design behaviors of the student to that of an acceptable professional engineer using the principle of behavior modification.” Table I sets forth common behaviors which students originally bring with them from lower division analytically oriented courses, often developed during secondary school years, and the corresponding desired behaviors which are expected of a mature professional. With one exception, these original behaviors have been specifically targeted for modification as shown, with the methodology set forth in this paper.

This author conceived of a strategy wherein the setting would be a pseudocorporation, Oyster River Enterprises, Inc. The course in which this was introduced was a second-semester junior year (three credit) electronics design laboratory course, ECE 302, required of all electrical engineering students. It must be taken concurrently with a second semester course in electronic circuits and is a prerequisite to the senior year capstone design project experience. The course format consists of one 75 minute lecture per week plus two 2.5-h periods in the laboratory. At the very first lecture, the students are greeted by the instructor (for the first year, the author) and welcomed as new employees of the Analog Electronics Division of the “company” and as participants in the design

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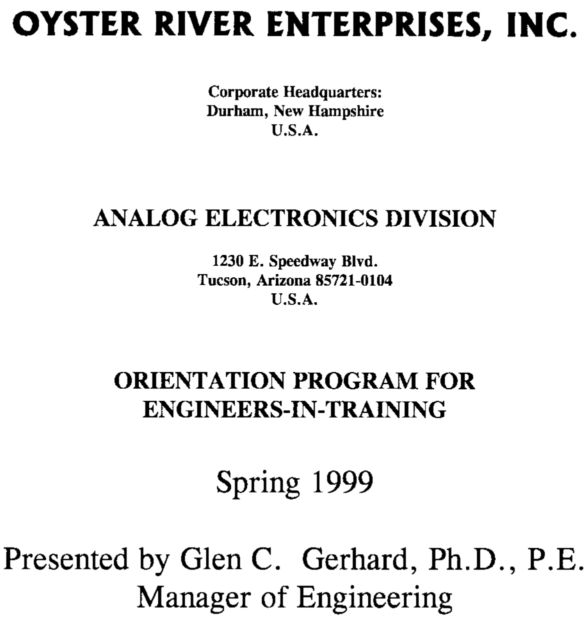
TABLE I
TARGETED STUDENT BEHAVIORS AND DESIRED MODIFICATIONS

Original Behavior	Desired Behavior
"Formula-grabbing"	Intuitive understanding
Compartmentalization of knowledge	Better vertical and horizontal integration and associative skills
Crisis mode time management (excuses for late work)	Time use planning (responsibility)
Expectations of "Textbook" problems with unique solutions (analytical formula-based approach)	Ability to deal with open-ended problems/solutions (synthesis approach)
"Trial and error" approach to design	Methodical design process
Student as a "student"	Student as a pre-professional
Write a few notes now, decipher later	Organized lab notebook
Avoidance of information technology	Active use of same
Working as a lone individual	Working as an active member of a team

orientation program required of all new hires. The instructor introduces himself as the Manager of Engineering for the division and then introduces the Teaching Assistants as young staff engineers who will be serving as mentors and resource personnel. The introduction is, of course, presented using professionally appearing overheads with the corporate name in the heading as shown in Fig. 1. Not once during this initial presentation are the words “student,” “instructor,” “class,” or “course” used. The students are called “program participants” in all lectures, handouts, and communications. While there are a few bewildered looks in the initial moments of this first presentation, the class seems to quickly catch on and appreciate the concepts. One of the major points in this first lecture is the need for the program participants to understand the “corporate culture.” The use of e-mail is mandatory (memos outlining specifications or changes in same for projects are eventually be delivered in this manner), a division news-server is to be read, and communication skills are set forth as an important component of the program. Participants are told that they will be “evaluated” as new employees. To that end, a sliding grading scale is used for this course with little attention to statistical distribution of evaluation scores; each student is competing against an ideal standard with no quotas for any grade, from “A” to “E.” Writing and oral presentations are evaluated as are corporate “patent” laboratory notebooks. The latter has no tedious series of proscribed questions to be answered! Guidelines for the notebooks are given and the participants quickly learn that they can rise or sink, depending on how well they followed these guidelines! A previously developed course handbook was extensively modified as an “Orientation Manual” to cover all guidelines, using the new terminology and philosophy.



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ORIENTATION PROGRAM FOR
ENGINEERS-IN-TRAINING

Spring 1999

Presented by Glen C. Gerhard, Ph.D., P.E.
Manager of Engineering

Fig. 1. Initial overhead transparency for first class lecture.

Another major point in Koen’s paper [3] was that any strategy developed to effect a desired behavioral change must include a schedule of reinforcement. In this “corporate” setting, reinforcement means stricter adherence to deadlines and less leniency than permitted by many faculty, no “overtime” in the laboratory (generally requested to compensate for inadequate or incorrect prelaboratory design work or poor laboratory skills), and specific requirements on the format of written communications. In order to demonstrate to participants that

TABLE II
THE SIX STEPS OF THE DESIGN PROCESS

Step 1:	Translation of problem statement into technical specifications
Step 2:	Conceptual framework and block diagram
Step 3:	Paper and pen design of circuits
Step 4:	Simulation of design (SPICE)
Step 5:	Construction of prototype circuit on breadboard
Step 6:	Verification of specifications by measurements

desirable behavioral changes were rewarded and undesirable behavior lead to lack of reward and penalties, it was necessary to construct the learning experiences at the beginning of the program so that feedback could be delivered rapidly. This, in turn, imposed temporal and structural constraints on the design experiences.

The one behavior set forth in Table I which has not yet been addressed in this course is the last one so listed, relating to working as a lone individual as opposed to being a member of a team. The author has been loath to dilute the pressure on individual students to modify those behaviors which need attention, but still recognizes the need for incorporating well-organized project team experiences within the pseudocorporate model. This goal will hopefully be incorporated in the next phase of the development of this course.

III. THE DESIGN EXPERIENCE

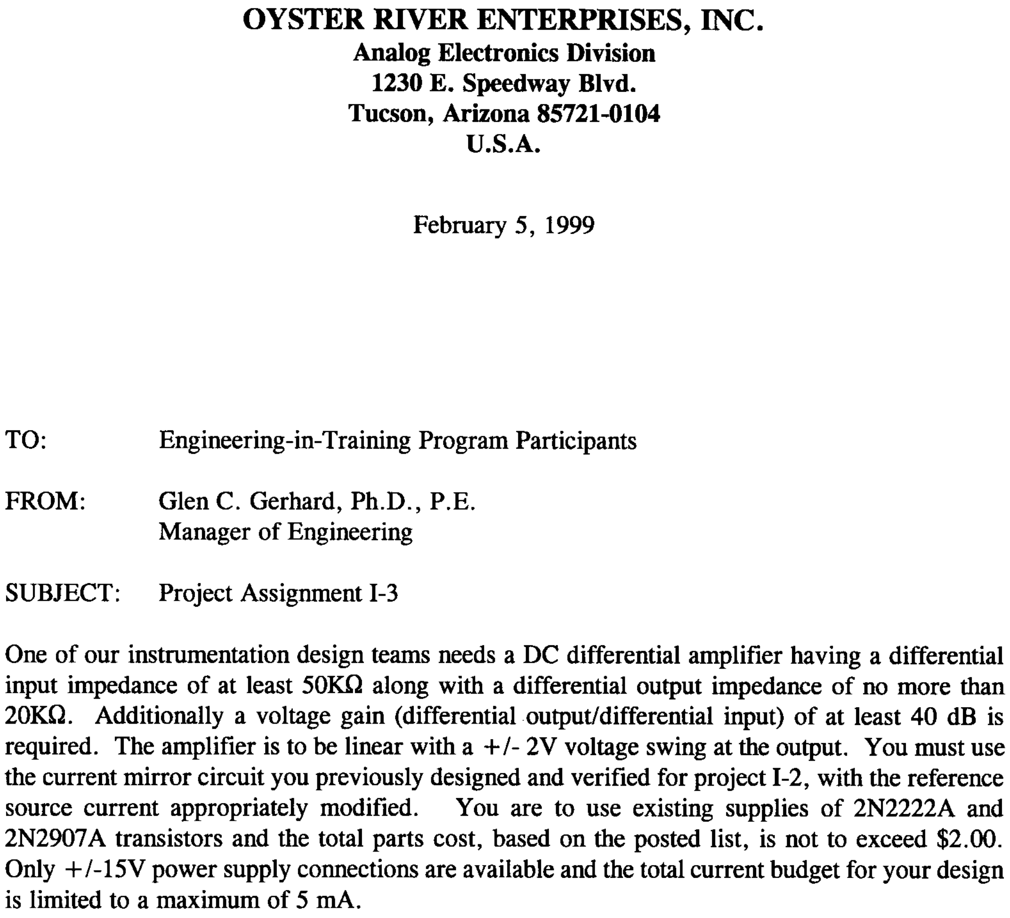
In order to provide rapid feedback and to rapidly effect behavioral changes, a series of assignments which provided five weekly short open-ended design experiences was instituted. Each of these provides an opportunity to practice the design process and to permit evaluation and feedback to the participants. Each assignment is given to the participants in the form of a memo, stating the application-driven specifications. To reinforce a methodical approach to the design process, it was "formalized" into the six defined steps as shown in Table II.

The first three steps of the process outlined above often are very difficult for students to initiate. Some students seem to have difficulty "translating" specifications from a business memo format into a technical specification list, no matter how carefully written and precise is the memo. Then the conceptual framework step is difficult for some; they want to find a unique solution or circuit topology that exactly fits the problem. They are unaccustomed to being given open-ended problems with free choices of quiescent operating points (within a specified current budget) for active devices, along with freedom to choose circuit topology and standard component values. Therefore, the initial series of weekly design problems starts with circuits introduced in course work from the previous semester and then utilizes topics recently covered in the current semester, using a just-in-time approach. A typical series might start with a common-emitter or common-base amplifier, then move to a current source, to a current mirror, and then to a differential amplifier which could utilize the current mirror design from the previous week. An example of such as assignment is shown in Fig. 2.

After this series is completed, the student is randomly assigned to write a technical report, as a program participant, to the Manager of Engineering, about his or her design. Sample report outlines are presented in lecture along with instructions and examples of the required IEEE format. The latter is used for figures, tables, references, equations, punctuation, and related items. As a discipline, the "company" style, is defined as one emanating from the author's original industrial experience; third person, past tense is required for the report. Since there is no opportunity to go back into the laboratory and redo a design, students are forced to rely on what is already in their laboratory notebooks. This experience can be eye-opening for certain students! The standard for the report is clearly stated to the class; in order for a report to be truly acceptable, the Manager of Engineering must be able to forward it to corporate engineering management with pride, not apologies.

At the completion of this first series, a series of several larger design problems of three or four weeks duration are assigned. These may require direct-coupled multistage circuitry, such as for a simple operational amplifier, as cited in Fig. 3, and hence are of greater complexity than the short projects in the initial series. As before, the topics utilized are synchronized with the corequisite lecture course. Since master lists of components available from the stockroom, along with their costs, are included in the course handbook, cost constraints were easily incorporated into the design specification statement. At least one additional written report is required; the last project for the semester culminates in an oral presentation for which both instructor and peer evaluations are utilized. Since all of the designs are open-ended, specifications and types of applications are readily changed each semester, thus rendering work from previous semesters of little direct use.

The need for frequent consultations between the "participants" and "mentors" and the "manager" is acute and must to be addressed. Student difficulties often center around a lack of understanding of the meaning of node voltage measurements (either simulated or actual) with respect to achieving desirable device bias conditions. Students who ignore instructions to always record these values, regardless of whether their circuit worked or not, cannot be easily helped. Those who do follow this instruction were often quickly helped by simply pointing out the obvious; a particular transistor was either in cutoff or saturation due to a design error. Direct current loading in



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February 5, 1999

TO: Engineering-in-Training Program Participants

FROM: Glen C. Gerhard, Ph.D., P.E.
Manager of Engineering

SUBJECT: Project Assignment I-3

One of our instrumentation design teams needs a DC differential amplifier having a differential input impedance of at least 50KΩ along with a differential output impedance of no more than 20KΩ. Additionally a voltage gain (differential output/differential input) of at least 40 dB is required. The amplifier is to be linear with a +/- 2V voltage swing at the output. You must use the current mirror circuit you previously designed and verified for project I-2, with the reference source current appropriately modified. You are to use existing supplies of 2N2222A and 2N2907A transistors and the total parts cost, based on the posted list, is not to exceed $2.00. Only +/-15V power supply connections are available and the total current budget for your design is limited to a maximum of 5 mA.

Fig. 2. Memo form of design project (one week duration) assignment.

direct-coupled circuits may be a new experience for many students! The many requests for frequent consultations by a number of students was partially addressed electronically.

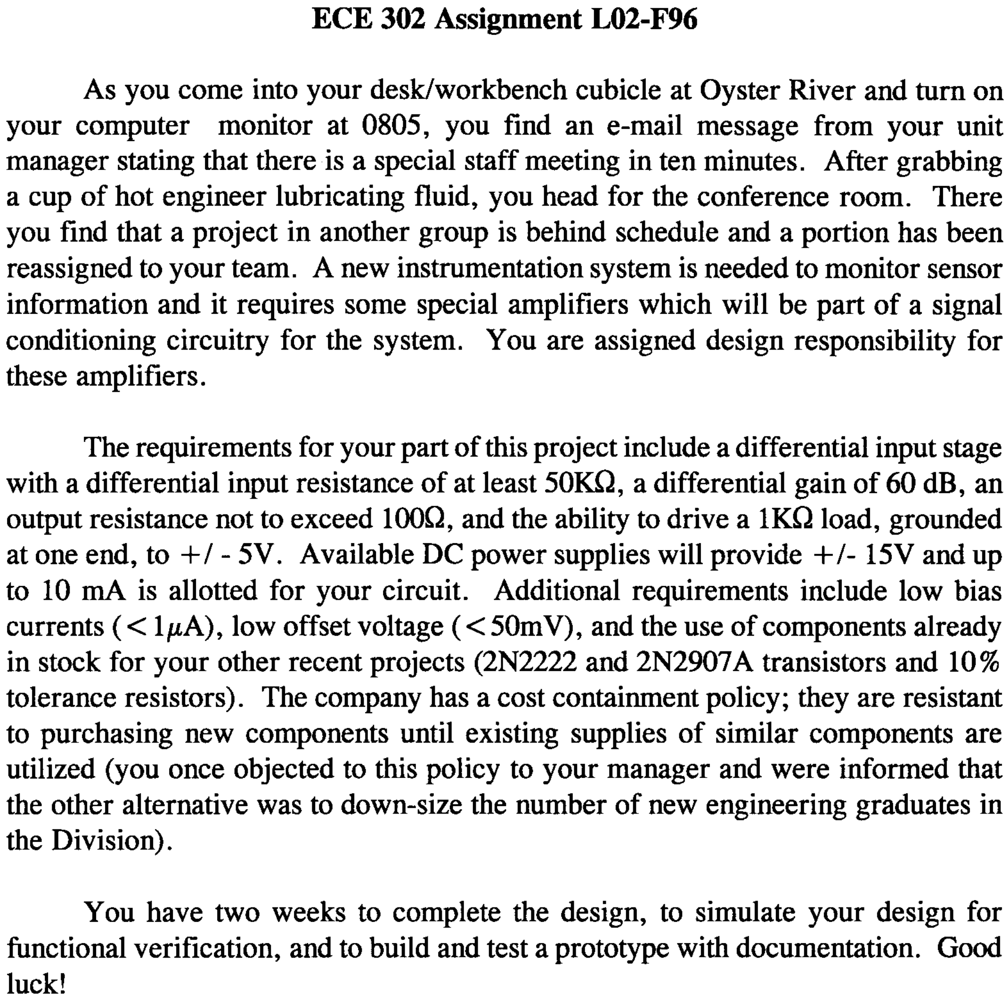
IV. COMMUNICATIONS AND EVALUATIONS

Since the number of formally scheduled office hours must have some limits for any instructor or manager, some way of facilitating timely responses to student questions between such office hours is clearly needed. Since all students now have e-mail access on the departmental Unix-based computer cluster, students are encouraged to extensively utilize this medium. This writer, when serving as the manager (instructor), logs onto the network nearly all days during the week and also checks messages from home each night before retiring. Additionally, a news server service was initiated for the course and everyone was encouraged to read and respond to it. Many times, a circuit description with some node voltages allows a quick and easy diagnosis of the problem. Other cases require setting a specific time for a short appointment outside of normal office hours.

Some students for whom English is not their first language have an insufficient knowledge of the English grammar and writing and, not surprisingly, have difficulty both understanding written materials and in-class discussions. Writing project reports is especially difficult for them, although proofreading by and consultation with outside readers is encouraged. Support from a college-based writing center is desirable in such circumstances; such a center was independently established at the author's institution around the time these modifications were made to the course under discussion.

The instructor and teaching assistants meet weekly as a manager-staff engineer project team; the assistants are treated as colleagues in this effort and hence buy into the pseudocorporate concept and actively contribute to it. This team develops evaluation (with numerical scoring) sheets for all written and oral work which are posted for participants (students) to consider. The teaching assistants evaluate laboratory notebooks along with most of the technical content and format of the project reports. The instructor personally grades the grammar and quality of writing in all reports; this alone accounts for 25% of the score awarded for the report. Several examinations are employed to evaluate the mastery of specific design skills during the semester. These are strictly based on the laboratory course content and are independent of the examination topics in the corequisite lecture course.

One problem that had been encountered in this course during previous years when students were allowed to take their laboratory notebooks home between laboratory sessions was that they would take measurements and notes on loose paper and then spend hours meticulously copying everything into the



ECE 302 Assignment L02-F96

As you come into your desk/workbench cubicle at Oyster River and turn on your computer monitor at 0805, you find an e-mail message from your unit manager stating that there is a special staff meeting in ten minutes. After grabbing a cup of hot engineer lubricating fluid, you head for the conference room. There you find that a project in another group is behind schedule and a portion has been reassigned to your team. A new instrumentation system is needed to monitor sensor information and it requires some special amplifiers which will be part of a signal conditioning circuitry for the system. You are assigned design responsibility for these amplifiers.

The requirements for your part of this project include a differential input stage with a differential input resistance of at least 50KΩ, a differential gain of 60 dB, an output resistance not to exceed 100Ω, and the ability to drive a 1KΩ load, grounded at one end, to +/ - 5V. Available DC power supplies will provide +/- 15V and up to 10 mA is allotted for your circuit. Additional requirements include low bias currents ($<1\mu$A), low offset voltage (<50mV), and the use of components already in stock for your other recent projects (2N2222 and 2N2907A transistors and 10% tolerance resistors). The company has a cost containment policy; they are resistant to purchasing new components until existing supplies of similar components are utilized (you once objected to this policy to your manager and were informed that the other alternative was to down-size the number of new engineering graduates in the Division).

You have two weeks to complete the design, to simulate your design for functional verification, and to build and test a prototype with documentation. Good luck!

Fig. 3. Situational form of multiweek design problem assignment.

notebook so as to maximize the grade for the notebook. The "corporate culture" adopted to address this situation treats the contents of the notebooks as "highly proprietary" and hence the instructor may stipulate that notebooks may not be taken outside the laboratory area until a project is completed. All prelaboratory design calculations and simulation results, as necessary, are permanently fastened onto notebook pages at the beginning of a laboratory session and all subsequent data is written directly in the notebook without any loose sheets of paper permitted at the lab bench. This reduces the nonproductive time a student spends on the course and also minimizes the temptation for one student to copy another's data.

V. ASSESSMENT: THE STUDENT RESPONSE

Assessment instruments for this course include formal course evaluation questionnaires with additional written student comment forms, student course exit interviews, and anecdotal feedback from recent graduates who have taken industrial positions. This latter information, while limited, suggests that the experiences in this course has greatly enhanced their ability to quickly become productive employees. The response of the students to this "pseudocorporate" approach has been quite positive. In particular, many have commented that these open-ended design projects, while sometimes challenging, are far more instructive and interesting than "cookbook" projects. Many eagerly adopt the spirit of the corporate setting and send e-mail messages in "official" memo format to the instructor. There has been no indication that the emphasis on the corporate setting distracts from the major emphases of the course (design and communications skills).

Negative comments have been directed to time constraints in the laboratory when initial designs proved unworkable (some students would prefer an "open" lab environment), lack of sufficient lecture material on "how to design" for a specific set of specifications, desire for more individual attention in the laboratory itself when circuits did not work as expected, and some frustration on the part of students whose native language was not English on obtaining the level of assistance with their writing which they apparently required. In particular, during the most recent offering of this course (Spring 1999), student comments indicated that additional design sessions beyond the instructor's normal office hours would provide more effective instruction. A highly motivated student, whose first language was not English, indicated some resentment that lack of facility with English grammar could cause an A grade to slip to a B.

Discussions with students indicates that many of the needs for greater assistance and extended laboratory time result from a lack of an intuitive understanding of the material, especially from the prerequisite first electronics course. The original behavior they had adopted to learn electronic circuits often was the memorization of equations as set forth earlier in this paper. A number of students attempted to continue this behavior despite a number of cautions that failure to modify their behavior would, and did, result in great difficulty in meeting program expectations. Some would not even record node voltages if the circuit did not work at their first attempt, but randomly change component values on the bench with no analysis of the problem or methodical attempt at redesign. Those students who are able and willing to change to the desired behaviors felt they learn a great deal from the course and appreciate the synchronization with the corequisite lecture course. Those who can or will not change are often frustrated; some monopolize office hours for individual help with problems which demonstrate the cited lack of basic intuitive understanding of both the subject matter and of the design process being emphasized. Therefore, some additional effort must be placed on design problems which demand some level of behavior modification, and which result in a greater degree of intuitive understanding in earlier prerequisite courses. Additionally, increased efforts to better address the problem both during the laboratory lectures and by improved integration with the corequisite lecture course are underway. The use of intelligent simulation software in lower division core laboratory courses [4] is now established and it is hoped that this will also stimulate improved student learning behaviors.

A number of students have pointed out that an "open laboratory" policy would better simulate an industrial environment. Indeed, it is difficult to negate their point, at least with respect to access to common electronic test and measurement equipment. The author's department, like most, has adequate resources for supervisory laboratory personnel on a scheduled "lab section" basis, but inadequate resources for the *same* level of staffing on a 40 or 48 h per week basis in each and every laboratory which could benefit from an open-door policy. However, some institutions have moved to such a system; one [5] by creating a common large open lab facility with some attendant reduction in the staff loading. Unfortunately, some physical plants are constructed so as to make the required space modifications difficult or impossible. Liability and security requirements are additional major considerations, especially for evening and weekend usage. Nevertheless, these options are being examined as means of more efficiently delivering an improved engineering education.

VI. CONCLUSION

The adoption of the name and culture of a pseudocorporation as a vehicle for effecting changes in student behavior so as to better teach design as a process and to provide meaningful open-ended design problems for upper-division undergraduate students in electrical engineering has proven to be useful and, for a large percentage of the students involved, a definite improvement over previous instructional methodologies. Student motivation and active learning involvement appears to be greater. Design projects are easily changed or modified each semester, thus minimizing plagiarism of past designs and reports. Teaching of professional communications skills is facilitated in this environment.

There still exist many problems for students who, either by choice or because of deficiencies in understanding or learning skills, do not appreciably alter their behavior patterns so as to facilitate their ability to utilize an effective design process. It is the opinion of this author that the behavior modification process must begin much earlier in the professional curriculum to help these students. Additionally, integration of corequisite courses to emphasize the design-oriented approach of the laboratory enhances student learning and behavioral change.

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In 1962, he joined the research staff of the Electronics Laboratory of the General Electric Company where he worked on optoelectronic semiconductor devices. In 1967, he joined the faculty of the Department of Electrical and Computer Engineering at the University of New Hampshire. He spent 1974 to 1975 as a Senior Fellow at the Center for Bioengineering, University of Washington, before returning to the University of New Hampshire to continue research in medical instrumentation. In 1991, he retired as Professor Emeritus and was appointed Professor and Associate Head of the Department of Electrical and Computer Engineering at the University of Arizona, serving as Interim Head during 1996–1997. In 1999, he returned to teaching and research in electronic design and biomedical engineering.