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Integration of Liberal Learning Skills with Engineering Design Skills in Microelectronic Fabrication*

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We describe here, an innovative experiment for preparing engineering students for the twenty-first century by integrating, within the professional curriculum, liberal learning skills which cut across the traditional disciplines covering communication, design planning, simulation, control, global economic and environmental concerns, and prototype manufacturing and testing. In view of the above philosophy, an environment for conducting this experiment was created in a laboratory/lecture course on semiconductor microelectronic fabrication, an area subject to severe competition in the global market. In this model environment the students were successfully engaged in collaborative learning, peer instruction, self and peer evaluation of formal writing, critical thinking, incorporation of new technologies, computer aided learning, positive feedback for sharpened skills, etc. Despite the intensive nature of the course, the student response to all facets of this comprehensive learning was extremely positive. The non-traditional learning experience resulted in students who became more communicative, expressive, respective of peer's work, and cooperative in enhancing the value of their engineering education and its application to societal problems. By varying the degrees of emphasis laid on various aspects of this methodology, it is portable to a variety of courses considering education as one coherent system with levels or stages in concert with each other.

INTRODUCTION

INDUSTRIAL jobs are becoming more demanding and more complex. This requires schools to produce students who will have lifetime skills of meaningful employment in order for industry to compete in today's global economy [1, 2]. The knowledge gap between the preparation of tomorrow's engineers and industrial needs must be narrowed as we approach the twenty-first century. While debate rages about how changes should be made, almost everyone agrees that something needs to be done. An educational process flexible enough for the industrial needs of the day yet rigid enough for fundamental concepts is not merely desirable but imperative for excellence in competitiveness, productivity, and engineering design. Therefore, facts need to be taught in the context of projected environments. Since a single faculty is unlikely to have all the desirable traits, a team-teaching approach involving nontraditional sources of faculty, e.g. industrial personnel as suggested by Locke [3], is perhaps the best solution to capture the best of both worlds, industrial and academic. In addition to enhancing the value of education, nontraditional sources and innovative educational approaches may be necessary as traditional sources may not be sufficient. Typically, traditional approaches are deficient in their liberal outcome towards meeting the needs of changing industrial patterns. The advantages of employing industrial personnel, on a part-time basis, may include cost advantages, increased industry/university contacts for contributions and grants, and an opportunity for the institution to evaluate the person for possible permanent position or for industrial personnel to evaluate prospective graduates for industrial employment. The disadvantages of employing a part-time industrial personnel are his reduced contact with students, little or no contribution to research or service functions of the university, and secondary nature of the teaching profession for him. But in a team-teaching approach, the gap created by the negative factors of part-time industrial personnel is filled by the full-time faculty through careful planning and course organization, while at the same time making efficient use of the positive factors in state-of-the-art industrial technology and idea transfer to academia. With this approach, engineering education can be considered as one coherent system with levels or stages interconnected.

In engineering the education for educating the engineers-to-be, high school preparation plays a crucial role. A shift in trend of high school students from preferring either vocational or college preparatory education twenty years ago to general education today has recently become evident [4]. Despite this observation, advocates of General and Liberal Education at the university level insist on

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an extensive 'cafeteria' plan of non-engineering core courses to make the engineering student a well-rounded citizen. This results in duplication of emphasis on General Education at the cost of the much needed courses in newly developed technical areas. Often such an approach imparts fragmented pieces of knowledge leaving the students with a deficiency in understanding real-life complex engineering systems in an industrial environment, which prevents them from being productive members of the industrial workforce. An engineer-to-be must recognize that many assignments in modern day industrial and global environments cut across the often compartmentalized traditional disciplines: humanities skills, communication skills, design, planning, simulation, control, and global economic and environmental concerns, in addition to technical innovations. Appropriate education for the future, therefore, ought to be meaningfully integrated rather than artificially segregated. This integration does require a thorough knowledge, on the part of the university faculty member, of constantly changing industrial environments. This is especially true in the semiconductor fabrication area, where tough competition from Japan has puzzled educators and industrialists alike. The question often posed is, 'should mathematicians, social scientists, or humanities-oriented faculty teach engineers or should engineering faculty teach their own versions of these subjects?'. The general feeling among engineering faculty is that the traditional non-engineering disciplines are too insular for engineers to gain much perspective from them. Perhaps the team-teaching approach can provide answers to these puzzles, and also enhance the appreciation of the other specialities.

With this perspective in mind at Wilkes University, we put into practice a team-teaching approach for a lecture/laboratory course in semiconductor microelectronic fabrication in order to capture the best of academic and industrial worlds. The team includes several engineering faculty (electrical engineering, physics, and materials engineering, for example), the technical manager and other personnel from a nearby Harris manufacturing plant, with an appropriate input from faculty from humanities departments, to fulfill the objectives of the integrated education. Through careful planning, the humanities skills were, we believe, successfully incorporated, thereby considerably enhancing the value of the professional preparation.

THE LEARNING ENVIRONMENT

Educational practices around the world tend to follow a widely accepted model of education that treats students as passive receptacles of information, rather than active learners. This model will not suit the needs of the workforce of the twenty-first century. Educators should be recognized as a true faculty of coaches who should have greater responsibility for creating schools where the key measure of success is the student's ability to integrate knowledge from a wide spectrum of sources in identification and formulation of an engineerng problem, followed by search and presentation of the solution. Fact and context must be taught simultaneously to meet this goal. We are faced with a typical situation in the classroom, where the problem is not that students don't know enough facts to solve a complex engineering problem, but that they know the facts, and they don't know how to use them. In quite another scenario, they know this fact and they know that fact from a Cafeteria Plan, but they don't know how to integrate the two into a meaningful functional engineering design. The same philosophy is evident in a recently issued position statement of the Office of Undergraduate Mathematics, Science, and Engineering [5]. The recommended program emphasizes: (1) the integrative ability—the recognition of engineering as an integrative process in which analysis and synthesis are supported with sensitivity to societal needs and environmental fragility; and (2) contextual understanding—the appreciation of the social, economic, industrial, and international environments in which engineering is practiced, and the competency to accept societal leadership effectively. In support of this philosophy, a first-two-year model engineering program is being experimented with at Drexel University [6].

A liberally educated engineer should be capable of functioning in situations that he never encountered before. He should not be hesitant in combining *knowing* with *doing*. He should be prepared to work as a member of a team of engineers as well as non-engineers of diverse expertise [7]. To create a learning environment in meeting the above challenges of training the future workforce, the teaching team should be textbook-proof, instead of requiring a teacher-proof textbook, which is to say the team should know the subject and peripherals so thoroughly that any textbook is merely a reference book. In a sense this team is a 'Guru' (from Sanskrit, *gu* meaning darkness or ignorance, and *ru* meaning destruction or removal) who leads the students to a vantage point from which problems and their solutions can be viewed in wider perspective, taking into account repercussions and side effects.

The following course outline [8] of our Microfabrication course indicates how we tried to create an environment conducive to integrated learning by following this team approach.

EE381: MICROELECTRONICS LAB
Course Outline—fall 1989

Mandatory common session:

Tuesdays 17:00–17:50, SLC-1

Laboratory Sections:

Mondays	*13:00–18:00, SLC-16 (Sec. A)*
Thursdays	*13:00–18:00, SLC-16 (Sec. B)*
Tuesdays	*18:00–23:00, SLC 16 (Sec. E)*

Textbook:

Introduction to Microelectronic Processing, Richard C. Jaeger, Volume V of Modular Series on Solid State Devices, Addison-Wesley, Reading, MA, 1988

Writing Style:

Information for IEEE Authors, IEEE Press, New York. A synopsis these instructions appears at the back of every IEEE journal. An example of this style is found in the paper entitled, "Industry/University Cooperative Program in Microelectronics Instruction and Research," co-authored by G. M. Dolny and V. S. Osadchy, describing Harris Semiconductors/Wilkes College Cooperation. A copy of this paper is included in the laboratory manual.

Description:

The course is devoted to the design, fabrication, and performance evaluation of a semiconductor device, with particular emphasis on diodes and bipolar junction transistors (BJT). This is a most sophisticated laboratory requiring seriousness and discipline from all students attending the course. Several hazardous chemicals are used in the processing of BJT using silicon epitaxial wafers. Each student is required to design and process silicon epitaxial wafers through the device fabrication procedures of wet chemistry, oxidations, photoresisting, oxide etchings, depositions/diffusions, etc. The fabrication process has been divided into several phases. Each phase is to be completed in one six-hour laboratory session in addition to a one-hour lecture. These phases of the fabrication process are described in Chapter VII of the laboratory manual.

As part of new core curriculum operational at Wilkes, this course has been designated as Writing-Intensive. This requires a substantial amount of writing in meeting the course objectives. This, also, gives you, the student, an excellent opportunity to practice formal and informal modes of expression of your achievements in the form of written documents. Each document will be graded for its stylistic organization, syntax, clarity, cohesiveness etc., in addition to the technical merit. While preparing these written documents for evaluation, you must keep in mind that you are not sitting next to the reviewer for explanation in case the document or a part of it is not clear to him. Therefore, your presentation should be self-contained and cohesive so that the reviewer can understand your work in a way you want him to understand. If you fail to meet this objective, you have not met the requirement of satisfying the Writing-Intensive component of the course, which carries a substantial portion of your final grade. To enhance your understanding of this objective, each written document must be accompanied by a Self-Evaluation Report Form (available from the instructor). Each document will go through a peer review process before it receives the final grade from the instructor. Your document as well as your review as a peer will be graded. Guidelines and evaluation forms for peer review are provided.

Data sheets are provided for each group (3–5 students) for the group captain to record each week's operation. These data sheets must remain in the laboratory and will be checked and graded for their completeness by the instructor at the end of each lab period. You can transfer this data to the data sheets provided in the lab manual.

You will keep a "journal" of your activity related to this lab in the form of a notebook properly page-numbered, titled, and dated. This journal should be written in the first person (I) to record the writer's responses to the subject matter (it). You are strongly advised to write a concluding paragraph summarizing your lab activity of the day. This journal is a valuable source for your formal lab report as it provides a place for you to record your impressions, speculations, questions, and insights. This journal will be collected three times in the semester for peer review and subsequent evaluation by the instructor. The comments of the peer and those of the instructor will be available to you for implementation in the subsequent recordings. Whenever asked by the instructor, you should be able to backtrack the history of your wafers using your journal.

A formal lab report is to be prepared in the following two stages. At the conclusion of your diode fabrication steps, you will be asked to prepare a formal lab report on design, fabrication, characterization, and performance evaluation of your diodes. It will go through the peer review process and will receive a grade by the instructor. You can implement the suggested changes in the second stage of this formal lab report and recover one-half of the missed grade. The second stage will have additional material on bipolar junction transistor, in addition to the work already submitted for the diode. This completed document should be submitted in conjunction with the graded work received back at the first stage. This should allow the instructor to give proper credit for the missed grade at the first stage. The final version of your lab report will be graded by the instructor only.

Course Grade:

The course grade will be determined according to the following distribution:

Record keeping-group data sheets	*05*
Record keeping-individual journal	*05*
Performance as a peer reviewer	*05*
Lab performance (weekly evaluation)	*10*
Home assignments	*10*
Formal reports	*15*
Mid-term exam	*15*

Quizzes	*15*
Final Exam	*20*
Total	*100*

Inadequate lab performance will result in negative contribution to the final grade. Keeping in view the School's Policy, 10% of the maximum points can be deducted in all examinations and homework assignments for incompetent presentation even if the answer is correct.

The course outline makes a mention of the new core curriculum operational at Wilkes which has an extensive general education program directed towards making the students well-rounded citizens and productive members of the workforce. During the development of this core, it was clear that almost everyone involved was more interested in getting a fair contribution of their subject to the proposed core. This situation is typical on campuses across the United States, resulting in core curricula consisting of fragmented and often unrelated courses. We at Wilkes are no exception. It is too early for us to assess the impact of the new core on the graduated student in his or her preparation for the job environment, but we decided to experiment with a viable parallel approach to implement the ideals of a liberal education.

In support of the fundamental philosophy of the new core, i.e. to give a student a broader educational base in which to practice professionalism, we decided to try an experiment to create an environment in which the desirable humanities-oriented skills are automatically integrated in an engineering course. The microelectronics fabrication course was an appropriate course for trying this experiment because of the involvement of industrial personnel from a nearby Harris Semiconductor plant in our teaching program. Another advantage was that the maximum size of each section was 12 students. This enabled the faculty-members-in-charge to monitor the progress very closely.

As is clear from several national reports, and confirmed by adjunct faculty from the industry, newly hired engineers are deficient in preparing reports and proposals, for which normally the help of a technical writer is needed, thereby increasing the cost base of the industry making it uncompetitive. For this reason, in the first phase of our experiment, we decided to start with the integration of the development of writing skills as part of the course. The proposal was approved by the Committee on Writing and an able teaching assistant from the Wilkes Writing Center was assigned to help us in evaluating each of the documents for stylistic and syntactic appropriateness as well as other linguistic deficiencies.

As discussed in the course outline, the major objective of this phase was to evaluate their formal and informal modes of expression in the form of written documents. This objective met with great success. In the process, we found that several additional objectives were fulfilled because of the grade distribution. One such objective emerging from the proposed experiment was to inculcate respectful evaluation of the work of peers and others, and in doing so, demonstrate high ethical standards. This was fulfilled by asking students to be anonymous reviewers of the lab journals and formal lab reports. Appropriate worksheets were prepared to guide the reviewers through a set of well-focused questions regarding the merit of material under review from different perspectives. Eventually, they were asked to integrate these answers in the form of a one-page descriptive report as a critique of the work reviewed. The reviews as well as the reports were then graded by the instructors and the teaching assistant from Wilkes Writing Center. These comments were given back to reviewers and reviewees, so that they could amend their deficiencies in the works to follow. This, therefore, was a practical way for them to view different modes of presentations and to understand these in a way that would develop their skills in the world of humans and machines.

An atmosphere of collaborative active learning was another component which became visible during this experiment. Each group of four students was expected to maintain accurate data records in group data sheets which remained in the laboratory. These then served as a reference for the class to compare notes and draw inferences from observations by different groups under varied experimental conditions. They were encouraged to note differences in processing conditions, electrical characteristics, yield, etc. As part of a process of collaborative learning and lab performance evaluation, we implemented a peer tutoring process [9]. A lead group which was trained by the faculty on a piece of specialized equipment conveyed information to the next group, and it in turn did the same to the next in queue. The faculty members-in-charge monitored this technical know-how transfer process and intervened when some points were missed or not clearly made.

The use of modern educational technology—audiovisuals, communications, computer, and print—to increase effectiveness (long term retention of ideas) as well as efficiency (rate of learning) was extensively made use of during the learning process. All lectures were presented by using viewgraphs using an overhead projector. The students received printed copies of viewgraphs which they could annotate for emphasis or clarity. This allowed us to incorporate new material in the course, which has not reached the textbook, making the faculty involved textbook-proof. Students integrated this new knowledge in the preparation of their formal lab reports. The students were also asked to view videotapes of advanced microfabriction facilities either on prerecorded videotapes or those received via satellite communication network of the IEEE Continuing Education Program. Often, they integrated this material in their written documents. The computer was extensively used in the course. All formal reports were prepared on a word processor which could import files from engineering software. The students' preferred choice was the Macintosh network available in the University. In addition SUPREM and SPICE programs were available on the mainframe VAX computer. This allowed them to simulate their process or evaluate the expected electrical output of the soon-to-be fabricated device.

On the advice of our adjunct faculty, we also felt that the uses and abuses of statistics [10] should be integrated in the course, and are due to be integrated in the next phase of the experiment in the following Fall semester. In the present semester, we discussed with them the processing of grades using Excel and Statworks software on the Macintosh computer. The analysis of the course grades using histograms, the correlation coefficient between different categories of grades, their reliability, and teacher operation under these uncertainties were discussed in the common lecture session. This increased understanding of fair intentions of the teacher and possible difficulties which an educated person may face in the decision-making process.

In order to appreciate the economic importance and cost effectiveness of their design, the students included in their formal lab reports a section on cost analysis. This allowed them to evaluate a situation of whether or not the market can bear the cost of the design. Students were also asked to indicate the areas where their fabricated product could find applications and what other competing products could do the same job and at what cost. This gave them some training in optimization of the design by including economic factors in addition to technical factors.

Another factor visible in the Course Grade category of the Course Outline is that of quizzes. Every lecture started with a short quiz of 10 minutes duration followed by a quick discussion of the solution which was prepared on the overhead transparency. The impact of this teaching pattern was the enhanced learning for students as well as a reduction of tardiness. Immediately following our experiment, an independent finding confirmed the value of the methods we were experimenting with in this course. Therefore, we are in agreement with the findings of the article which appeared in *New York Times* [11] that simple changes such as those described above can produce significant gains in learning. We created an environment with frequent checkpoints, like quizzes, tests, formal reports, and for positive feedback for enhancing their skills. Quick turnaround of their graded documents was another positive factor in their understanding of the following lab modules.

In addition to the ample opportunity for learning to do 'trouble shooting' that the diversity of equipment used provided, we, as instructors, also seized every occasion to raise and address ethical questions. Waste disposal of chemicals used for etching (e.g. hydrofluoric acid) and photolithography (e.g. photoresist) as an ever more serious question was discussed. Material Safety and Data Sheets (MSDS) are formally shown and an awareness of laws and their general intentions and attitudes regarding hazardous waste disposal is brought.

No engineering course could possibly include all humanities' traits. Our emphasis was in creating an environment in which to practice professionalism. Looking at the results and feedback of students, we succeeded in the present phase of our experiment. The availability of computer software allowed some students to give artistic and rhythmic touch to their presentations, thereby enhancing the value of their traditional education in a nontraditional manner. We have succeeded in at least alleviating their previous perceptions of humanities courses as a mandatory nuisance. Integrative learning breeds familiarity and familiarity may not necessarily breed contempt.

WILKES MICROFABRICATION FACILITY

Very few Electrical Engineering undergraduates get the opportunity to acquire hands-on experience in microfabrication because of prohibitive costs of initial equipment, the ongoing cost of laboratory material, and limited experience of the faculty in state-of-the-art technology [3]. Using equipment denoted by Harris Semiconductors and other companies, Wilkes was able to set up a Class-100 clean room facility for processing silicon wafers. This equipment is in good working condition but its use had been discontinued by the industry as it moved on to larger diameter wafer processing. This donation was accompanied by a large supply of unused wafers which could not be used in the updated assembly line. Wilkes employed, on an honorarium basis, Harris engineers and technical managers to help the university faculty in equipment and laboratory maintenance. With this kind of rapport built up, it was easy for Wilkes to obtain necessary consumable supplies, e.g. electronic-grade acids and etches etc., on a continuous basis from Harris. Under an active co-op program at Wilkes, many of our current engineering students work as interns at the plant. This also gives an excellent platform for Harris to evaluate these and other students for their appropriateness for employment at Harris after their graduation from Wilkes, in fact, saving part of the tremendous costs associated with entry level positions. Our laboratory facility, on the other hand, mimics the assembly line and engineering design environments of an industrial plant at an affordable cost.

In order to put a strong emphasis on the design component of the course, the University has made workstations available just outside the clean room for students to practice design using SUPREM III/SPICE modelling programs while their wafers are being processed in the furnace or at any other time.

The facility recently acquired an epitaxial reactor, ion implanter, a plasma etcher and a

Capacitance Voltage Bias Test (CVBT) instrument for oxide quality analysis. Installation of these is being done primarily by senior students with help from our technical support staff. Senior design projects, a mandatory part of all degree programs in engineering, are organized around some of these advanced facilities to great advantage both to the students as well as the institution. They are encouraged to be responsible as well as innovative while learning to take maximum advantage of all resources available elsewhere. For example, they might use equipment in the Centre of Materials Processing and Diagnostics for their design projects, such as optical microscopes, Scanning Electron Microscope (SEM), X-ray analysers, evaporators and sputtering chambers. In this way the laboratory facility is constantly in a state of development, adding facilities whose use is gradually incorporated within the teaching environment of the courses.

CONCLUSIONS

The team-teaching approach which allowed the university faculty working with adjunct faculty from the industry to integrate desirable non-engineering skills to enhance the value of engineering skills proved to be very successful. The outlook of the students was found to be dramatically changed. They were more communicative, expressive, respectful of peer's work, and cooperative in the use of design software and other technical equipment. They expressed great enthusiasm for their active learning in their written comments in computerized student evaluations and also in their open discussions with the other faculty.

This 'learn and apply' approach taught them to learn facts in the context of synthesis, involving manpower, computer power, money power, knowledge power, etc., to produce a desired result. In this complex world, one will find a lot of people (teachers, students, and workers) who have been trained to do something in a particular way. In battling with two demands, 'what students need' and 'what they want,' schools tend to provide the latter in the spirit of a consumer satisfaction. This is thought to ensure the popularity of the teacher and the institution. In providing the former of the two, a certain risk is involved as the effect can be measured in short period. In a team-teaching approach, a platform to view the effect in the long range is established. It also minimizes the risk and relieves the anxiety of an individual faculty member. This is perhaps the best way to develop a 'teacher-guru', who may otherwise be afraid to change his ways for fear of exposing his weaknesses. For example, many foreign-born faculty, who often dominate engineering departments, are reluctant to emphasize the writing skills in engineering labs. In a team-teaching approach, one may learn from the others and hence enhance skills in weaker areas. This is also true for student and worker groups. Global competition has taught us to practice cooperation within competition.

To conclude, what is needed is a model environment in which to practice professionalism, which we have tried to create and which we have described in this paper.

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REFERENCES

1. Education Supplement to *Wall Street Journal* (9 February 1990).
2. P. C. Jennings, R. P. Rohrer, J. Bordogna, L. P. Grayson, J. R. Eifert and E. E. David Jr., Restoring the Edge: Education and 'Made in America' Challenge, *ASEE Engng Ed.* **79**(5), 602 (1989).
3. C.E. Locke, Non-traditional Sources of Engineering Faculty, *ASEE Engng Ed.*, **79** (5), 558 (1989).
4. A. S. Tilmans, Preparing High School Students for Technical Careers, *Engng Ed.* News (ASEE), **16**, No. 6 (1990).
5. E. W. Ernst, Revitalizing Undergraduate Programs: Curricular Development, *ASEE Engng Ed.* **79**(1), 20 (1989).
6. E. Fromm and R. G. Quinn, An Experiment to Enhance the Educational Experience of Engineering Students, *ASEE Engng Ed.* **79**(3), 424 (1989).
7. G. M. Dolny and V. S. Osadchy, Industry/University Cooperative Program in Microelectronics Instructions and Research, *IEEE Transactions in Education* **E-20**(2), 93 (1986).
8. V. K. Arora, V. S. Osadchy, and V. Choudhry, *Microelectronics Fabrication—A Laboratory Manual*, Wilkes University Press (1989).
9. U. R. Nejib, Peer Instruction in Microelectronics Laboratory-Oriented Study, *IEEE Transactions on Education* **E-18**(2), (1975).
10. R. G. Batson, Statistical Training: A National Necessity, *ASEE Engineering Education* **79**(6), 598 (1989).
11. E. B. Fiske, How to Learn in College: Group Study, Many Tests, *New York Times* (5 March 1990).