A VLSI Design Laboratory Implemented in a Simulated Corporate Environment

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Abstract

This paper presents an innovative teaching method applied to a Junior/Senior level integrated circuit design course. The premise of this methodology is to help students prepare for the environment they will encounter in the workplace as well as teach the course material. Frequently the traditional laboratory for undergraduates consists of simply performing measurements and recording data from prepared experiments, and gaining little knowledge of how to design an experiment, interpret measured results, or report findings in a clear manner. The "simulated corporate environment" is designed to prepare engineers for situations in the workplace where they will evaluate problems, define potential solutions, form their own plan of action, and communicate their ideas with both peers and superiors in written, oral and electronic form (e-mail). In this course, students act as employees in a company and work as members of a variety of teams, all working to solve a common problem. The problems are designed to be open ended yet illustrate specific concepts in VLSI design. This "corporate environment" structure could be adapted to many other laboratory courses, however is especially suited to integrated circuit design since the successful production of any IC chip requires the close working relationship of many corporate divisions. This paper reports on this course format including the advantages and disadvantages for both student and instructor. This work is supported in part by a National Science Foundation Instrument and Laboratory Improvement Grant (DUE #9551598).

I. Introduction

Ideally, an engineering laboratory should serve several purposes: 1) aid in the understanding of classroom material through hands-on experiments, 2) teach measurement techniques, 3) provide opportunity to analyze and interpret real measured data, and 4) give practice in reporting technical information in a clear and informative manner. These four goals focus on preparing the student to be a successful engineer in the workplace. However, many times the laboratory experience for undergraduates falls far short of these goals. Students simply perform measurements and record data from prepared circuits, and gain little knowledge of how to design an experiment, interpret measured results, or report findings in a clear manner. To be successful engineers, students need be able to evaluate problems, define potential solutions, and form their own plan of action. They also need to communicate their ideas effectively with both peers and superiors in written, oral and electronic form (e-mail). Since most undergraduate engineers enter the workforce directly from college (~20% attend graduate school), an engineering curriculum should better prepare students for the type of skills they will need in industry. [1,2,3,4]

This "simulated corporate" environment presented in this paper is design to emulate the learning process students will encounter in industry. This course is designed as part of the electrical and computer engineering curricula that exposes students to all aspects of integrated circuit design and fabrication. Specifically this course 1) gives students hands-on experience with computer aided design tools for designing integrated circuits; 2) allows students to fabricate their designs through NSF sponsored facilities (MOSIS); 3) has students conduct measurements on fabricated chips; 4) lets students work in teams that must work together for project success; and 5) provides numerous situations to develop student communication skills in written, verbal and e-mail form. Under this format, students play the role of new employees of a company instead of students at a university. They are assigned to a team and a project, hold meetings to discuss plans of action, and communicate with their co-workers and boss through e-mail, while learning more about what their new company does (design and fabricate integrated circuits). This "corporate environment" structure could be adapted to many courses, however is especially suited to an integrated circuit design course since the successful production of any IC chip requires the close working relationship of many corporate divisions (Fabrication, Simulation/Layout, Test, and Marketing/Sales). The course format and implementation are detailed in this paper along with a discussion of assessment issues and course evaluation. This project is made possible through partial funding by a National Science Foundation Instrument and Laboratory Improvement Grant (DUE - 9551598).

II. Goals and Objectives

There are several desired goals for the students participating in this course. The first is that the students become more proficient and confident in expressing their ideas to their peers and supervisors in both written and oral form. Secondly, they learn to work well in groups. It is also desired that this course format will help students realize that there are many solutions to a problem (not a single answer) and that they are capable of finding these solutions, evaluating them, and suggesting a course of action. This is one step toward students taking charge of their own learning and not looking only to the instructor for answers. Students will obtain information from numerous sources including the World Wide Web. Last but not least, students in this course should learn about the field of integrated circuits including using software to physically layout and simulate circuit designs, conduct measurements on fabricated chips, understand the relationships between circuit performance and fabrication parameters, and design their own circuit suitable for fabrication.

This course format is not specifically geared to impact women and underrepresented minorities in engineering. However, studies have shown that both women and minorities benefit from working in small groups over a traditional lecture format[5]. Therefore any class format which improves student self-confidence or self-image, and emphasizes group work, such as this one, would benefit female and minority engineers.

III. Course Format

A. Implementing the Course

This “simulated corporate environment” is implemented in a Junior/Senior level electrical engineering course where students study integrated circuit design and fabrication. An introductory integrated circuit course that covers basic IC fabrication and design is present in most every electrical engineering curriculum in the country. At the University of the Pacific this course is entitled Digital Integrated Circuits (ELEC 136) and is a four unit course with three hours of lecture and three hours of laboratory each week. The “simulated corporate environment” format is used in both laboratory and class time as detailed below. This course is taken by Electrical and Computer Engineering majors, as well as some Engineering Physics majors, and is the students' first exposure to integrated circuit fabrication and design.

The company framework is created using a local area network (LAN) of ten Pentium-based computers' connected to the UOP campus wide network. Extensive use of e-mail is made for student groups to communicate their progress, questions, and results. Software available to the students on the LAN include Microsoft Office for spreadsheet, word-processing, and presentations, along with circuit simulation (Microsim’s PSpice A/D) and layout tools (Tanner Research’s L-Edit). All applications are Windows based, which allow students to easily transfer text messages, files, and graphs between their "co-workers" and the "boss". Students quickly became proficient using Microsoft’s Power Point to combine their work and produce high quality presentations. At UOP a data display panel was used to conduct Power Point presentations from a laptop computer. This allowed students to give dynamic color presentations without producing costly transparencies.

Since all applications were Windows based, simulation and layout results were integrated in the talks and reports.

The "simulated corporate environment" could be accomplished with either very modest or very elaborate test equipment. Minimally a 2-channel high-speed oscilloscope, function generator, multimeter, dual power supply to measure transfer characteristics, and a Logic Analyzer to test functionality of fabricated designs is needed. In addition to this equipment a Semiconductor Parameter Analyzer, pA Meter/Dc Voltage Source (like the HP 4140B), and temperature stage could be used to measure semiconductor properties and perform lifetime testing. Although this equipment (and others) could enhance the measurement portion of the course, most of the semiconductor and MOSFET parameters are given (or can be extracted) from information supplied by MOSIS for each fabrication run.

B. Course Structure

The first day of class, students are immersed in the idea that they are employees of a pretend IC design company called "Pacific Silicon" and that this is not simply "just another EE course". After welcoming them aboard and handing out the employee training manual, their responsibilities are outlined. The training manual includes information about the type of products that Pacific Silicon currently produces and recent press releases regarding problems with some of their new products. The manual also contains documentation about the computer system used at Pacific Silicon and the software with which they will need to become proficient. The "employee induction" program lasts 15 weeks (1 semester), and is divided into three sessions as detailed below.

Session 1: In the first five weeks of the induction program the students learn the basics of integrated circuit layout and fabrication procedures, learn to use the CAD layout software, review SPICE simulation (a skill they should already possess), become proficient e-mail users, measure transfer characteristics of digital gates, and gain insight to the four main divisions of the company (Design, Test, Marketing/Sales, and Fabrication). The instructor leads the training sessions much like a regular class with homework, quizzes, and 1 exam.

Session 2: The following 6 weeks are designed to expose the students to the different divisions of Pacific Silicon through three two-week projects. Students are divided into three teams (Simulation/Layout, Test, and Marketing/Sale). The Fabrication team is played by the instructor. The responsibilities of the different teams are outlined below.

<u>Simulation/Layout Team:</u>	conducts circuit simulation; makes all changes to layout; documents all work.
<u>Test Team</u> :	measures chips; compares actual performance to anticipated simulation results; helps update data sheet specifications; documents all work.
<u>Marketing/Sales Team</u>:	prepares product data sheets; handles customer requests/complaints communicates with all teams; investigates new markets for the company.
<u>Fabrication Team</u> : *(played by instructor)*	maintains database of process parameters; works with Marketing/Sales team for requirements for new products; responds to inquiries from all teams regarding fabrication.

Each project consists of a "situation" which requires that all teams work together to gather information, analyze possible solutions, devise a plan of action, implement the plan, and document all changes. The problems are designed to be open-ended yet illustrate specific concepts in VLSI design, and require group participation to solve. Students pick up the project in mid-stream (like in industry), meaning students are comparing the design and pre-fab simulation results of an existing design to the actual measurements they make on the fabricated chip. Students must determine where the problem lies (in circuit design, layout, fabrication, or possibly measurement). At the end of the two week project, they have documented all changes to the circuit layout, created new simulation using latest fabrication information, and created an updated spec sheet for the product.

The projects used in the Fall 1995 course are available in detail on the Web page created for the course at http://www.uop.edu/eng/courses/elec/elec136/pacificsi.html. Briefly, the first project forced students to fully investigate the transfer properties of an CMOS inverter and adjust the physical dimensions of the layout to meet specification. Actual fabrication data was used in simulation to discover differences from original design. The second project dealt with timing, parasitic capacitances and loading effects, and the third with scaling issues from 2.0 μm to 0.8 μm.

Throughout Session 2, extensive use is made of electronic mail to communicate among the groups. In addition to e-mail, every group is made aware of the other divisions' findings through numerous meetings and short presentations by the students. Each student is responsible for understanding the concepts involved even though their group may not be directly involved. A considerable amount of class time is taken up, not by the instructor, but by students presenting their findings and brainstorming to decide what to pursue next. At the end of each two-week project, each team gives an oral presentation and submits a joint report. One class period is used after each project's completion for an individual quiz on the material covered during that project. Before students rotate to a new division with different team members, each student completes an evaluation of their performance, their teams performance, inter-team communications, and the process as a whole. This is an integral part of the course which allows students a moment to consider their contribution to the team and how the team dynamics could have been improved. Many good ideas on how to improve the process came out of these evaluations which will be detailed in Section V.

Session 3: During the final three weeks of class students select and finish a final project while class time is used to cover topics not addressed in the projects. Students are allowed to work alone, or in teams up to three for these projects. Students selected from a list of projects or had the option to create their own. Each project involved physical layout, simulation, and background research. Each project included a final written report and oral presentation. Projects that simulate successfully and are fully documented are submitted to fabrication. Students test the chips when they are returned. Students final projects can be recycled for next years "situations" so the instructor is not constantly creating new project chips. Some of the students projects from the Fall 1995 semester at UOP are listed below.

1. A 16-bit microprocessor (three students)
2 A 4-bit ALU (one student)
3. Improved ESD protection on the input and output pads (two students)
4. 4-bit D/A converter using R-2R scheme (one student)

In addition to the assignments mention above each student also gave a 5-10 minute presentation during Sessions 2-3 on a current topic in integrated circuits design industry. Topics ranged from X-ray lithography and sub-micron devices structures to Multiple Chip Modules (MCM). This helped keep the course content very current.

IV. Assessment

For the instructor a traditional course format is fairly straightforward to assess. Students' homework assignments, quizzes, reports, and tests are averaged using a weighting scheme presented to the students in the syllabus. Since most all work is individual, assigning a grade is based on a single students knowledge or performance. With any course format change, the types of assessment used should be examined. Since much of the work in the "simulated corporate environment" structure is completed in groups, and knowledge is demonstrated by completing projects the assessment techniques used by the instructor must change. This aspect of the course reform is still in its infancy. However, the goal in assessment for this type of class is to move away from criterion based assessment and include many more forms of performance based, peer-review, and self-assessment which are more typical of the types of evaluation used in industry.

An example of an embedded assessment used right after the completion of the first project in Session 2 asked the students to complete an evaluation describing their contribution to the project, their teams performance, and suggestions to improve the process. These self evaluations were in a much different format than a quiz, yet yielded very similar information. Those students who could explain what the different members of their team were doing and why, performed very well on the written quiz following the project. At this point in time these evaluations were used by the instructor to examine group dynamics and facilitate the process, but in the future they could be used to actually evaluate the students understanding of the material in lieu of a written quiz. As indicated on an initial course survey, students are very uneasy with the fact that their grade will be determined partly by the work of others. This is also a concern for the instructor to ensure that grades are fair. In the first semester of implementation, the following weighting scheme was used. Using this scheme, roughly 53% of the students grade is based on individual performance and 47% based on team work, unless the students completed a final project on their own, then this ratio changes to 73:27. These weights are only a suggestion, but if the group work is not a sizable portion of the grade, the motivation to participate fully may diminish.

Individual Grade		**Team Grade**	
5 Quizzes	10%	3 written reports	18%
5 lab reports	15%	3 team presentations	9%
7 HW assignments	10%	final project	20%
1 written exam	12%		
1 oral presentation	3%		
team participation	3%		
total	**53%**		**47%**

V. Evaluation of Course Format

Surveys were distributed to students at the beginning and end of the semester. On these surveys students rated statements on a scale from 1-5 where 1 is strongly agree, and 5 is strongly disagree. Students also had the opportunity to give suggestions on how to improve the course format at several points during the class including after the completion of each project during Session 2. In addition to the students comments, the instructors observations and opinions are included below.

First a discussion of the things that worked well with this format. Students definitely became more proficient at defining a plan of action and deciding how to break up a problem. This didn't happen immediately, but developed over the course of Session 2. In the first project of Session 2, students fell into two groups. Those that jumped right in and started doing something immediately, without apparently giving much thought to what actually needed to be investigated. They were busy, but most just treading water. The second group didn't want to do anything, because they weren't specifically given something to do. To further the analogy those treading water were getting very frustrated with those sitting on the dock! By the end of Session 2 the students had self-imposed the following rules to facilitate the process. 1) E-mail should be sent to everyone in the class to keep abreast of all developments. 2) All e-mail correspondence should be of a standard form specifically stating who the message is directed for and what action is expected with a deadline included. 3) Students should spend more time discussing as a group what action should be undertaken before embarking on anything. 4) Within a group each member needs to know what portion of the project they are suppose to complete and when their portion must be completed. One team even created forms to distribute to the other teams to use when assigning work. Throughout the projects the students got better at dividing the work up equally, taking responsibility for the project success, and defining the problem at hand.

Another distinct improvement with the course format was the students oral presentations. Both the preparation time decreased and the overall quality increased over the five oral presentations that were given. Although students entered the course with different speaking abilities all the students responded with a 1 or 2, indicating that they agree strongly with the statement, "I feel my communication skills could improve". Students were also asked to agree or disagree with the statement, "I despise giving oral presentations". Perhaps not surprisingly over 80% strongly agreed (ranked it 1) with that statement at the beginning of the course, yet only 30% still strongly agreed by the end of the course. It was apparent that students' confidence in preparing for oral presentations had greatly improved by the end of the semester.

There are also several frustrations or suggested changes when using the "simulated corporate environment" format for both the instructor and student. As in any class the instructor must motivate the students. This is especially true for groups work, because if one group becomes lazy it affects the results of the other groups. The instructor should give a lecture or two about project management to smooth into the first project. Also a written final exam should be seriously considered. From the post-course surveys several changes were suggested to improve the course format. One was to eliminate the Marketing/Sales group and have two three week projects. The Marketing/Sales group could be played by the instructor so would not disappear entirely, but students in that group felt that they were out of the loop. Alternatively, when designing the projects, this team needs to be more involved with the problems at hand. Also students thought they should pick their final projects very early in the semester to have more time to do background research. Overall the students were very enthusiastic about the new format, and rated the course very highly.

Prep time for the instructor is less during Session 2 and 3 of the course than in a traditional lecture format. This is due to many class hours being taken up with student presentations and brainstorming sessions. One of the goals was to have the students use multiple resources to acquire information about integrated circuit design such as fellow students, the text[6], and the Web instead of from the instructor only. Students definitely started to take ownership of their learning process. The instructor spends a lot more time during Session 2 working with the students in small groups answering their questions, which is beneficial to both faculty and student. Overall the prep time for the instructor is probably equivalent to a traditional course format. Preparing all the course materials and projects can be very timely. The lecture format in Session 1 must very compact and precise in order to cover enough material in the five week time frame, and developing meaningful "projects" which can be completed in two-weeks takes some thought. This issue was one of the reason a NSF Course and Curricular Development Grant was funded to develop course material including all layout files, documentation, measurements, and project descriptions for other faculty to use. (DUE # 9555148) This project entitled "Teaching Digital Integrated Circuits in a Simulated Industrial Environment" is currently underway, and completed course material be available on the Web by December 1987 at the latest. (http://www.uop.edu/eng/courses/elec/elec136/pacificsi.html)

VI. Summary

By having the classroom experience more closely simulate the work environment, students are preparing for their transition into the corporate world. With this course format students become more proficient and confident in expressing their ideas in both written, oral and e-mail form. Students realize that there are many solutions to a problem and that they are capable of finding these solutions, evaluating them, and taking a course of action. They discover that team work is not a simple matter, but requires coordination and cooperation. Students start to realize that learning on the job is a fact of life as well as working on a team and communicating ideas!. Deviating from a traditional lecture format requires the students to take an active part in their education instead of a passive one.

This course format is still under development at the University of the Pacific. Assessment issues and evaluation methods still need to be examined. Also, more testing and evaluation needs to be completed to determine if students are learning and retaining the course material as effectively as a traditional class format.

VIII. References

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