AC 2007-922: WEB-BASED DESIGN AND ANALYSIS PROJECTS FOR A JUNIOR LEVEL INTEGRATED CIRCUITS COURSE

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Web Based Design and Analysis Projects for a Junior Level Integrated Circuits Course

Abstract

Just as the electronics industry can increase productivity with web-based tools, web-based design offers opportunities to improve education in the area of electronics and integrated circuits. This work describes a variety of web based design and analysis projects for a junior level electronics course and assesses their impact on student learning. Since the course using the projects comprises the second quarter of electronics instruction subsequent to introductory circuit analysis courses, the projects focus on relatively well-defined electronics subsystems. The projects exercise students' skills with a range of course learning objectives, ranging from lower level calculation, analysis and circuit simulation objectives to higher level integrative and design objectives. The projects also give students experience using the web as a form of technical communication and collaboration.

Our working hypothesis predicts that having students practice analysis within the environment of web based design problems strengthens their analysis abilities more than conventional drill style problem solving. As measured by survey data of student attitudes, students view the projects enthusiastically and believe the projects contribute to their technical understanding. However, as measured by tests requiring problem solving, project results do not always correlate significantly with students' abilities to master the course objectives. Also, great variation exists in the correlation between student performance on traditional problem solving exercises and student ability to master the course objectives. This work summarizes project results and student performance over eight years of course offerings.

Introduction

At Cal Poly, the majority of courses in electrical and computer engineering have laboratory components to provide active learning opportunities and teach practical skills. Instructors increasingly use active and collaborative learning techniques to enhance the learning value of lecture sessions.[1] This work seeks to augment active and collaborative learning to help students learn key electronics and integrated circuits concepts more deeply, namely, by finding a better way for them to practice problem solving outside class than traditional homework problems. The idea surfaced to have students complete design projects in electronics courses. Doing the projects online makes it easy for students to convey their results to the instructor and to each other. After employing such design projects for four years (projects 1-6), it became apparent that most students seemed to enjoy working on the design projects and felt they learned lots from doing so. However, the abundance of analytic and conceptual errors the students committed in project reports and on subsequent exams seemed at odds with their enthusiasm. Subsequent project assignments emphasized analysis (projects 9, 13-16) and explanation (projects 8, 10-13). To strengthen conceptual understanding, the course projects required students literally to explain design decisions, analysis, and key course concepts.

Learning Objectives

The context for this work is a course titled Digital Electronics and Integrated Circuits. The course is the second course in a three quarter sequence of electronics courses in the junior year following a year of introductory circuit analysis courses. The general course learning objectives are the abilities to analyze, interface, simulate, implement, test, layout, and design integrated circuits for use in digital applications. More specific outcomes include the abilities to list, explain, distinguish, analyze, simulate, interface, and compare the voltage transfer characteristics, logic levels, transient characteristics, power dissipation, and fan-out of the major logic families. A complete list of learning outcomes appears online.[2] Compared to topics and outcomes described by the Computer Engineering 2004 Joint Task Force on Computer Engineering Curricula, our course coverage corresponds approximately to Electronics areas CE-ELE3 through CE-ELE8 and a few topics in the VLSI areas.[3] The course seeks to prepare students for a technical elective course in VLSI design and subsequent required courses in analog electronics, mixed-signal electronics, and digital design and embedded systems. Each of our three unit lecture courses in electronics has a one unit laboratory associated with it. This work results from efforts to enhance the lecture portion of the course. The most recent course syllabus details course mechanics and how the course schedules reading, homework, quizzes, midterm exams, a final exam, and the course project.[4]

Project Assignments

The projects focus on digital electronics subsystems. Table 1 lists project problems assigned to date. Complete assignments and a subset of student work appear online.[4] Not as significant as the VLSI projects students would complete in a senior level IC design course, the design projects point in the direction of VLSI design by requiring similar and simpler analysis and simulation support. The projects have wider scope than homework problems. Assigned mid-quarter to groups of 2-4 students, students work on the projects for 3-4 weeks, mainly outside of class and concurrent with ongoing course assignments. Each student group addresses the same project assignment during one quarter, and the assignments vary each quarter. Design style projects ask students to design an interfacing circuit or optimize the performance of a circuit, sometimes using multiple logic families. Some projects require students to calculate and, in some cases, optimize a figure-of-merit (FOM in Table 1), which entails a Delay*Power*Area product. Figure 1 shows a screen shot of the top of one design style project assignment webpage.[5]

Other projects, labeled “Teach” style in Table 1, emphasize explanation and analysis instead of design. The design style projects do require students to analyze circuits and explain their design decisions and analysis. Other projects stress explanation more heavily. Guided by the adage “the best way to learn is to teach,” groups prepare online project reports intended to explain key course concepts to their colleagues. In subsequent course offerings, the better project reports posted online become required course readings. A “MoHAT” theme underlies all projects.

All course assignments and projects seek to improve students’ abilities to perform self-consistent analysis of circuits containing non-linear elements, including diodes and transistors. MoHAT, short for Model-Hypothesize-Analyze-Test, provides a helpful version of self-consistent circuit

Title	Task	Year	Quarter	Style
1 Output Buffer Design Project	Design a non-inverting CMOS buffer to allow the specified 5V CMOS gate drive a 5V TTL gate. FOM	1998	fall	Design
2 Output Buffer Design Project	Design a CMOS buffer to allow the specified 3.3V CMOS gate drive a 5V TTL gate. FOM	1999	winter	Design
3 Low Voltage Interfacing Project	Interface a low voltage logic family to drive 5V CMOS, TTL, & ECL gates.	1999	fall	Design
4 Translation Buffer Design Project	Design a CMOS buffer to allow the specified 100k ECL gate to drive 5V CMOS. FOM	2000	fall	Design
5 Translation Buffer Design Project	Design a CMOS buffer to allow the specified 100k ECL gate to drive 2.5V CMOS. FOM	2001	winter	Design
6 Translation Buffer Design Project	Design a CMOS buffer to allow the specified 100k ECL gate to drive 2.5V CMOS. FOM	2001	fall	Design
7 CMOS Buffer Design Project	Design a CMOS buffer to allow the specified TTL gate drive a 5V CMOS data bus. FOM	2002	winter	Design
8 CMOS MoHAT Project	Explain the operation of a CMOS inverter.	2002	fall	Teach
9 CMOS Buffer Design Review	Review fall 2001 designs. Evaluate, compare, and select a preferred design. FOM	2002	fall	Design review
10 NMOS MoHAT Project	Explain the operation of an NMOS saturated enhancement load inverter.	2003	winter	Teach
11 BJT Inverter MoHAT Project	Explain the operation of a BJT inverter.	2003	fall	Teach
12 ECL Gate MoHAT Project	Explain the operation of an ECL gate.	2004	winter	Teach
13 NAND Gates MoHAT Project	Compare and contrast the operation of two NAND gates in article by Ye & Galton.[6]	2004	fall	Teach
14 Unified MOS Model MoHAT Project	Compare and contrast the operation of a CMOS inverter using the standard long-channel vs. the Unified MOSFET model.[7]	2005	spring	Teach
15 TTL AND-Gate MoHAT Project	Improve performance and power dissipation of TTL NAND gate from course text by Gopalan.[8]	2005	fall	Design
16 TTL AND-Gate MoHAT Project	Optimize FOM of TTL NAND gate from course text by Gopalan.[8]	2006	spring	Design

Table 1 – Project topics and tasks. During fall 2002, each student completed two projects, so fall 2002 data occupy two rows. FOM indicates the project entails calculating a figure of merit as part of the assignment. Complete assignments and a subset of student work appear online.[4]

analysis to assist both students and instructors.[9] Analysis of circuits containing non-linear elements benefits from the use of equivalent circuit models. For this reason, introductory electronics and circuit analysis textbooks often outline a strategy for problem solving and suggest students apply equivalent circuit models.[10,11] The MoHAT approach appeals to students' desire for useful and widespread application while allowing instructors to insert the technique easily into courses during passive lectures, during active learning exercises, and during homework assignments. Instructors at Cal Poly apply the MoHAT approach primarily to Sophomore and Junior level electronics lecture and laboratory courses.

The MoHAT technique packages self-consistent problem solving into four familiar steps:

1) Select an appropriate circuit **Model** for each circuit element.
2) **Hypothesize** the mode of operation for each circuit element.
3) Apply circuit analysis methods to **Analyze** the operation of the equivalent circuit.
4) **Test** results against hypotheses and iterate if necessary to achieve self-consistent results.

The MoHAT technique helps students perform hand analysis, particularly the type of hand analysis to clarify the student's understanding of circuit operation in a manner benefiting subsequent design decisions. It nicely complements graphical solution techniques such as load-line analyses and computer aided circuit simulation. The technique provides students with a roadmap to use, when analyzing even relatively complex circuits containing diodes and transistors. The MoHAT technique generalizes well to a wide variety of circuits and is easy for students to learn.

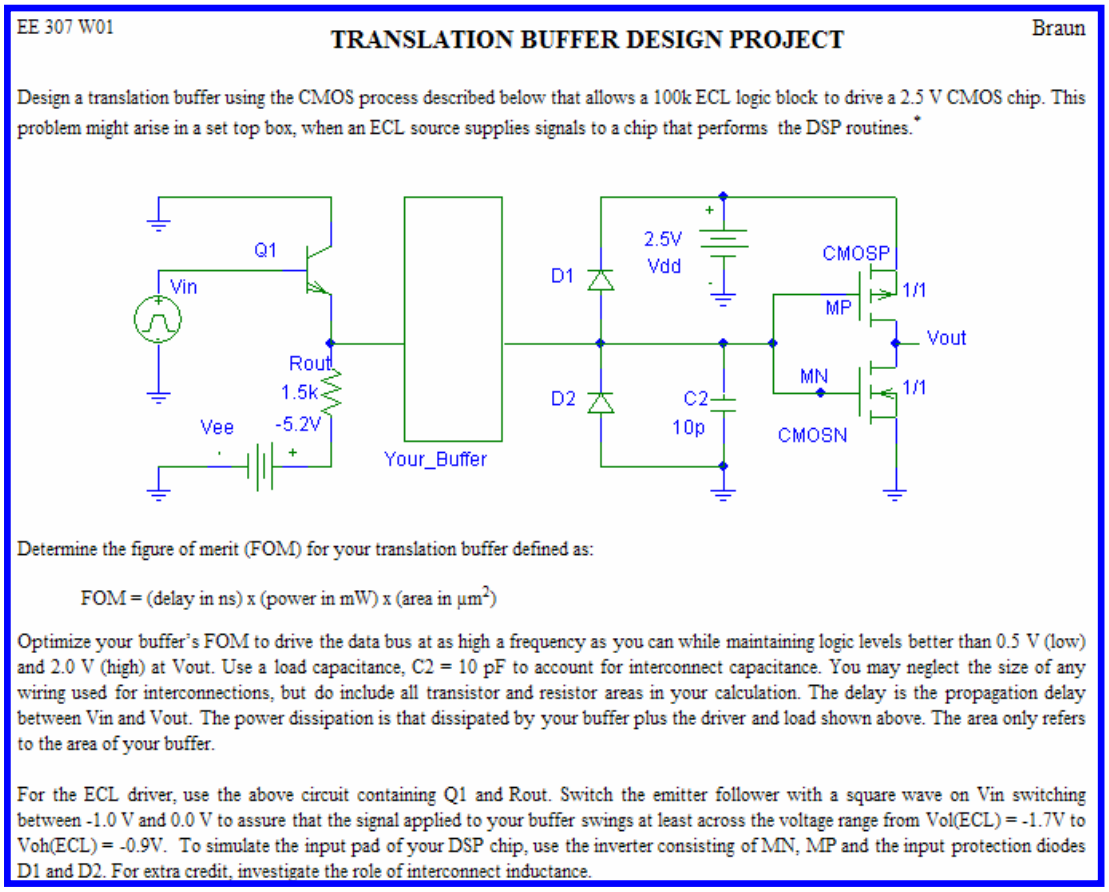

Figure 1 – Screen shot of the top of the project assignment webpage for winter 2001.[5]

Survey of Students Attitudes

Students completing the course during spring 2006 responded after the course ended to the questions listed in Table 2. We used the Blackboard Academic Suite to administer the survey anonymously online only to students registered for the course. The Likert scale survey questions (1-5) each received 25-26 responses, and the short answer questions (6-8) each received 5-16 responses.

Multiple Choice Questions:	(1) % Strongly Agree	(2) % Agree	(3) % Neither Agree nor Disagree	(4) % Disagree	(5) % Strongly Disagree	Average	Std. Dev.	% Agree or Strongly Agree	% Disagree or Strongly Disagree
1 The MoHAT Project enhanced my understanding of digital electronics and integrated circuits.	15.4	69.2	7.7	7.7	0.0	2.1	0.7	84.6	7.7
2 The MoHAT Project improved my performance on my EE 307 final exam.	19.2	19.2	38.5	19.2	3.8	2.7	1.1	38.5	23.1
3 EE 307 should include a MoHAT Project next quarter.	32.0	52.0	16.0	0.0	0.0	1.8	0.7	84.0	0.0
4 Having each group prepare a webpage enhanced the value of the MoHAT project.	3.8	46.2	19.2	26.9	3.8	2.8	1.0	50.0	30.8
5 The MoHAT Project should require students to work individually rather than in groups.	0.0	4.0	4.0	24.0	68.0	4.6	0.8	4.0	92.0
Short answer questions:									
6 In what ways did the MoHAT Project provide a valuable educational experience for you? "*The MoHAT project forced us as a group to really look into how and why these circuits performed the way they did, and made me really understand the circuits and the effects different layouts and components had on the overall performance. It excelled where the homework failed*" "*a more real, industry-type design problem. … it shows that in the industry there are many ways to approach a problem but some solutions are more efficient than others. Good team-building activity if students are serious learners, otherwise it's a joke*"									
7 What changes could improve the value of the MoHAT Project? "*Try to come up with a way that the project could be approached more analytically and logically. The one in spring the way that my group and I believe the other groups approached the project wise primarily a method of guess and check.*"[sic] "*Maybe emphasize the need for hand analysis (this was something that our group partially grazed over since we relied a lot on pspice).*" "*The formatting on it was a pain….*"									
8 If desired, please provide any other comments. "*I really liked the project even if my team did poorly on it.*"									

Table 2 – Survey questions, results, and representative student comments.

Survey responses appear in Table 2. More than 80% of the responses agree or strongly agree the project "enhanced" their understanding of course topics (question 1) and the course should include a project next quarter (question 3). More than 90% of the responses disagree or strongly disagree with the statement "The MoHAT Project should require students to work individually" (question 5).

The other opinion questions elicited ambivalence. With average responses closest to the neutral category, the average respondents neither agree nor disagree that the project improves final exam performance (question 2). Direct measures reported below concur. The survey indicates student ambivalence towards the web-based communication portion of the project (question 4). The ambivalence is consistent with the following somewhat competing observations: As a whole, students do seem more proficient at preparing the web pages than performing some of the design and analysis portions of the project, yet on several occasions over the years, students have commented how valuable they found the requirement to prepare a web page. Having the students post their project reports online does easily permit classmates—and students who take the course subsequently—to review and learn from results of other groups.

All responses to the short answer questions appear online.[12] The short answer responses are similar in flavor to those received in past surveys. Students comment about the need to avoid "guess and check," even though the course heavily emphasizes the need to approach problems methodically and analytically. Too many project groups prefer to run computer simulations rather than use a pencil to move their project work forward. Sometimes pushing a pencil can save time and effort. Pushing it effectively can indicate a deeper conceptual understanding. Such comments may provide guidance in understanding the lack of correlation with direct measures described below.

Multiple comments complaining about too rigid "formatting" guidelines deserve discussion. The formatting requirements are typically minimal, along the lines of "submit your report electronically as one webpage (.html)" with a request to turn in a subset of the report in class as hard copy. Rather than formatting, the student complaints more likely refer to detailed instructor feedback regarding poor writing. Although some students may initially resist such feedback, the Paramedic Method by Richard Lanham provides helpful tips for students to improve their writing with minimal time investment.[13]

Do the Project Assignments Improve Student Learning?

Survey results indicate students tend to appreciate the projects and feel they learn something from the project. Responses express less confidence that the project experience translates into better performance on the final exam. To investigate the connection further, this work seeks correlations between student performance on the course project, homework, midterm exams, a final exam, and the total course score.

This work uses linear regression analysis to test the hypothesis that having students practice analysis within the environment of web based design problems strengthens their analysis abilities more than conventional drill style problem solving. The regression analysis compares the correlation between course assignments or exams and final exams or total course scores following similar analysis of student assessment found in the literature.[14] Our analysis extends the technique described by Green[14] and includes the observed significance level (OSL or P-value) of the Pearson correlation coefficients.[15] For the regression analysis, Pearson correlation

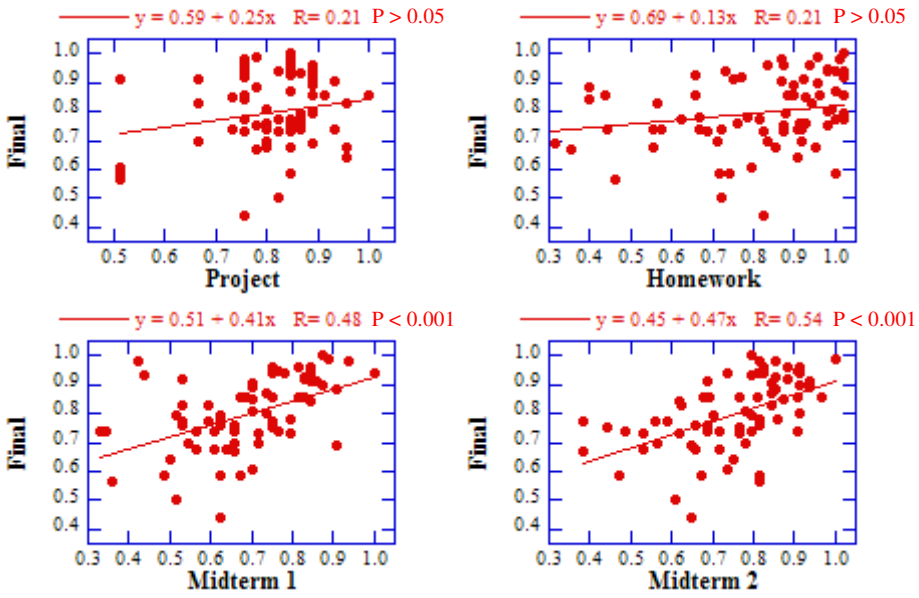

Figure 2 – Scatter plots of course assignment scores and final exam scores for winter 2001. Each symbol represents one student, and the lines represent the linear regressions.

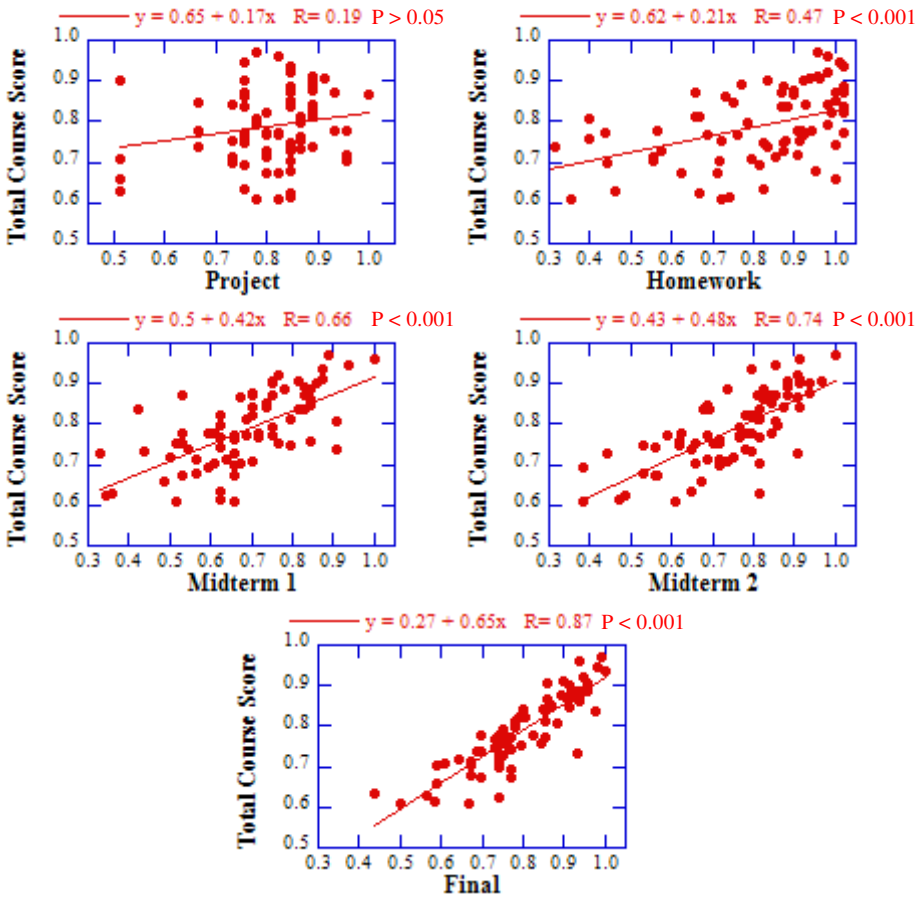

Figure 3 – Scatter plots of course assignment scores and total course scores for winter 2001. Each symbol represents one student, and the lines represent linear regressions.

	Project		Homework		Midterm1		Midterm2	
Project Title	**R**	**P**	**R**	**P**	**R**	**P**	**R**	**P**
1 Output Buffer Design	0.13		0.36	**	0.56	***	0.61	***
2 Output Buffer Design	0.25		0.21		0.52	**	0.49	**
3 Low Voltage Interfacing	0.09		0.14		0.38	***	0.38	***
4 Translation Buffer Design	0.28	*	0.21		0.30	**	0.41	***
5 Translation Buffer Design	0.21		0.21		0.48	***	0.54	***
6 Translation Buffer Design	-0.06		0.27	*	0.55	***	0.49	***
7 CMOS Buffer Design	0.07		0.16		0.24	*	0.61	***
8 CMOS MoHAT	-0.05		0.06		0.34	**	0.22	
9 CMOS Buffer Design Review	-0.07		0.06		0.34	**	0.22	
10 NMOS MoHAT	0.28	*	0.10		0.48	***	0.53	***
11 BJT Inverter MoHAT	-0.09		0.05		0.44	***	0.57	***
12 ECL Gate MoHAT	0.37	*	0.16		0.51	***	0.43	**
13 NAND Gates MoHAT	0.22		0.09		0.66	***	0.69	***
14 Unified MOS Model MoHAT	0.12		0.53	**	0.34	***	0.74	***
15 TTL AND-Gate MoHAT	0.04		0.23		0.49	***	0.49	***
16 TTL AND-Gate MoHAT	0.13		-0.09		0.48	***	0.73	***
*: P < 0.05 (significant); **: P < 0.01 (highly significant); ***: P < 0.001 (extremely significant)								

Table 3 – Correlation results between course assignments and final exam scores.

	Project		Homework		Midterm1		Midterm2		Final	
Project Title	**R**	**P**	**R**	**P**	**R**	**P**	**R**	**P**	**R**	**P**
1 Output Buffer Design	0.27	*	0.62	***	0.74	***	0.82	***	0.88	***
2 Output Buffer Design	0.25		0.43	*	0.71	***	0.69	***	0.90	***
3 Low Voltage Interfacing	0.18		0.51	***	0.69	***	0.69	***	0.78	***
4 Translation Buffer Design	0.26	*	0.50	***	0.54	***	0.72	***	0.83	***
5 Translation Buffer Design	0.19		0.47	***	0.66	***	0.74	***	0.87	***
6 Translation Buffer Design	0.07		0.53	***	0.71	***	0.75	***	0.86	***
7 CMOS Buffer Design	0.15		0.39	***	0.59	***	0.78	***	0.81	***
8 CMOS MoHAT	0.28	*	0.50	***	0.65	***	0.68	***	0.72	***
9 CMOS Buffer Design Review	-0.22		0.50	***	0.65	***	0.68	***	0.72	***
10 NMOS MoHAT	0.30	*	0.48	***	0.74	***	0.77	***	0.82	***
11 BJT Inverter MoHAT	0.00		0.46	***	0.69	***	0.85	***	0.79	***
12 ECL Gate MoHAT	0.31	*	0.27		0.77	***	0.68	***	0.84	***
13 NAND Gates MoHAT	0.28	*	0.24		0.82	***	0.80	***	0.92	***
14 Unified MOS Model MoHAT	0.22		0.68	***	0.49	**	0.88	***	0.93	***
15 TTL AND-Gate MoHAT	0.07		0.46	***	0.60	***	0.71	***	0.84	***
16 TTL AND-Gate MoHAT	0.21		0.29	*	0.80	***	0.79	***	0.77	***
*: P < 0.05 (significant); **: P < 0.01 (highly significant); ***: P < 0.001 (extremely significant)										

Table 4 – Correlation results between course assignments and total course scores.

coefficients, R, and the P-values were calculated with Excel's Data Analysis Regression Tool or MINITAB statistical software. Correlation coefficients from winter 2001 lie close to the average R values for all quarters analyzed, and, as such, represent "typical" data. Figures 2 contains

scatter plots of course assignment scores and final exam scores for winter 2001, and Figure 3 contains scatter plots of course assignment scores and total course scores for winter 2001.

Table 3 contains values of correlation coefficients, R, and the associated P-values for regressions using either project, homework, midterm 1 or midterm 2 scores as predictors for final exam scores. Table 4 contains values of correlation coefficients, R, and the associated P-values for regressions using either project, homework, midterm 1, midterm 2, or final exam scores as predictors for total course scores. The total course scores weigh the project 5%, homework 10%, quizzes 10%, midterms 40% and final exam 35%. Bearing in mind the magnitude of the Pearson correlation coefficient, R, indicates correlation or lack of correlation, not causality, we follow convention and label $R<0.5$ weak correlation, $0.5<R<0.8$ moderate correlation, and $R>0.8$ strong correlation.[15] Seeking statistical significance at the 0.05 level, we label and emphasize with yellow shading in Table 3 $P < 0.05$ as significant (*), $P < 0.01$ as highly significant (**), and $P < 0.001$ as extremely significant (***). No yellow shading indicates a P-value above 0.05.

Regarding correlations between midterm exam scores and final exam scores, moderate or weak correlations exist. Statistically, the correlations are highly significant ($P < 0.01$) for all quarters except fall 2002. Regarding correlations between project scores or homework scores and final exam scores, few correlations are statistically significant. The three significant ($P < 0.05$) correlations between project scores and final exam scores are weaker than the corresponding midterm to final exam correlations.

Regarding correlations between homework, midterm exam, or final exam scores and total course scores, strong, moderate or weak correlations exist. Correlations between midterm or final exam scores and total course scores are strong or moderate. Statistically, the correlations are highly significant ($P < 0.01$) for all quarters. Homework correlations are weaker for all quarters other than spring 2005. Statistically, the correlations are significant ($P < 0.05$) for all quarters except two during 2004. Regarding correlations between project scores and total course scores, few correlations are statistically significant. The six significant ($P < 0.05$) correlations between project scores and total course scores are weaker than the corresponding midterm and final exam to total course score correlations.

The above data arise from discarding all scores from students who skipped one or more exams or ended up with total course scores below 50%. Doing so tends to reduce correlation coefficients by a few percent. The few students in this category tend toward those who gave up on the course or students with special situations seriously hindering their studies. This distinction could explain why some of the correlation coefficients with total course scores are lower than those reported by Green.[14]

The regression analysis ignored quizzes. Used in the course mainly as a tool to urge students to keep up with reading and homework assignments, the three quizzes throughout the quarter focus on small problems, typically involving only one or two concepts. The literature cautions against seeking correlations among assignments sampling incomplete coverage of course concepts,[14] specifically when involving a small number of quizzes.[16]

Discussion

Thinking the projects could inspire more significant learning[17] to occur and further enduring understanding[18] better than the course would otherwise, we anticipated a positive correlation between the project performance and learning as measured by final exam and total course scores. Correlations between the course's traditional assignments exhibit higher values. Even the weak correlations between homework and final exam or total course scores exceed on average those correlations with the project. Green warns of the variation of correlation resulting from random sampling of course topics.[14] Because most of the final exams explicitly include at least one question based directly on the quarter's project, we might expect to minimize the effect of random sampling and observe an even higher degree of correlation between the project and final exams. Our data do not bear out this prediction. In fact, we don't have evidence for any correlation between student performance on a course project and their performance on the final exam problem specifically derived from the course project. Green agrees and explains lower correlations to individual exam question performance than to entire exam scores due to variations "noise" of student performance from one question to another.[14]

The lack of correlation between project and final exam or total scores may not imply a lack of learning. Weighting the project as only 5% of the total course score would tend to decrease the correlation between the project and total course scores. Most projects were assigned as group projects. The low weight of the project would tend to decrease the direct influence high or low performing group member would have on the total scores of other group members. Having students work in groups could produce indirect opportunities for students to learn from each other, and, thereby, increase their total course scores. Despite a poor score on the project, a student can learn course material in time for the final exam. Conceivably, a poor score on the project could prompt a student to learn material in time for the final exam as sometimes happens after poor midterm exam performance. Also, the lack of linear correlation between project scores and final exam or total course scores does not rule out the existence of a non-linear correlation. However, the scatter plots in Figures 2 and 3 don't suggest a more appropriate non-linear correlation.

Other explanations could explain the lack of direct correlations observed: The lack of correlation between project scores and final exam scores may stem from students preferring the hands-on nature of the project to the traditional problem solving required by a final exam. The project took place in groups of 2-4 students, while final exam scores should rely primarily on a student's individual work. Projects may show less correlation with comprehensive final scores and total course scores, since they tend to cover a subset of the course technical material. All projects do practice with hand analysis (MoHAT) and circuit simulation (PSpice) the key course concepts of logic levels, noise margins, transient circuit operation, fan-out, and power dissipation. However, only the design projects bring out interfacing issues and involve at least two logic families, though not by necessity. Instructors could devise non-design projects to cover a larger fraction of course concepts. Such shortcomings and lack of correlations remain consistent with literature advice to triangulate with multiple strategies to teach concepts and multiple assessment tools to determine the success of the learning.[19-20]

EE 307 W01 **TRANSLATION BUFFER DESIGN PROJECT** Braun

Project Evaluation

Project Group Members for Group #__:

_____ _____

_____

Schematic with node numbers	/5
Summary Table, FOM	/6
PSpice Input/Output for Delay Simulation	/10
PSpice Input/Output for Power Calculation	/10
Web Page Quality	/5
Report Quality	/4
Project Total	/40

Comments

Figure 4 – Sample scoring sheet for winter 2001 project.[5]

The lack of correlation between project assignment scores and final exam or course scores could indicate the final exams test the wrong topics. This is possible, but unlikely given the comprehensive range of course concepts covered by the final exams. Rather, a majority of students working on the projects may fail to grasp key analytical concepts while doing the project. Inadequate feedback on the project from the instructor may also fail to teach the requisite concepts. Figure 4 shows a sample score sheet for the winter 2001 project. The project awards up to 75% of the points for analysis, simulation, and explanation and 25% of the points for following instructions and preparing a professional report. For projects from other quarters, score sheets weigh 50%-75% of the points for technical and conceptual issues and 25%-50% of the points for professionalism.

Project Title	Quarter		Final Score Mean	P
3 Low Voltage Interfacing	1999	fall	0.66	**
5 Translation Buffer Design	2001	winter	0.80	*
12 ECL Gate MoHAT	2004	winter	0.80	**
15 TTL AND-Gate MoHAT	2005	fall	0.79	*
None	2006	winter	0.73	
*: P < 0.05 (significant); **: P < 0.01 (highly significant)				

Table 5 – Statistically different final exam averages.

Table 5 summarizes one statistically defendable perspective possibly indicating the project assignments have a favorable influence on final exam scores during three of the quarters under study. During one quarter of the period under study, winter 2006, the students did not complete a

project. Comparing the mean final exam scores of the winter 2006 quarter without a project and the mean final exam scores of each of the other quarters listed in Table 1 produces mainly statistically insignificant differences ($p>0.05$). When compared with the four other quarters listed in table 5, statistically significant differences between the means result. For three of the four quarters with projects—winter 2001, winter 2004, and fall 2005—the mean final exam score exceeds the winter 2006 mean. During one quarter with a project—fall 1999—the mean final exam score is less than the winter 2006 mean.

Future design and analysis projects will likely benefit from implementing the web portion of project development and communication using wiki tools, as our campus is in the process of deploying such infrastructure. Convenient and helpful tools could make the process of cooperative design and online project development more attractive than posting web pages and could relieve some student ambivalence unearthed by the survey results. Evolving from project scoring sheets into more meaningful rubrics could incite students to devote a greater fraction of their project energy and time to thoughtful analysis and better conceptual understanding rather than report formatting. We would appreciate feedback about the projects, assessment efforts, and further ideas for improvements.

Conclusion

This work presents 16 projects designed to enhance significant and enduring learning of junior level digital electronics and integrated circuits concepts. Project styles include design, analysis, and teaching. The design projects require students to conceive their own designs or modify existing circuits for improved performance. The analysis tasks seek correct determination of circuit performance and specifications. The teaching projects have students convey key course concepts to their colleagues using web-based tools, computer simulations, and clear explanations. For all projects, having students complete the reports online allows them to share results with each other and learn from each other's best practices.

As measured directly by tests requiring problem solving, project results do not always correlate significantly with students' abilities to master the course objectives. The few statistically significant correlations between project scores and final exam scores or total course scores are weak at best. Perhaps the project assignments benefit students in ways this study did not assess. For example, we did not measure whether students improved teamwork and communication skills as a consequence of completing their group projects, nor did this study collect data from students several years after the course to ascertain longer term benefits. As measured by survey data of student attitudes, students view the projects enthusiastically and believe the projects contribute to their technical understanding.

Acknowledgement

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