Active and Cooperative Learning in a VLSI Design Course: Lessons from the Trenches

J.W. Bruce[1]

Abstract – Active and cooperative learning techniques have been researched extensively and shown to be effective teaching tools. This paper describes how a senior/introductory graduate course in very large scale integration (VLSI) design was adapted to make extensive use of active and cooperative learning techniques. Heterogeneous student teams are formed by the instructor early in the semester. These teams work cooperatively on nearly every aspect of the course, including homework, lab assignments, a semester project, and active exercises in lecture. Students are guided through exercises to improve teaming, communication, and leadership skills. Positive interdependence and thoughtful reflection on student teaming and communication abilities are encouraged throughout the semester. This paper gives examples of practical active and cooperative learning exercises that have been used with success for eight consecutive semesters in Mississippi State University's VLSI design course.

Keywords: active learning, cooperative learning, team-based learning, electronics, integrated circuits

INTRODUCTION

The computer engineering program at Mississippi State University (MSU) requires a three hour course and laboratory in integrated circuit design. (This course is commonly called the "VLSI course" by our students.) A significant number of electrical engineering students interested in microelectronics or integration also enroll in the course as an elective. Because of the long prerequisite chain, this course is often taken by students in one of their last two semesters. The course covers traditional static CMOS digital circuits while reinforcing the principles of digital design and electronics learned in previous classes. (Graduate students with undergraduate degrees from other universities and interests in microelectronics and computer engineering research also take the course, usually during their first or second semesters.)

Surveys of the largest employers of our graduates and our GOLD (Graduates of the Last Decade) cohort indicate that interpersonal skills, specifically communication and teamwork skills, are the most lacking and most needed in the engineer's professional career. These findings are very much inline with similar surveys in the literature and ABET criteria. While the ECE capstone design course at MSU requires team projects and technical communication instruction, there is a concerted push to include teaming and communication activities in as many earlier classes as possible. The VLSI course is a natural place to practice these skills as modern integrated circuit design is almost never done by a solitary engineer, but by large teams of circuit designers.

I have been the sole instructor for MSU's VLSI course for eight consecutive semesters enrolling more than 230 students. Over the last four years, I have made the course my own and have found it an ideal location to improve my teaching skills with active and cooperative learning techniques. This paper describes many of the lessons I have learned in this course. The experiences described in this paper can be applied to engineering courses in all disciplines.

---

[1] Department of Electrical and Computer Engineering, Mississippi State University, 216 Simrall, Mississippi State, MS 39762-9571 (*jwbruce@ece.msstate.edu)*

ACTIVE LEARNING

Educators should judge their performance by "what is learned" rather than by "what is taught".

The statement above is my personal philosophy toward teaching. Far too often, educators fall into the habit of describing courses by what topics are "covered", not by how much the students actually learn. Moreover, the more topics we can cram into a semester, the better teacher we must be. Right? Of course, it sounds ridiculous when phrased this way. But, we must all be vigilant in measuring our teaching performance the same way we would measure the performance of any product we design or any research we conduct – results. Active learning has been shown to be effective in helping students learn by many different researchers [14]- [17]. I use active learning activities heavily in my classroom and have been very pleased with results.

Background

Learning psychologists have determined that knowledge retention declines precipitously from a maximum of about 70% to below 20% after a few minutes of traditional, or passive, lecturing [16]. (See Figure 1.) This passive lecture style, where the professor speaks and transcribes notes onto a blackboard for students to copy into their notes, is the primary engineering learning method used for decades. Effective learning requires pedagogy to keep students in their "retention groove". Active learning exercises (introspective high-level thinking skills problems, small-group exercises, "one-minute" reports, small-group brainstorming, etc.) interspersed through a "traditional" lecture do just that [14]-[17].

Active learning techniques have been used in K-12 education and general university education with great success since the 1970s. Starting about 1990, engineering educators initiated, measured, and published efforts and success with active learning techniques in the undergraduate engineering curriculum [2], [7]-[11]. Through studies in engineering education, much of it funded by NSF, active learning exercises have been shown to cater to various student learning styles [5], hone student communication skills [14], reinforce "learning communities" [2], [16], and effectively exercise higher thinking levels in Bloom's Taxonomy [17]. Active learning will keep students awake and engaged. Consider it the most "passive" learning method in your arsenal. Cooperative learning methods structure learning to occur outside of the classroom. It also develops teaming and communication skills. The literature is overflowing with its benefits and implementations. Those new to active learning are encouraged to read [14]- [17] before and during use of active learning techniques in the classroom.

Active learning exercises during lectures are relatively easy to initiate. A simple way to create those first active learning exercises is to take an example exercise from the lecture notes that is typically worked and explained by the instructor. Place the example problem on the top of blank page and distribute to the class. Give instructions to the class on how to perform the active learning technique, i.e. think-pair-share, brainstorming, etc. While students work actively, the instructor should circulate around the classroom to give and get feedback. After several minutes, the instructor reacquires the attention of the energized, awake, and knowledge-retaining students to discuss the problem, its solutions, and related concepts. In subsequent exercises and with time, instructors become quite adept at switching students into and out of active learning exercises. Likewise, students become very accustomed to the transitions after just a few exercises. In fact, students require no "training" at all if they have been exposed to active learning in prior courses. (In the ECE department at MSU, five other instructors use these techniques at least occasionally. By time students arrive in the VLSI course during their senior year, they are very accustomed to turning to their colleagues during active exercises in lecture.)

Learning is a feedback system. In general, students and faculty perform better when the feedback evaluations are numerous and frequent. Problems are more quickly detected and corrected. Active classroom exercises give the instructor and the students a chance to evaluate the comprehension and retention just moments after a concept is taught. I use the results of an active exercise to make the most efficient use of classroom time – reviewing concepts when the exercise shows that the concepts have not be retained, or moving more quickly if the exercise shows that class is proficient and bored.

ACTIVE LEARNING EXAMPLES

I started using active learning techniques in my classroom four years ago during the initial offering of the VLSI course. The student resistance to such exercises that is often reported in the literature was minimal and has decreased to nearly nothing today. If you explain to your students that the techniques that you are using are well-researched and proven effective, they appreciate your concern and effort. Soon thereafter, students recognize the effectiveness of the active learning and any resistance quickly dies away.

This section includes several examples of active learning exercises that I use in the VLSI course. While the examples are specific to the integrated circuits, other disciplines should be able to use these examples in forming exercises specific to their fields of study.

Think-Pair-Share

Think-pair-share is an active learning technique where students are given a problem to attempt and solve alone. After a few minutes of working individually, students turn to a teammate and compare solutions. Students discuss discrepancies and come to a consensus solution. Think-pair-share is a well-known and proven technique for active learning that caters to the students desires to work individually.

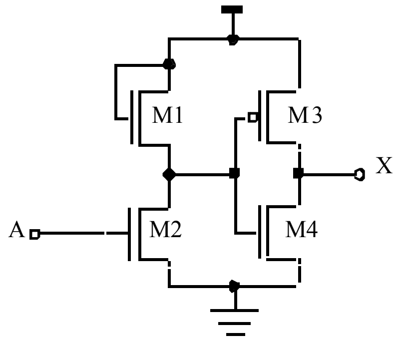
Because I am interested in improving the students teaming and communication skills, I use think-pair-share sparingly. However, think-pair-share exercises are useful when you must verify that students have knowledge and abilities individually and are not relying too heavily on their teammates. Below is an example of a typical think-pair-share exercise used in the VLSI course.

> Design a CMOS inverter to have a threshold voltage midway between its power supply voltage and ground. The CMOS process has minimum channel length of 0.5μm and minimum channel width of 1.5μm. Assume V_{TN}=-V_{TP}=0.5V, L_N=L_P, and μ_e=2μ_h. How does your answer change if the power supply voltage changes? How does your answer change if μ_e=3μ_h?

Team Solution

Team solution is the active exercise used in most often in the VLSI course. Team solution works very well with open ended and design oriented problems. In team solution problems, I select one member of the team at random to be the team recorder. Team members are identified by their circuit symbol (see "Forming Teams" section in this paper). The recorder is instructed to record the comments and solution suggestions by their teammates. The other team members are instructed that they cannot write any thing down but must communicate with the recorder and their team mates. This structure forces team members to communicate clearly and in an orderly fashion. Team solution emulates industrial and professional situations where engineers brainstorm and banter back-and-forth with design ideas. During team solution, I wander about the classroom looking over the team's shoulders and eavesdropping on their conversations. In this way, I obtain immediate feedback on the progress of each student's abilities and can often recognize poor team dynamics. Below is an example of a typical team solution exercise used in the VLSI course.

> Consider the CMOS gate below. What logic function does the gate perform? What is a potential problem with this circuit? Under what conditions does it occur? If your boss insisted on using this exact logic gate in a very important project, what would you do to ensure proper functionality under the widest range of operating conditions? Be specific about what you would do and why it helps.



"Minute" Paper

Minute paper is an active individual exercise well known in the literature and is often used to gain qualitative feedback from students. A minute paper is just that - a paper written by the student in the time span of a minute or two. The topic of the minute paper can be almost anything. I often use minute paper to determine which topics are most confusing to students. I ask students to write a one minute paper about the "muddiest" or most confusing point(s) covered during this class period. Another good topic for minute papers is to have students paraphrase a design methodology or algorithm introduced during the lecture.

COOPERATIVE LEARNING

Cooperative learning is a pedagogic technique where students interact with one another while learning and applying course material [18]. Cooperative learning techniques can extend active learning beyond the course lecture period. Teams of three or four students work together on homework sets, lab experiments, course projects, and team-based exam questions. In short, cooperative learning is similar to team-based course projects common in many engineering courses, but cooperative learning is more formalized and structured to reinforce positive teaming and learning skills while avoiding common teaming problems [13], [15]. Cooperative learning must meet five criteria [18]:

- positive interdependence -- team members must rely on each other to achieve the group's goals.
- individual accountability -- members are held accountable for doing their part and mastery of the material.
- face-to-face interaction -- some or all group members must work together to achieve the group's goals.
- appropriate use of interpersonal skills -- group members learn and practice teaming, communication, conflict management and leadership skills.
- regular self-assessment of group functioning -- groups periodically reflect and evaluate their performance and identify ways to improve that performance.

Correctly applied, cooperative learning techniques increase the students' motivation to learn, material retention, depth of understanding, and teamwork/communication skills [18] by forcing students to work in the more effective (lower) learning levels in Figure 2.

Cooperative learning techniques may be the most thoroughly studied teaching method ever devised, and has been shown to be highly effective [5][18]. Many engineering educators who have adopted and studied active learning techniques have also tried cooperative learning techniques. Success in reducing attrition and improving academic performance, student motivation, and student satisfaction with engineering has been documented extensively [7]-[11], [13], [20], [23], [25]. Faculty observe and students self-report gains in complex problem solving skills, teamwork/communication skills, and design abilities [11], [22], [23]. NSF considers cooperative learning techniques a critical part of engineering education reform [2]; however, engineering education journals report few examples[2] of its use in electrical and computer engineering instruction.

The cooperative learning references at the end of this paper have many effective activities. I have found team homework, team projects, and "jigsaw" exercises are particularly useful in engineering classes. The key is to ensure that all five criteria listed above are present to minimize problems and student resistance.

COOPERATIVE LEARNING EXAMPLES

Forming Teams

Cooperative learning requires teams be formed. Research results indicate that heterogeneous teams are more effective and emulative of industry. Student-selected teams tend to be homogenous, so I form three to four person student teams early in the semester. In fact, preliminary working teams are formed in the first few minutes of the first class period of the semester. Initial teams are formed randomly through an active exercise that demonstrates communication skills and shortcomings. I ask the entire class to stand and think some common "attribute" that is random and independent, birth date, mother's name, place of birth, etc. Students are then instructed to organize themselves, as quickly as possible, into a line across the front of the lecture hall in order (by birth date, alphabetical by name/place, etc.). With larger classes, it is interesting to see how long before "leadership" surfaces and a few students start orchestrating the entire assembly. It is also interesting to see the usually terse method of data exchange that forms spontaneously to facilitate the ordering. I use a stopwatch to time the process and share the results and previous semester results with the class. While standing in their ordered line, we reflect on how

- "leadership" just sprang up
- important a "common" data format was to the process
- communication on my part was inadequate (I am careful not to specify ordering by annual calendar birth dates or age birthdate, mother's first or last name, city, state or country of birth. In larger classes, there are usually examples of each.)

Teams are formed based on the "random" ordering of the line of students. These are the working teams until I reshuffle team membership after "drop day" based on performance, background, interests, etc. See [16], [18], [20] for how others form cooperative teams.

Teams must sit together during lecture in prescribed locations in a square arrangement. Each "corner" of the team square, therefore, each student, is assigned a circuit symbol designation (VOLTAGE SOURCE, RESISTOR, CAPACITOR, XOR) by a wall hanging in the respective corner of the lecture hall. This team member designation is convenient in assigning team roles, either during active exercises or for cooperative assignments like jigsaw.

Cooperative Learning Assignments

Cooperative class assignments are used throughout the VLSI course. The only individual assignments are exams. All other assignments (homework, lab, project) are team-based. Team assignments must generate a single team submission obtained by team consensus. Therefore, teams must meet and agree upon the one solution that represents them collectively. Each team member must attend this meeting and come prepared (bring their own individual idea, outline, solution in writing to the meeting). The team meeting has specific team member roles [14]:

- coordinator – responsible for calling meeting, making sure everyone knows when/where the meeting is held, providing agenda and material that members need to bring to meeting, and keeping meeting on task

---

[2] I recently surveyed 1985-present archival journals that commonly report ECE education research. Over that time span, I found little more than a dozen articles reporting formal active and cooperative learning techniques in ECE classes. I believe that ACL has more widespread use in ECE instruction than the literature suggests.

and tangential discussion to a minimum. It is made very clear that the coordinator is not the team leader, but a facilitor.

- recorder – Every team meeting produces some written team output, usually the team solution submission. It is the recorder's job to consolidate the team's consensus into one coherent, legible document with consistent notation and look-and-feel.

- checkers – The remaining team members are responsible for making sure the recorder's submission is free from typographical and technical errors. These errors are most often the result of transcription not understanding.

In order to give each team member experience in each of these roles, the team roles are rotated every assignment according to the student's circuit symbol designation. Team meetings, study sessions, lab periods, and work sessions are encouraged and often necessary to complete assignments. Repeatedly, students are getting together outside of the scheduled lecture period to learn.

Readings on engineering teams are required throughout the semester. I especially like the article by Philips [19]. I emphasize the importance of these "soft skills" readings by announcing to the class that the material in the reading will be included on exams at random. I follow through on this pledge.

Individual Accountability

Many of us instructors have tried "group" projects and assignments. It is likely that many of us can tell stories and anecdotes about the mixed results achieved. A few of us can likely tell of a few downright failures among our attempts. Successful cooperative learning must meet the five basic requirements listed earlier. The most common reason that "group" assignments are not successful is that one or more of the five requirements are not being met.

One of the most common failure modes in "group" assignments is the "hitchhiker". Everyone has witnessed one or more team members riding the coattails of their teammates. The hitchhiker contributes little to no productive effort toward the team solution, yet receives the same grade as the other contributing team members. When the efforts of many are combined into a team result, it is difficult for account for each member's individual contribution. Yet, successful cooperative learning requires such an accounting. A similar, but more rare, scenario occurs when one or more team members "hijack" the assignment because they are loners or feel they will produce higher quality results acting alone. The remaining team members are willing but shut out from providing meaningful contributions.

Each individual student must be rewarded commensurate with his or her effort. In individual exams, this contribution is clearly from one student and the exam's score is very easily attributed to the student. However, when the student is the member of team that submits one product, it is difficult for the instructor to ascertain the relative contributions of each team member. Several years ago, Kaufman *et al* published a method by which students perform effectively the same procedure [15]. However, the key is that students provided evaluation qualitatively, not quantitatively. Kaufman's process normalizes the team evaluations and gives a team-member relative multiplier, based on team citizenship, to obtain each member's score from the single team score based on technical merits. My procedure and evaluation form is very similar to the ones presented in [15], and I direct the reader to the source. My experience has been very positive and individual scores are very much inline with my causal observations and the individual test scores.

Positive Interdependence

Successful cooperative learning also require positive interdependence. Students need to internalize the positive benefits and values by working together toward a common goal. Homework assignments are often the same difficulty and length as they were in my "individual" effort teaching days. The three to four different perspectives that the team brings does make solving these problems a bit easier, but the increased overhead of communication and face-to-face meetings provide additional time demands on the team members. The net sum effort required to do the homework is very nearly what it would be if the students were working alone.

To promote positive interdependence, team projects are large and complex enough so that an individual working alone cannot possibly achieve the objectives. This forces the "loner" high-achiever to solicit assistance from his team. However, presenting the team with an assignment that appears insurmountable early on (in the "storming" and "norming" stages) is often disastrous.

Positive interdependence is also reinforced by a standing rule in my classes: "Whenever every team member on a team earns a 85% or better score on an individual effort exam, each member of the team gets an additional 5%." This rule encourages the stronger students, who are often motivated by grades, to assist the weaker students and make sure they stay abreast of the material. While the rule would appear to make the "rich richer", the extra 5% is usually awarded 2-5 times per semester. Team heterogeneity with regard to ability guarantees that each team has weaker and stronger students. However, I can recall one team several semesters ago with arguably average students, two of which were from underrepresented groups, rapidly progressed to the "performing" stage and earned the extra 5% at almost every opportunity after the mid-semester point. These four students all expressed satisfaction at the end of the semester for the positive benefits of teaming. They all agreed that they would have never performed as well working alone.

Another observation is that the stronger students tend to complain a bit more about working together, especially on assignments as "mundane" as homework. They complain that they spend too much time explaining the background and tutoring the weaker team members. While this may be true, a short discussion about the positive benefits of "cognitive rehearsal" that they receive usually makes them feel better. The weaker students very often praise the team approach, especially on homework. These students seem to benefit from explanations from peers who have similar educational experiences. Finally, underrepresented students, for whom learning communities are often more important than majority students, seem to respond very favorably to the positive interdependence aspects of cooperative learning. The sample size of underrepresented groups in my VLSI classes has been too small to obtain statistically significant data. However, I have several anecdotal experiences where underrepresented students performed significantly higher than their previous academic records would have indicated.

Lastly, grading in cooperative learning classes must be "absolute" or "criteria-based". I use the traditional ten-point letter grades to which we are all accustomed. Relative grading, or grading on a curve effectively creates a competition for a "limited supply of A's". This competition destroys any cooperation between team members that has been so carefully crafted. I constantly remind my classes that the only competition is between the individual student and me. Everyone can earn an "A" by earning 90+ points over the semester's assignment. Likewise, everyone can earn an "F".

When I explain that I use absolute grading, I always hear concerns from colleagues that their exam scores are too low to accommodate criteria grading. While agreeing that making out an exam of appropriate difficulty is not easy, I would argue that instructors with perpetually low exam scores suffer from one or more of the following: (i) exams are too difficult, (ii) exams are too long, (iii) exams are not covering concepts stressed in class, (iv) students are not learning effectively inside and outside of class. With this last statement, I am not condemning the personal teaching style of these instructors, but please be reminded of my teaching philosophy at the beginning of this paper: teaching performance needs to be measured by the results obtained in the end, not the actions and activities during.

RESULTS AND CONCLUSIONS

At the conclusion of the course, students were asked to perform a self-evaluation about the class and the instructional methods. One portion of the survey asked students to evaluate the progress that they made in several areas due to the course. The questions below were ranked by the students with a number from zero to three, zero being no progress made in the area and three being a great deal of progress made in the area.

SURVEY QUESTION	MEAN (*N*=31)
Understanding of what engineers do in industry.	2.51
Understanding of engineering as a field that often involves non-technical considerations (e.g., economic, political, ethical, and/or social issues).	2.09
Ability to solve an unstructured problem (that is, one for which no single right answer exists).	2.23

Ability to identify the knowledge, resources, and people needed to solve an unstructured problem.	2.31
Ability to evaluate arguments and evidence so that the strengths and weaknesses of competing alternatives can be judged.	2.03
Ability to apply an abstract concept or idea to a real problem or situation.	2.00
Ability to divide unstructured problems into manageable components.	2.26
Ability to clearly describe a problem orally.	1.71
Ability to clearly describe a problem in writing.	1.80
Ability to develop several methods that might be used to solve an unstructured problem.	1.91
Ability to identify the tasks needed to solve an unstructured problem.	2.00
Ability to weigh the pros and cons of possible solutions to a problem.	2.12
Ability to develop ways to resolve conflict and reach agreement in a group.	1.91
Ability to pay attention to the feelings of all group members.	2.06
Ability to listen to the ideas of others with an open mind.	2.11
Ability to work on collaborative projects as a member of a team.	2.26
Ability to ask probing questions that clarifies facts, concepts, or relationships.	1.80

Table 1: Student self-assessment results from a recent VLSI class

It is clear that students felt that they progressed a moderate (2.0) amount in their teaming and communication skills. Notice that students felt their ability to work as a team member improved more than their ability to resolve conflicts. This is probably because only some teams had severe team dynamic issues while in most teams operate smoothly. It is clear from the table that more effort needs to be given to training students to resolve conflicts and to better communicate orally and in writing.

This paper has presented some active and cooperative learning techniques used in the VLSI design course taught at Mississippi State University in the last eight semesters. Many other effective exercises exist but space prohibits their discussion here. Also, mastery of these techniques cannot be gained by simply reading papers but is best to gained by seeing them put into practice. Active and corporate of learning experts likely exist at your institution and can be found in the many effective teaching workshops offered by the ASEE and other organizations. If an instructor is just beginning to use active and cooperative learning techniques, it is best to small and simply. My experience has been that studying these techniques and dedication to the students will results in positive results for the instructor and the students.

REFERENCES

[1] Boice, R., *Advice for New Faculty Members*, Allyn & Bacon Publishers, 2000.

[2] Cordes, D., D. Evans, K. Friar, and J. Froyd, "The NSF Foundation Coalition: The first five years," *J. Engineering Educ.*, vol. 88, no. 1, pp. 73-77, Jan. 1999.

[3] Dale, E., *Audio-visual methods in teaching, 3/e*, Holt, Rinehart and Winston, 1969.

[4] Englelken, R.D., "Balancing rigor and rapport in the engineering classroom," *Proc. ASEE Annual Conference and Exposition*, Session 1531, 2003.

[5] Felder, R.M., "Reaching the second tier: Learning and teaching styles in college science education," *J. College Science Teaching*, vol. 23, no. 5, pp. 286-290, 1993.

[6] Felder, R.M. and R. Brent, "Objectively Speaking," *Chemical Engineering Education*, vol. 31, no. 3, pp. 178-179, 1997.

[7] Felder, R.M., K.D. Forrest, L. Baker-Ward, E.J. Dietz, and P.H. Mohr, "A longitudinal study of engineering student performance and retention I: Success and failure in the introductory course," *J. Engineering Educ.*, vol. 82, no. 1, pp. 15-21, Jan. 1993.

[8] Felder, R.M., P.H. Mohr, E.J. Dietz, and L. Baker-Ward, "A longitudinal study of engineering student performance and retention II: Differences between students from rural and urban backgrounds," *J. Engineering Educ.*, vol. 83, no. 3, pp. 209-217, July 1994.

[9] Felder, R.M., G.N. Felder, M. Mauney, C.E. Hamrin, and E.J. Dietz, "A longitudinal study of engineering student performance and retention III: Gender differences in student performance and attitudes," *J. Engineering Educ.*, vol. 84, no. 2, pp. 151-164, April 1995.

[10] Felder, R.M., "A longitudinal study of engineering student performance and retention IV: Instructional methods and student responses to them," *J. Engineering Educ.*, vol. 84, no. 4, pp. 361-367, Oct. 1995.
[11] Felder, R.M., G.N. Felder, and E.J. Dietz, "A longitudinal study of engineering student performance and retention V: Comparison with traditionally taught students," *J. Engineering Educ.*, vol. 87, no. 4, pp. 469-480, Oct. 1998.
[12] Grolund, N.E*., How to write and use instructional objectives, 6/e*, Prentice-Hall, 2000.
[13] Hilborn, R.B., "Team learning for engineering students," *IEEE Trans. on Educ.*, vol. 37, no. 2, pp. 207-211, 1994.
[14] Johnson, D.W., R.T. Johnson, and K.A. Smith, *Active learning: Cooperation in the college classroom 2/e*, Edina, MN: Interaction Book Co., 1999.
[15] Kaufman, D.B., R.M. Felder, and H. Fuller, "Accounting for individual effort in cooperative learning teams," *J. Engineering Educ.*, vol. 89, no. 2, pp. 133-140, April 2000.
[16] McKeachie, W.J., *Teaching Tips: Strategies, Research, and Theory for College and University Teachers, 10/e*, Houghton-Mifflin, 1999.
[17] Meyers, C., and T.B. Jones, *Promoting active learning: Strategies for the college classroom*, San Francisco: Jossey-Bass Publishers, 1993.
[18] Millis, B.J., and P.G. Cottell, *Cooperative Learning for Higher Education Faculty*, Oryx Press, 1998.
[19] Philips, P.L., "So, You're going to be a member of a team…", *Chemical Engr. Progress*, pp. 141-144, Jan. 1997.
[20] Pimmel, R., "Cooperative learning instructional activities in a capstone design course," *J. Engineering Educ.*, vol. 90, no. 3, pp. 413-421, July 2001.
[21] Reis, R.M., *Tomorrow's Professor: Preparing for Academic Careers in Science And Engineering*, IEEE Press, 1997.
[22] Stubberud, P. and J.W. Bruce, "Exposing undergraduates to collaborative engineering design teams," *Proc. of the Annual Meeting of the ASEE Pacific Southwest Section*, pp. 79-86, Las Vegas, Nevada, March 1999.
[23] Terenzini, P.T., A.F. Cabrera, C.L. Colbeck, J.M. Parente, and S.A. Bjorklund, "Collaborative learning vs. lecture/discussion: Students' reported learning gains," *J. Engineering Educ.*, vol. 90, no. 1, pp. 123-130, Jan. 2001.
[24] Terry R.E. and J.N. Harb, "Kolb, Bloom, Creativity, and Engineering Design," *Proc. of the Annual Meeting of the ASEE*, session 3230, 1993.
[25] Trytten, D.A., "Progressing from small group work to cooperative learning: A case study from computer science," *J. Engineering Educ.*, vol. 90, no. 1, pp. 85-91, Jan. 2001.
[26] Woods, D.R., *Problem based learning: How to gain the most from PBL*, Woods Publishing, 1994.
[27] Woods, D.R., "Participation is more than attendance," *J. Engineering Educ.*, vol. 85, no. 3, pp. 177-181, July 1996.

J.W. Bruce

J.W. Bruce received the B.S. degree from the University of Alabama in Huntsville in 1991, the M.S.E.E. degree from the Georgia Institute of Technology in 1993, and the Ph.D. degree from the University of Nevada Las Vegas in 2000, all in Electrical Engineering. Dr. Bruce has served as a member of the technical staff at the Mevatec Corporation and the Intergraph Corporation. Since 2000, Dr. Bruce has been with the Department of Electrical and Computer Engineering at Mississippi State University, where he is an Assistant Professor. Dr. Bruce teaches courses on embedded systems, VLSI, and systems-on-a-chip design and was named the Bagley College of Engineering Outstanding Engineering Educator in 2003. Dr. Bruce researches data converter architectures and embedded systems design. He is the author or coauthor on more than twenty-five journal articles and technical publications. Dr. Bruce served as Associate Editor of *IEEE Potentials* from 1997-2001. He is a member of IEEE, Eta Kappa Nu, Tau Beta Pi, and ASEE.

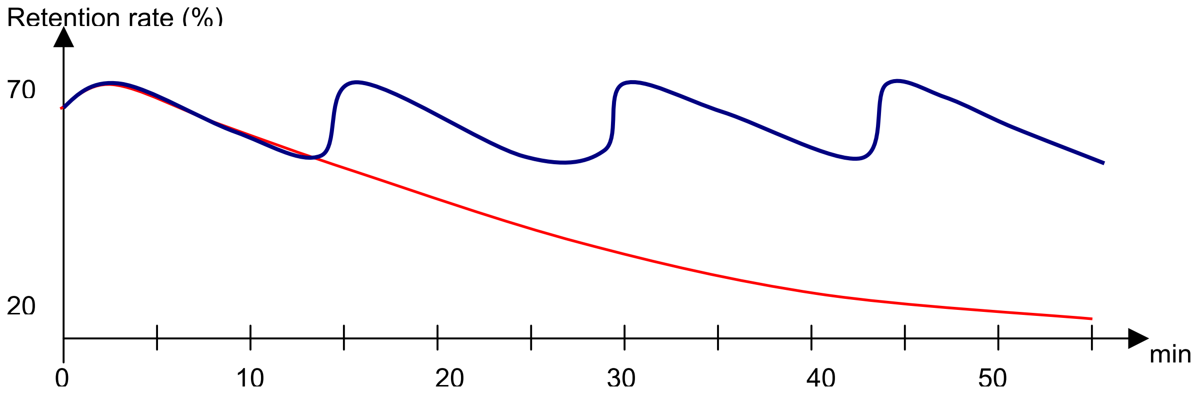


Figure 1 Student learning retention rates [16]

After two weeks, people tend to remember…

10% of what they read	Reading	Passive Learning
20% of what they hear	Hearing	
30% of what they see	Seeing pictures	
50% of what they see and hear	Seeing a movie	
	Looking at an exhibit	
	Watching a demonstration	
	Seeing it done on location	
70% of what they say	Participating in a discussion	Active Learning
	Giving a talk	
90% of what they do	Performing a dramatic reenactment	
	Simulating the real experience	
	Doing the real thing	

Figure 2 Student learning retention rates [3]