# Effects of Types of Active Learning Activity on Two Junior-Level Computer Engineering Courses

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*Abstract -* **In several computer engineering and computer science courses, it has been observed that active learning activities (ALAs) aid the students in better understanding of the technical material. In this paper, we explore the influence of the type of the ALA and the academic quality of the student on the effectiveness of the technique. We perform the study in two junior level courses—a course on discrete mathematics as applied to computer engineering topics and an ASIC (Application-Specific Integrated Circuit) design course. The first course has no laboratory component and teaches several abstract mathematical concepts. The latter course deals with the design of digital circuits using the VHDL hardware description language and has a laboratory component. We conduct ALAs of three kinds—solving problems in-class with active participation of the students; homework problems which are worked on collaboratively by the students and with solutions provided later; and, practice examinations handed out before the actual examination which the students are encouraged to solve in groups. The effect on the students is measured through examination questions. Looking at the aggregate class performance, the ALAs through in-class questions and homeworks do not appear to have a significant effect, while the practice examination questions do. However, on segmenting the data, we observe that the "A" students benefited from the in-class ALAs while both "A" and "B" students benefited from the practice examinations. The worst performing students did not benefit significantly from any of the ALAs. This study leads us to investigate further the possibility of tailoring the ALA to the different learning styles and academic calibers of the students.**

*Index Terms* – Active learning, ASIC design, Computer engineering courses, Discrete mathematics.

## INTRODUCTION

Active learning has been defined as a broad range of instructional techniques that stress students active involvement in their own learning [2]. Active involvement means that students are involved in more than passive intake of information [3]. Such active learning can take place individually, but it often takes the form of collaborative learning in which students work together to learn a concept [4]. Countless studies can be found, including those already cited, documenting the application of active and collaborative learning approaches in almost every discipline. While not all applications of active learning produce unambiguously positive results, all of the cases we have examined appear to pass the "do no harm" test with respect to student performance.

The objective of our study is to understand how different kinds of ALAs affect the understanding of the technical material for students of different academic strengths. The study is focused on two junior level Electrical and Computer Engineering classes, but with two very different foci. The first—ECE 369: "Discrete Mathematics for Computer Engineering"—emphasizes analytical reasoning as applied to Computer Engineering. This class has no laboratory component, involves significant amount of mathematical thinking and reasoning, calls for rigor in solving the problems and examination questions, and is a required course for all Computer Engineering majors[1]. The second—ECE 337: "ASIC[2] Design Laboratory"—has as its primary objective to learn and to practice the design of digital hardware using VHDL. It is a heavily lab-focused course with 70% of the course grade coming from laboratory exercises and a final project, which involves realizing a functional ASIC design. An example is a data encryption/decryption ASIC, using the RC5 algorithm. The target group of students in both classes are juniors in ECE, with the class population typically 25-35 for ECE 369 and 50-70 for ECE 337.

We conduct our study over Fall 2007 (ECE 369 only) and the first 8 weeks of Spring 2008. We apply three different kinds of ALAs: solving problems in-class with active participation of the students; homework problems

[1] In the School of Electrical and Computer Engineering, Bachelor of Science in Computer Engineering is a degree that is given to students who major in Computer Engineering. This is a separate track within our school, distinct from the Bachelor of Science in Electrical Engineering.
[2] ASIC = Application Specific Integrated Circuit

which are worked on collaboratively by the students and with solutions provided later; and, practice examinations handed out before the actual examination which the students are encouraged to solve in groups. For ECE 337, only the first and the third kinds are applicable.

The performances of the students are measured through examination questions. The questions are categorized according to the three kinds of ALAs and the questions that the students have not seen before form the control group.

The data is more extensive for ECE 369 at this point. The results for the class as a whole show that the ALA activities through in-class questions and homeworks did not benefit the students appreciably. This was a surprising finding. The ALA through practice examination questions however appeared to help the students across the board. The non-intuitive finding with the two kinds of ALAs caused us to look at the data in further detail. This examination turned out that the ALAs impacted students at different grade levels differently, where it did indeed positively influence the performance for "A" and "B" grade students. For ECE 337, the conclusions are that both kinds of ALAs helped students across the grade spectrum. We hypothesize reasons to explain our findings.

## BACKGROUND & RELATED WORK

Bonwell [3] described active learning in the following way: "in the context of the college classroom, active learning involves students in doing things and thinking about the things they are doing." If one allows that some of the active learning will take place outside of the classroom, this fairly well summarizes the kinds of active and collaborative learning activities described in prior literature as well as in this study. Hall [2] listed several classroom techniques that fit this description including cold calling of randomly selected students, reading quizzes, muddiest-point-in-the-lecture cards submitted by students, concept tests using an electronic response system (both individual and collaborative), turn-to-your-partner discussions, and demonstrations. One strong example of how active learning can be extended beyond the classroom is described by Lee [6] as the "Emporium Approach to Computer Science Education." The Emporium Approach provides a blend of 24x7 computing laboratories with instructional staff, online learning modules, immediate feedback projects, frequent assessments, and traditional lectures.

In addition it may be useful to mention here that cooperative learning is considered by some as a form of active learning in which discussion within small groups facilitates the process of learning [13]. For instance, a student who would not have ordinarily volunteered an answer to a question asked in class will possibly volunteer after gaining confidence in the answer via cooperative discussion. Further, as pointed out by Bruner [14], the "threefold analysis of experience" may enhance the learning experience and active learning and collaborative learning techniques definitely optimize the use of different levels of experience.

Assessments of active learning approaches typically take two forms: surveys of student perceptions or quantitative analysis of overall student success in courses that apply a particular set of active learning techniques compared to courses offered in a "traditional" lecture format. Selected examples are discussed below. Our study is different in that it looks at the performance on specific test questions for which different kinds of preparation were given to students. For example, one test question may be derived directly from an earlier homework question, an in-class active learning activity, or an old sample test question. In addition, we look at how performance on each category of question relates to student's overall performance in the course.

Hall [2] analyzed sophomore level student perceptions in the department of Aeronautics and Astronautics at MIT regarding the effectiveness of a variety of instructional tools and techniques, not all of which would be categorized as active learning. The techniques were incorporated into a "Unified Engineering" curriculum in which five disciplines were blended into the lecture sequence throughout the year. Techniques were rated as "very effective", "somewhat effective", "not effective", or "not applicable". Except for the "muddiest-point" cards, over 90% of students rated both the more traditional techniques and the active or collaborative learning techniques as either very or somewhat effective, but the active/collaborative techniques received considerably fewer "very effective" ratings. This would seem to weigh against active or collaborative learning, but course evaluations and comments from students pointed in the opposite direction. After the incorporation of active and learning collaboration tools, course evaluations and comments improved significantly (from 5.2 out of 7 to 5.9 out of 7) and comments along the lines of "professors had a genuine interest in their students" became much more frequent.

Similar to the MIT study, results from the Emporium Approach to Computer Science at Virginia Tech. were mixed. While 70% to 80% of students surveyed found active learning components to be helpful, students were evenly split with respect to agreeing or disagreeing with the statement "I would be interested in taking more of my courses using this approach to teaching and learning." However, more importantly, student performance in the course seemed to be substantially improved with a 50% reduction in the number of students failing after implementation of the Emporium approach.

One of the more detailed quantitative studies was presented by Chinn [1]. In this case, an approach known as the Triesman model [7] was applied to junior level data structures and an algorithms courses. The Triesman model involves intensive workshops where students collaborate in small groups to solve problems with the guidance of graduate student facilitators. A regression analysis of scoring for both courses indicated that students in the algorithms course improved by 0.561 points on a scale of 4, a substantial improvement. However grade differences for the data structures course were not statistically significant. The authors offered three possible reasons for the last result: 1) What happens and what is learned in the workshop is not reflected in the course grade, 2) The workshop for data structures (or programming courses in general) doesn't work because students tend to focus on product issues rather than process issues, or 3) The workshop model is less effective in courses where students have acquired all of the basic skills.

Previous studies have found that the outcomes of ALAs depend on the type of ALA; good ALAs can result in better understanding of important ideas [11][16]. Not only do ALAs need to be tailored around important learning outcomes, but effective engagement of students is important. In fact, student engagement has been touted as a critical indicator of success in college [15]. Thus it appears relevant to ask the question what kinds of ALAs are suited to the retention of material in Computer Engineering classes.

## TARGET OF STUDY

ECE 369 "Discrete Mathematics for Computer Engineering" is a course that introduces discrete mathematical structures and finite-state machines to the students, who for the most part have not yet been exposed to rigorous mathematical and analytical principles applied to their major of Computer Engineering. The students learn how to use logical and mathematical formalisms to formulate and solve problems in computer engineering. The major topics are formal logic, proof techniques, recurrence relations, sets, combinatorics, relations, functions, algebraic structures, and finite-state machines. For Fall 2007, the class size was 37 and for Spring 2008, it is 21. The vast majority of the students in the class are of junior standing.

ECE 337 "ASIC Design Laboratory" is a course in which students learn and practice the design of custom digital integrated circuits using hardware description language (HDL), circuit synthesis, circuit simulation, physical layout, and layout verification software. The lecture portion of the course is used primarily to discuss the use of an HDL to create circuit descriptions that map well into hardware and to guide students in the design of an architecture for a final team project of their choosing. This course is required for junior year computer engineering students and is an elective for electrical engineering students who typically take the course during their senior year. In recent years, enrollments typically range from 30 to 80 students. For the Spring 2008 semester when this study was conducted, the enrollment is 53. The students in this class are of junior or senior standing.

## DESIGN OF STUDY

In this study, we seek to answer three inter-related questions.

First, we ask the question what is the impact of ALAs on a junior level course for Computer Engineers and Electrical Engineers. Doubtless, it takes a non-negligible amount of effort to prepare and conduct ALAs on the part of the course staff. Also it takes class time in conducting these activities. So are the effort and time being spent worthwhile? While this question has been answered in many different contexts, it has also been found that differences exist in different contexts. For example, several authors have reported on the benefits of interrupting a traditional classroom lecture with active learning activities on the retention of the material [10]. Significantly, Redish has reported in [12] that the nature of active learning, not the additional time, spent in it has a benefit over the traditional lecture method. However, there are other studies that are not so enthusiastic. For example, McKeachie admits that the measured improvements of discussion over lecture are small [8]. Scorcelli [9], in a study aimed at presenting the research base for Chickering and Gamson's "Seven Principles for Good Practice" [11], states that, "We simply do not have much data confirming beneficial effects of other (not cooperative or social) kinds of active learning." Taking these different opinions into account, we felt a need to benchmark the utility for our curriculum and for the target class populations.

Second, we seek to understand if there are variations of the utility of ALAs with the kind of student. To the best of our knowledge, there has not been a study that has addressed this question for the Computer Engineering curriculum. For the purposes of this study, we categorized students by their final grade in this class (or intermediate grade in case of the ongoing semester). Example questions that we wanted to answer are do the top students benefit more from ALAs or do all students benefit equally. If only certain kinds of students are benefiting, this would point us toward the design of alternate techniques to reach out to the students who are being left out.

Third and finally, we seek to understand if the type of ALA has an effect. This question has indeed been posed before as described in the Related Work, but not in our context. If there is overwhelming positive impact of one kind of ALA compared to the others, then this would lead us to stress on that kind of ALA. The three kinds of ALAs considered here fall on different points of the spectrum of how much help is provided by the instructor, time gap between participating in the activity and being tested on the questions in the activity, and importantly the interactive nature of the activity. The activity with in-class problems provides the most interactivity and is also the most expensive in terms of the class time.

Next, we give the details of the three kinds of ALAs considered in the study.

1. Solving problems in-class with every student expected to work on the problem, either individually or in groups. The instructor then optionally calls on some student to solve the problem and then he walks the class through the correct solution. This activity also involves pointing out what the common errors are. The activity is held at the beginning of most, but not all, lectures and usually takes 10-15 minutes.
2. Homework problems, for which the students are allowed to work on collaboratively up until it is time to write out the solutions. Thus the students can discuss the solution and clarify doubts with each other, but are expected to write out the solutions on their own. For a class like ECE 369, the exercise of writing out a solution clearly and rigorously is an important activity. From discussions with students, it appears the students do make use of the option of discussing the homework problems. The correct solutions to the homeworks are provided after they have been submitted by the students. Thus, going into the examination, the students have had the option of seeing the correct solutions.
3. Practice examination questions which are handed out shortly before the actual examination (typically 2-3 days before). The students are encouraged to solve these questions in groups and then in a help session prior to the examination, the instructor solves a subset of these questions that the students bring up. The attendances at these help sessions are not very high, possibly owing to the pressures of preparing for the examination for this specific class as well as those for several other classes. The examinations often tend to be clustered around the same days, both for mid-term examinations and the final examination.

For ECE 337, only the first and the third kinds of ALAs are relevant.

The evaluation of the effect of the ALAs is done through examination questions. In the examination, some questions are given from each of the ALA kinds and the remaining questions are those that the students have not seen before, which form the control group. Of course, even for the control group, variants of the problems have likely been discussed by the instructor in class or covered through one of the ALAs. For this study, only if the question matches exactly with what has been covered in an ALA, is it counted in the experimental group; otherwise, it is counted in the control group. For ECE 369, the data comprises results from 5 examinations (4 from Fall 2007) while for ECE 337, these are from 1 examination.

## RESULTS

Table 1 summarizes the test performance for the students in ECE 369 for Fall 2007, reflecting the performance over 4 examinations. Table 2 does the same for Spring 2008 for the single examination. From the Fall 2007 results, the following conclusions can be drawn. The "A" students are benefited by all kinds of ALAs, the "B" students are benefited only by the practice exams, while the "C" students are not benefited by any of the three kinds. In an aggregate sense for the entire class, the practice exam kind of ALAs are the only ones that are significantly beneficial.

From the Spring 2008 results, the following conclusions can be drawn. All three kinds of ALAs appear to benefit all kinds of students. Among the three kinds of ALAs, homeworks appear to benefit students the most.

The difference between the results for the two semesters can possibly be explained by the fact that the single examination in Spring tested only a small amount of material. The material covered in the in-class ALAs and the homeworks were fresh in students' memories when they were tested in the examination. In contrast, for the Fall study, when the students went into take their final examination, the memory of the ALAs done early on in the semester may have faded. This affected the "A" students the least and the "C" students the most. Also, the material tested in the first examination is simpler than the material covered in the rest of the semester and therefore the absolute scores are significantly higher than the scores for the entire semester.

| **Average score %** | **Student Count** | **ALA-In-class** | **ALA-Homeworks** | **ALA-Practice Exam** | **Control** |
|---|---|---|---|---|---|
| **Total class** | 36 | 73.22 | 71.91 | 76.40 | 71.19 |
| **"A" students** | 10 | 88.65 | 85.48 | 89.51 | 81.96 |
| **"B" students** | 9 | 73.72 | 77.78 | 82.38 | 73.55 |
| **"C" students** | 14 | 65.00 | 62.25 | 67.29 | 65.84 |

**Table 1. Performance of students in ECE 369 for Fall 2007 (based on 4 examinations)**

| **Average score %** | **Student Count** | **ALA-In-class** | **ALA-Homeworks** | **ALA-Practice Exam** | **Control** |
|---|---|---|---|---|---|
| **Total class** | 21 | 87.57 | 97.14 | 85.24 | 77.68 |
| **"A" students** | 5 | 97.78 | 100.00 | 96.00 | 90.45 |
| **"B"** | 7 | 92.06 | 100.00 | 85.71 | 76.97 |

| | | | | | |
|---|---|---|---|---|---|
| students | | | | | |
| "C" students | 9 | 78.40 | 93.33 | 78.89 | 71.14 |

**Table 2. Performance of students in ECE 369 for Spring 2008 (based on 1 examination)**

Table 3 summarizes test performance as a function of question type for the entire class and on the basis of student's grades as of the eighth week of the Spring 2008 semester. At this point of the semester, the number of poor overall scores is disproportionately large, but the final course project and remediation opportunities for earlier design assignments have historically enabled most students to improve their semester score to at least 70%.

| | Student Count | ALA based questions | Pract. Test Questions | Control | All question types |
|---|---|---|---|---|---|
| Total points on the test | | 11.0 | 49.0 | 40.0 | 100.0 |
| Avg points entire class | | 10.1 | 43.1 | 25.6 | 78.8 |
| Avg test % entire class | 53.0 | 91.8 | 87.9 | 64.1 | 78.8 |
| Avg test % given current course grade: | | | | | |
| ≥ 90% | 16.0 | 100.0 | 97.6 | 80.8 | 91.1 |
| ≥ 80% | 9.0 | 94.9 | 87.8 | 61.1 | 77.9 |
| ≥ 70% | 4.0 | 100.0 | 91.8 | 71.3 | 84.5 |
| ≥ 60% | 7.0 | 77.9 | 85.7 | 55.7 | 72.9 |
| < 60% | 17.0 | 86.1 | 78.9 | 51.6 | 68.8 |

**Table 3. Performance of students in ECE 337 for Spring 2008 (based on 1 examination)**

While there were benefits to ALA and practice test based questions in both ECE 337 and ECE 369, the benefits of ALA and practice test based questions were far more widely distributed throughout the student population in ECE 337. Unlike ECE 369, the poorer performing students in ECE 337 appeared to benefit slightly more from the ALA and practice test based questions than did the higher performing students. Table 4 illustrates this by presenting results for each type of question normalized with respect to the test average for each group of students.

In ECE 337 the majority of the course grade is based on laboratory design assignments. This invites the question of whether the test scores correlate with laboratory assignment scores. Figure 1 presents a scatter graph in which each data point represents a pairing of a test score and a laboratory score. From the graph it is apparent that the correlation between laboratory and test scores is low. At least two interpretations are possible, given that the test focused on concepts applicable to the laboratory assignments. Since the test took place after the laboratory assignments reported here, it could be that at least some students who were unsuccessful in obtaining working designs still acquired an understanding of the concepts being applied. It could also be that many students prepared more thoroughly for the exam in order to compensate for low laboratory scores.

| Normalized Performance with respect to total test score | ALA based questions | Pract. Test Question | Control |
|---|---|---|---|
| All students | 1.2 | 1.1 | 0.8 |
| Students with course score > 89.9% | 1.1 | 1.1 | 0.9 |
| > 79.9% | 1.2 | 1.1 | 0.8 |
| > 69.9% | 1.2 | 1.1 | 0.8 |
| > 59.9% | 1.1 | 1.2 | 0.8 |
| <= 59.9% | 1.3 | 1.1 | 0.8 |

**Table 4. Normalized scores for students in ECE 337 for Spring 2008 (based on 1 examination)**

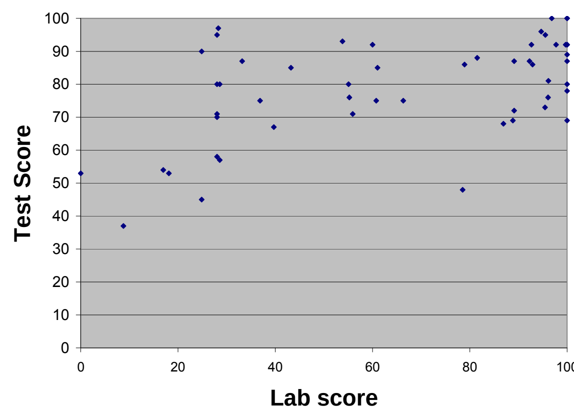


**Figure 1. Scatter graph to determine correlation between test and lab scores for students in ECE 337 for Spring 2008**

Combining the ALA results for both classes, we conclude that ALAs do help students in understanding and retaining the material compared to the standard lecture method. However, the amount of material being tested on in an examination and the duration that has elapsed between the ALA exercise and the examination affects its effectiveness. The effect is less on the "A" students and greater on the weaker students. If the time lapse is small, then these differences between the different kinds of students vanish.

### CONCLUSIONS

This study points to the need to develop different kinds of ALAs for including all kinds of students in a class. It hints at the possible benefit of repeating some ALAs for better retention. The study targeted two different courses and for the beginning part of the semester, the results for both courses were in agreement. However, when results for one of the courses (ECE 369), were taken for the entire length of the semester, the study showed the better students were able to benefit from the ALAs significantly more than the weaker students. The students that were near the middle of the class were able to benefit from the practice examination questions but not from the other kinds of ALAs.

Going forward we will collect data from ECE 337 for the entire semester and observe if the trends match that of ECE 369 over the length of the semester. We will also be developing some other kinds of ALAs and repeating some ALA questions closer to the final examination to determine their effect on student performance. It appears convincing to us that ALAs if properly used can be an effective learning tool. However, an instructor needs to be aware of the effect on different kinds of students and has to be careful not to leave a part of the class feeling that it is not getting much out of these activities. This study points to some leading indicators for different ALA types and different kinds of students. We expect further studies will shed light on the generalizability of these results and lead to the development of exemplars for ALAs.

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### REFERENCES

[1] Chinn, D., Martin, K., Spencer, C. "Treisman Workshops and Student Performance in CS", SIGCSE'07 Technical Symposium on Computer Science Education, Covington, KY, 7-10 March 2007.

[2] Hall, S., Waitz, I., Brodeur, D., Soderholm, D., and Nasr, R. "Adoption of Active Learning in a Lecture-Based Engineering Class", 2002 Frontiers in Education Converence, Boston, MA, 6-9 November 2002.

[3] Bonwell, C. C., and Eison, J.A. "Active Learning: Creating Excitement in the Classroom", ASHE-ERIC Higher Education Report No. 1, George Washington University School of Education and Human Development, Washington, DC 1991.

[4] Johnson, D.W., Johnson, R.T., and Smith, K.A., "Cooperative Learning Returns to College: What Evidence is There That it Works", Change, July/August 1998, p. 27-35.

[5] Lee, J.A.N., "The Emporium Approach to Computer Science Education", ITiCSE'02 Conference on on Innovation and Technology in Computer Science Education, Aarhus, Denmark, 24-26 June 2002.

[6] Lee, J.A.N. "Incorporating Active Learning into a Web-based Ethics Course", 1999 Frontiers in Education Conference, San Juan, Puerto Rico, 10-13 November 1999.

[7] Treisman, U. Studying Students Studying Calculus: A Look at the Lives of Minority Mathematics Students in College. The College Mathematics Journal, vol. 23, no. 5, November 1992, 362-372.

[8] McKeachie, W., "Research on College Teaching," Educational Perspectives, Vol. 11, No. 2, May 1972, pp. 3–10.

[9] Sorcinelli, M., "Research Findings on the Seven Principles," in A.W. Chickering and Z.F. Gamson, eds., Applying the Seven Principles for Good Practice in Undergraduate Education, New Directions in Teaching and Learning, #47, San Francisco: Jossey-Bass, 1991.

[10] Ruhl, K., C. Hughes, and P. Schloss, "Using the Pause Procedure to Enhance Lecture Recall," Teacher Education and Special Education, Vol. 10, Winter 1987, pp. 14–18.

[11] Di Vesta, F., and D. Smith, "The Pausing Principle: Increasing the Efficiency of Memory for Ongoing Events," Contemporary Educational Psychology, Vol. 4, 1979.

[12] Redish, E., J. Saul, and R. Steinberg, "On the Effectiveness of Active-Engagement Microcomputer-Based Laboratories," American Journal of Physics, Vol. 65, No. 1, 1997, p. 45.

[13] Kvam, P., "The Effect of Active Learning Methods on Student Retention in Engineering Statistics," The American Statistician, vol. 54, pp. 136-140, 2000.

[14] Bruner, J. S., "Toward a theory of instruction," Belknap Press of Harvard University Cambridge, Mass, 1966.

[15] Astin, A. W., "What Matters in College," Liberal Education, vol. 79, pp. 4-15, 1993.

[16] Wiggins, G. P., and J. McTighe, "Understanding by design," Association for Supervision and Curriculum Development Alexandria, VA, 1998.

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