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Assessment of Peer-Led Team Learning in an Engineering Course for Freshmen*

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In ECE 110, a required course for freshmen (first-year students) majoring in electrical or computer engineering, students may attend optional supervised study sessions, which implement peer-led team learning. Small, permanent teams of students met weekly in 90-minute sessions, under the supervision of graduate teaching assistants, undergraduate teaching assistants, or undergraduate volunteers. In these sessions, student teams worked on difficult problems adapted from examinations given in previous semesters. We hypothesized that students who attended the study sessions would earn higher scores on examinations, and they would persist at higher rates in engineering. We also sought to describe the affective benefits that students perceived from attending the study sessions. For three semesters, we recorded students' study session attendance and final exam scores. We surveyed students to obtain their average hours each week spent on ECE 110 and to gauge the perceived benefits of the sessions. We performed linear regression and analysis of covariance tests on the numerical data to analyze student performance. To analyze retention (persistence), we used data about the courses that students took immediately after ECE 110 to form two-way contingency tables. In all three semesters, regular session attendees did not have significantly higher persistence rates, but they scored significantly higher on final exams. Regular attendees reported that they improved their understanding of the material, and made new friends. Some students began to see peers as helpful sources of knowledge. In summary, regular attendance in peer-led team learning sessions benefits students both academically and socially.

Keywords: cooperative learning; peer-led team learning; workshop; first-year students; retention

1. Introduction

Introduction to Electrical and Computer Engineering, ECE 110, is a large gateway course for engineering students at the University of Illinois at Urbana-Champaign. Although primarily for electrical engineering and computer engineering majors, students from several other departments also take ECE 110. Traditionally, ECE 110 has consisted of lecture and laboratory sessions with online homework. Outside of the laboratory, ECE 110 students do not work cooperatively in formally structured teams, although they might possibly form independent study groups. We hypothesized that cooperative learning could provide important affective benefits, improve student persistence, and improve students' academic performance. Therefore, we implemented a form of cooperative learning, peer-led team learning (PLTL) [1, 2], in ECE 110 as optional study sessions where students could elect to join permanent learning teams. Once students elected to participate in the PLTL study sessions, they were expected to attend meetings with the same team for the rest of the semester.

We first review the relevant work in cooperative learning in engineering and PLTL in engineering. Next, we present our PLTL implementation and our assessment techniques. We then report the quantitative results of the analysis, along with a qualitative assessment of student surveys.

2. Prior work

In cooperative learning, small groups of students work on assignments that are structured so that each student has a well-defined task or role. There are three kinds of cooperative groups [3]: learning teams (base groups) that last throughout a semester, informal groups that are formed ad hoc during a class session, and project teams that deliver a product after several weeks. Prior research shows that cooperative learning benefits students both cognitively and affectively [4]. More focused investigations have shown that engineering students benefit from cooperative learning activities [5, 6].

Peer-led team learning (PLTL) is a form of cooperative learning that uses learning teams [1, 2]. Each team contains six to eight students who meet for 90 to 120 minutes once a week in a workshop, where students collaborate to solve challenging problems: their solutions may require several students to contribute ideas. Each team has a leader who serves as a facilitator, but not as a content expert. The team leader is typically an undergraduate student who previously took the course.

PLTL workshops resemble Supplemental

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Instruction (SI) sessions [7]. Unlike PLTL leaders, however, SI leaders are typically paid undergraduate and graduate teaching assistants who attend lectures, prepare workshop materials, and serve as content experts. At an SI session, an SI leader might teach a prepared lesson, whereas a PLTL leader would not. Because SI sessions are optional, students are not assigned to permanent learning teams. In fact, an SI session need not use cooperative learning techniques. PLTL workshops also resemble in-class peer tutoring (ICPT) sessions [8-10], in which undergraduate volunteers assist students with active learning exercises during scheduled class times. Similar to SI, however, ICPT does not require permanent learning teams.

According to Born, Revelle, and Pinto [11], workshop-style pedagogies such as PLTL and SI can promote the retention of women and underrepresented minorities in the sciences. Tien, Roth, and Kampmeier [12] found that in an undergraduate course on organic chemistry, students who regularly attended PLTL workshops earned significantly higher scores on examinations and developed better attitudes about the subject. PLTL has been implemented in large undergraduate courses in biology, chemistry [13], physics, and computer science [14-17].We cannot infer that an implementation of PLTL or SI in engineering would produce the same learning outcomes as in the sciences, however, because the population of engineering students differs from the population of students who take an introductory chemistry course. In the United States, general science courses, such as introductory chemistry, draw students from a wide range of majors, especially students who take the courses merely to fulfill a general education requirement. Compared with the general population of college students, engineering students on average start with higher scores on the mathematics portions of college entrance tests, such as the American College Testing program (ACT) and the Scholastic Aptitude Test (SAT), and they take more mathematics and physics courses. Finally, the affective outcomes of PLTL or SI in an introductory engineering course could be very different from an introductory science course; student persistence in engineering can be influenced by the structure of first-year engineering courses [18–20].

A variety of engineering courses have implemented SI with paid SI leaders who attended lectures [21–24]. In all of these studies of SI in engineering, students who attended SI sessions earned higher grades than those who did not. Blat, Myers, Nunnally, and Tolley [21] and Jacquez, Gnaneswar Gude, Hanson, Auzenne, and Williamson [22] did not report statistical analyses, however. Marra and Litzinger [23] showed that SI attendees earned higher quiz scores. Webster and Dee [24] performed several statistical analyses; they showed that students who attended more SI sessions received higher grades.

We found only three previous reports of implementations of PLTL in engineering. Foroudastan [25] reported on peer-led team learning in multisemester student projects to develop experimental vehicles, not in a regular engineering course. Munkeby, Drane, and Light, [26] and Pazos, Drane, Light, and Munkeby [27] analyzed the effect PLTL on student performance and retention in the required four-quarter sequence of engineering analysis courses for first- and second-year engineering students at Northwestern University. Munkeby, Drane, and Light, [26] found that in six of nine quarters, women who attended the PLTL workshops were significantly more likely to earn high course grades (B+ or better). Pazos, Drane, Light, and Munkeby [27] found that students who attended the PLTL workshops were more likely to complete the fourth course of the sequence, although the statistical significance was marginal.

3. Research questions

We implemented PLTL in an engineering course for freshmen (first-year students). Our implementation of PLTL resembled that of Munkeby, Drane, and Light [26] and Pazos, Drane, Light, and Munkeby [27]: our PLTL workshops were optional for students enrolled in the course, and most of the team leaders were unpaid volunteers. Whereas Munkeby, Drane, and Light [26] and Pazos, Drane, Light, and Munkeby [27] studied engineering students at a highly selective private university, we studied engineering students at a large public university—more typical of engineering students in the United States. We sought to answer three questions:

- What benefits do ECE 110 students gain from participating in PLTL workshops?
- Does participation in PLTL improve ECE 110 students' scores on examinations?
- Does participation in PLTL improve ECE 110 students' retention in engineering?

We hypothesized that the findings about the effectiveness of PLTL in college science courses would extend to engineering courses, and that engineering students who participated in PLTL would report important affective benefits, earn higher examination scores, and would be more likely to remain in engineering after the first year. Because our PLTL workshops were implemented as optional sessions, we were able to quantitatively compare students who were regular attendees of

PLTL study sessions with non-participants within each semester.

This paper builds on our preliminary report [28] to include a detailed statistical analysis and two additional semesters of data. In a companion paper [29, 37], we performed a detailed, qualitative analysis of the benefits to team leaders.

4. Implementation of PLTL

We implemented PLTL in ECE 110, *Introduction to Electrical and Computer Engineering*, at our university. Carrying four semester hours of credit, ECE 110 is required for first-year students majoring in electrical and computer engineering. It is also required for students majoring in general engineering (systems engineering), who are typically second- or third-year students when enrolled in the course. The enrollment runs from 250 to 300 students per semester. Students should have completed or be concurrently registered in a first-semester calculus course. ECE 110 introduces selected topics in circuits, electronics, and digital systems, all directed toward the design of an autonomous line-following vehicle in the laboratory [30]. In the laboratory, students work in pairs, and occasionally in triads [31]. The lectures cover the theory and analysis of circuits and devices, but students have few opportunities to collaborate during lectures. There are no discussion sections. Students use the LON-CAPA system (www.lon-capa.org), which replaced the Mallard system [32], for online homework. There is no written homework. Students take three one-hour exams and a final exam.

Since Fall 2007, we have implemented PLTL in ECE 110. We called each weekly 90-minute workshop a "supervised study session" (SSS). At the beginning of each semester, during one of the first lectures, the course instructors announced the availability of the study sessions. The instructors explained the nature of PLTL and expected benefits from participation before distributing sign-up sheets containing this information in writing. An announcement was also placed on the course website. Participation in the sessions was optional, but about half the students in each semester elected to join the SSS program. Sessions were offered from 3:30 to 5:00 p.m., 7:00 to 8:30 p.m., and 8:30 to 10:00 p.m. on Sundays. Students indicated their availability, and they were assigned to learning teams in their available time slots. Once assigned to a team, students were expected to attend each study session. Each team had nine students, because we expected some students to discontinue participation. Following the recommendations of Roth, Goldstein, and Marcus [33], we ensured that no learning team had an isolated female student, and we tried to ensure that no learning team had an isolated Black or Hispanic student. It is important to note that these permanent learning teams met every week. Although students were not directly penalized for missing study sessions, the expectation was clear that if they planned to join a study session, they needed to attend the team meetings.

Each team had one or two team leaders, who were graduate teaching assistants, undergraduate teaching assistants, or undergraduate volunteers. Most leaders were undergraduate volunteers who had recently completed ECE 110. New team leaders attended a two-hour training session at the beginning of the semester. During the Fall 2007, Fall 2008, and Spring 2008 semesters most leaders attended thirty-minute weekly meetings throughout the remainder of the semester. The weekly meetings were devoted to brief overviews of key ideas in college teaching [33], such as Perry's model of student intellectual development [34–35] and Grow's model of self-directed learning [36]. The structure and readings for these enrichment sessions were largely drawn from a handbook for peer leaders [33]. In the supervised study sessions, the team leaders encouraged all students to participate, and they continually asked students questions to probe their understanding of fundamental concepts and principles. Team leaders were also responsible for administrative duties, such as sending e-mail messages to their teams and recording student attendance. Further details of the team leader training and the team leader roles can be found in our companion paper [37]. Because our team leaders did not attend lectures—the majority of the team leaders were unpaid volunteers who had no other role in teaching ECE 110—and because they functioned as facilitators instead of content experts, our supervised study sessions implemented peer-led team learning (PLTL) rather than supplemental instruction (SI). Furthermore, although the students could choose whether they would participate in the supervised study sessions, students who committed to the program were assigned to permanent learning teams, a feature of PLTL but not of SI.

During the fifteen-week semester, there were eleven or twelve supervised study sessions. In each study session, every learning team worked on four to eight difficult problems adapted by the instructors from ECE 110 examinations given in previous semesters to suit the PLTL format. These problems were more difficult than most routine homework problems: their solution required understanding of basic concepts, analysis of unusual situations, and integration of several ideas. These problems included circuit design and digital logic design problems and were especially tailored for group work. Engineering design problems are well suited for group collaboration because design problems require students to think creatively in constructing and evaluating several potential solutions.

We recommended a standard procedure for each problem. One student would serve as the "chalkboard scribe": this student would write what the other students suggested. Two students would serve as designated questioners: they would continually ask for the reasons for the suggestions. These roles would rotate to other students for the next problem. Students often resisted this formal structure, however.

At the first meeting, each learning team drafted a team charter, which stated students' expectations of each other [38]. Each team was provided with example rules:

- I will prepare for supervised study sessions: I will read the textbook and bring questions.
- I will arrive on time for every supervised study session: I will bring my textbook, notebook paper, calculator, and pens or pencils.
- During sessions, I will not interrupt other team members while they are speaking.
- I will listen attentively and respectfully.
- Every team member will participate; no one will dominate.
- I will help others answer questions and solve problems, and I will thank others for their help.
- I will direct all criticism at ideas, not at individuals; my criticisms will be accompanied by constructive alternatives.
- I will speak positively about others and will maintain a positive attitude.
- Our team will celebrate successes and have fun!

For each rule, students were asked to discuss what it "looks like" or "sounds like": for example, "attentive listening" requires looking at the speaker, making eye contact, and remembering what the speaker has said. Also students were asked to identify acceptable reasons for missing a study session, such as serious illness, death in the family, or court summons.

At the fourth meeting, each team conducted a plus-delta exercise [38] to identify what was working well and how the team could improve. They received the following instructions:

- One member of your team reads aloud your team's charter, which you developed at your first meeting.
- On one side of a 3x5 index card, each team member anonymously writes what the team is doing well. Label this side "+".
- On the other side of the card, each individual anonymously writes a constructive suggestion for how the team can improve. Label this side "Δ".
- Shuffle the cards, and deal them back randomly to team members. Around the circle, each individual reads the contents of the + side. Each individual then reads the Δ side, and team members decide whether to adopt the suggested change.

After this exercise, students were invited to amend their team charters.

Students requested solutions for the problems, but following [2], we did not give students written solutions because we wanted students to take responsibility, and to develop self-confidence. We did provide bottom-line numerical answers for some problems (e.g., final values of voltages), so that students could detect incorrect solutions. Nevertheless, we emphasized that students should still develop their own full solutions to the problems.

In Spring 2008 and Fall 2008, we also provided mock exams for the study sessions that occurred just before the three midterm examinations. Students worked individually on two exam-like problems in exam-like conditions for a short time, and then they assembled in their learning teams to discuss the solutions to the problems. The mock exam allowed students to assess their own understanding of difficult concepts before they discussed these concepts with peers.

To avoid penalizing students who did not elect to participate in study sessions, we provided copies of the study session problems, along with other practice examinations, to all students via the course Web site.

5. Assessment methods

In order to understand the benefits of PLTL to ECE 110 students, we administered surveys, collected exam scores, and gathered attendance data. We analyzed the data to determine whether participation in study sessions improved students' exam scores or persistence in electrical and computer engineering by comparing the subpopulations of regular attendees with non-attendees in three semesters. Because the study sessions were optional, we can compare the performance of the two subpopulations of students on the *same* exam within each semester. Finally, we analyzed the affective benefits reported by students participating in PLTL.

5.1 Data collection

We received approval from the local Institutional Review Board (University of Illinois IRB #08262) to administer two paper surveys to students in ECE 110 and to collect their examination scores. Each survey took less than ten minutes in a lecture class session. The surveys provided information about the supervised study session program and the research goals of the project, and it was made clear that participation was voluntary and would not affect students' grades. All completed surveys were sequestered until after course grades had been filed; only then were the data analyzed. Thus, the completion of a survey did not affect the course grade of any student. Students who completed the surveys were assumed to have consented to participation in the study.

In the first survey, around the tenth week of the semester, students reported their names, genders, majors, and highest mathematics scores on the college entrance test of the American College Testing program (ACT). These self-reported ACT-Math scores were not used in our analysis; we replaced self-reported scores by ACT-Math scores provided by the College of Engineering at the University. Our previous work [49] indicated that ACT-Math scores explain a large amount of the variance in examination scores in ECE 110. We planned to test whether attendance at the optional study sessions would improve students' examination scores by more than would be predicted by the ACT-Math scores.

Since participation in our PLTL implementation was voluntary, we wanted to determine whether the effect of the study sessions was more than simply ninety more minutes of study time per week, so in Spring 2008 and Fall 2008 students estimated how many hours they spent on all ECE 110 activities, including lecture, laboratory, homework, and study sessions. By including this self-reported measure of student effort, we intended to control for the possibility that PLTL participants performed better on exams simply because they spent more time on coursework. The first survey appears in Appendix A.

The second survey, at the end of the semester, was anonymous. Students reported their majors, whether they regularly attended the supervised study sessions, and whether they intended to continue taking courses in electrical and computer engineering. In Spring and Fall 2008, students were also asked to report their genders. Regular attendees identified the benefits of the sessions. Other students explained why they discontinued attendance, did not attend, or studied in groups outside these sessions. The second survey appears in Appendix B.

To measure retention in engineering, we obtained course enrollment data from the College of Engineering. For each student, we requested demographic information and courses completed in the semester immediately following ECE 110. The College of Engineering also supplied the students' true ACT-Math scores for the analysis. When ACT-Math scores were not available, SAT-Math scores were substituted using a standard concordance table. After matching students' attendance with the data from the College of Engineering, all identifying information was removed from the dataset.

After the course ended, the final examination scores for all students were collected. The raw scores, which could range from 0 to 200, were converted to percentages in the range from 0 to 100. The team leaders also recorded the study session attendance for each student. We combined the students' ACT-Math scores from the College of Engineering, the self-reported study hours from the first survey, final examination scores, and study session attendance to measure the effect of regular session attendance on final examination scores.

5.2 Influence of PLTL participation on final exam scores

We used inferential statistics to determine whether regular attendance at study sessions produced higher final examination scores. In addition, we explored whether there was a significant difference in the final exam scores of regular attendees and non-attendees. Our goal was to understand the relationship of final exam scores (as a dependent variable) to ACT-Math, study session attendance, and study hours (as independent variables). Any student record missing any of variables was eliminated from the analysis.

Using a multivariate linear regression, we quantified the relationship between supervised study session attendance and final examination scores. Then, with an analysis of covariance (ANCOVA), we determined whether there was a statistically significant difference (after controlling for ACT-Math and hours per week) in final examination scores between regular session attendees and non-attendees.

Our multivariate linear regression model measured the correlation between the independent variables and the final exam scores. In addition, we used the multivariate linear regression to determine the significance of each factor through a model selection process. In this model selection process, we used Akaike's Information Criterion (AIC) to measure the tradeoff between bias and variance of the model [40]. This criterion penalizes complex models based on the number of parameters and rewards models that fit the data well. The AIC elimination test finds the model with the lowest AIC by eliminating factors based on the residuals. Out of all the possible models that can be constructed from our independent variables, we inferred that the model found by the AIC elimination test is the simplest. The factors in this model were therefore significant predictors of students' final examination scores.

In our multivariate linear regression analysis, the number of study sessions attended is a discrete variable ranging from zero to eleven or twelve. There are three independent variables: *ACTMath*, *Hours*, and *Attendance*. Including all three independent variables, the model has the form:

$$\mathit{Final} \leftarrow B_0 + B_1\ \mathit{ACTMath} + B_2\ \mathit{Hours} + B_3\ \mathit{Attendance}$$

where *Final* is the final examination score, on a scale of 0 to 100, *ACTMath* is the score on the ACT mathematics section, on a scale of 0 to 36, *Hours* is the total hours per week spent on ECE 110 activities, and *Attendance* is the number of study sessions attended.

We used the AIC elimination test to determine which factors are important in this linear model, and using the linear parameters (the B values), we quantified the relationship between final exam scores and the independent variables. The difference in R^2 values between the model and a linear model containing only *Hours* and *ACTMath* is the square of the semipartial correlation coefficient corresponding to the *Attendance* variable. The semipartial correlation coefficient is a measure of improvement in the goodness of fit of the linear regression model by including the *Attendance* variable.

To further explore the effect of PLTL participation on final exam scores using ANCOVA, we defined two populations: regular attendees and non-attendees. We defined a regular attendee as a student who attended six or more study sessions. The ANCOVA test determines whether there is a significant difference in final exam scores between the two populations, controlling for ACT-Math and hours spent per week. In essence we compared two models of the form:

$$\mathit{Final} \leftarrow B_0 + B_1\ \mathit{ACTMath} + B_2\ \mathit{Hours} + B_3$$
$$\mathit{Final} \leftarrow B_0 + B_1\ \mathit{ACTMath} + B_2\ \mathit{Hours}$$

In this method, B_3 represented the difference in final examination scores between the two populations, when controlling for ACT-Math and hours per week. The two models were compared using an analysis of variance test. If the difference in the models was significant, we then concluded that there was a significant effect of study session attendance on final exam scores after controlling for ACT-Math and hours per week. The multivariate regressions were carried out in the Matlab programming language, and ANCOVA tests were conducted using the statistical programming language R.

5.3 Influence of PLTL participation on ECE student persistence

In addition to measuring the effects of study session attendance on exam performance, we were interested in persistence of engineering students. At Illinois, students must declare their engineering major within their first year. To measure the effect of study session attendance on engineering student persistence, we examined the courses each student took in the semester immediately following ECE 110. We define a persistent student as a student who was enrolled in electrical and computer engineering while taking ECE 110, and who subsequently took an ECE course in the semester immediately following ECE 110. Since the official college enrollment lags behind student decisions by at least a semester, our definition is a better indicator of the immediate effect of study session attendance on student persistence than the official college enrollment. Also, since the engineering curricula at our university have long prerequisite chains, it is very likely that any student planning to continue in an ECE major would take another ECE course immediately following ECE 110. We believe this definition allows us to measure the direct influence of study session attendance on student persistence without the influence of additional courses in later semesters.

In addition to testing the effect of regular attendance on persistence in the overall population, we also examined persistence in four sub-populations: male students, female students, students with low ACT-Math scores (less than 31), and students with high ACT-Math scores (greater than or equal to 31). If a student record did not have gender or an ACT-Math score (or equivalent) specified, we excluded the student record from the sub-populations.

To assess the effect of regular study session attendance on persistence rates, we analyzed the two-way contingency tables of regular attendance versus persistence for each subpopulation. We calculated Cramér's ϕ between the two groups to determine the effect size. To assess statistical significance, we used an exact test rather than the common chi-squared approximation for contingency tables. This test is appropriate because several of the student numbers in our two-way tables are less than five. For the contingency tables, the null hypothesis is that the Cramér's ϕ is 0.0 (no change in persistence across the populations).

Because of the low numbers in the subpopulation of female and low-ACT students, we used Barnard's exact test, which is an unconditional test of significance for two-way contingency tables. This test is considered to have more statistical power for two-way tables than other exact tests, such as Fisher's exact test. We would like to note, however, that there is considerable debate among statisticians about the statistical power and philosophical implications of conditional tests (such as Fisher's test) and unconditional tests (such as Barnard's test) for contingency tables [41]. The exact tests were all carried out in the Matlab programming language.

5.4 Assessment of open-ended survey questions

Finally, in the surveys, PLTL participants provided anonymous, open-ended feedback on our PLTL implementation. To explore the additional benefits of participating in the PLTL program as well as the difficulties encountered, we began by independently coding the students' responses. After the initial coding, we refined the coding into categories reflecting the students' common responses, and we discussed the placement of each comment into the categories until we reached agreement. This coding forms a rough description of the students' experience participating in our PLTL implementation.

6. Results

We collected surveys, student demographic information, and exam scores for three semesters: Fall 2007, Spring 2008, and Fall 2008. The survey response rate varied from 64% to 73%. In all three semesters, the demographic characteristics of the students who completed the surveys were similar to those of the entire enrollment in ECE 110: among the respondents, the relative percentages of different majors, and of men and women, were nearly the same as among the entire class. Tables 1, 2, and 3 summarize these demographics. Consequently, we inferred that survey respondents were representative of the entire population of students. The student demographics differ significantly between spring and fall semesters. In the spring, the student population is slightly smaller, and the majority of the students are not electrical and computer engineering majors. Many of the students in spring semester are general engineering (systems engineering) majors in their sophomore or junior years. ECE students taking the course in the spring will already be in their second semester.

The team leaders counted and reported the number of study sessions attended by each student. This number ranged from 0 to 11 or 12, depending on the semester. We defined a regular attendee as a student who attended six or more of the eleven or twelve sessions. All other students were considered non-attendees. Table 4 summarizes the total number of students who completed ECE 110 and the number of students who regularly attended study sessions. Note that some of these records could not be used in every statistical test because an ACT-Math score or hours studied per week was not reported.

Descriptive statistics for the three semesters are displayed in Tables 5 and 6. Overall, the statistics are quite consistent across semesters. Table 5 shows

Table 1. Demographics of survey respondents, Fall 2007

Population	**Entire class ($n = 286$)**	**First survey responses ($n = 208$)**	**Second survey responses ($n = 198$)**
Computer engineering	28%	30%	28%
Electrical engineering	47%	48%	52%
General engineering/other	25%	22%	20%
Male	87%	87%	–
Female	13%	13%	–

Table 2. Demographics of survey respondents, Spring 2008

Population	**Entire class ($n = 237$)**	**First survey responses ($n = 153$)**	**Second survey responses ($n = 154$)**
Computer engineering	18%	18%	18%
Electrical engineering	22%	24%	22%
General engineering/other	60%	58%	60%
Male	83%	82%	81%
Female	17%	18%	19%

Table 3. Demographics of survey respondents, Fall 2008

Population	**Entire class ($n = 259$)**	**First survey responses ($n = 173$)**	**Second survey responses ($n = 170$)**
Computer engineering	30%	29%	30%
Electrical engineering	47%	51%	49%
General engineering/other	22%	20%	21%
Male	87%	84%	84%
Female	13%	16%	16%

Table 4. Total number of students completing the course and regular attendees

Semester	Total enrollment	Regular attendees
Fall 2007	286	62
Spring 2008	237	62
Fall 2008	259	56

the means and standard deviation for the data collected for students from Fall 2007. The self-reported study hours were available only from the surveys distributed in Spring 2008 and Fall 2008.

Table 6 shows the difference in ACT-Math and Final Exam scores for the subpopulations of regular attendees and non-attendees for all three semesters. These two variables are reasonably close in both mean and standard deviation between the two groups. Table 7 shows the breakdown of these subpopulations by gender and major. In both Table 6 and Table 7, any student missing an ACT-Math score was omitted.

6.1 *Elimination of incomplete records*

Over the course of three semesters, 782 students enrolled in ECE 110. For this analysis, we omitted any students with incomplete records. There were 299 incomplete records of self-reported study hours. There were 62 records missing ACT-math scores. Attendance and final exam scores were available for all records with an ACT-math score. The incomplete records were omitted from the hierarchical multivariate regression analysis and ANCOVA analysis. After omitting records missing the study hours variable, there were 265 complete records in Fall 2007. Of those records, 54 corresponded to regular attendees. There were 225 complete records in Spring 2008, of which 58 were regular attendees. In Fall 2008 there were 230 complete records, of which 51 were regular attendees. These records were then used in our multivariate regression and ANCOVA analysis.

The persistence analysis was conducted using only the 517 ECE majors who took ECE 110. The College of Engineering did not supply gender for one student, leaving 516 ECE majors for the persis-

Table 5. Summary Statistics, Students Completing First Survey

	ACT-Math *M* (*SD*)	Study Session Attendance *M* (*SD*)	Study Hours *M* (*SD*)	Final Exam Score *M* (*SD*)
Fall 2007	33.5 (2.3)	2.2 (3.6)	N/A	69.5 (15.9)
Spring 2008	31.9 (3.3)	2.6 (3.9)	9.5 (3.2)	66.7 (19.8)
Fall 2008	33.3 (2.6)	2.4 (3.8)	9.4 (3.8)	70.8 (14.5)

Table 6. Summary Statistics for Subpopulations of Attendees and Non-attendees, Omitting Incomplete Records

	ACT-Math *M* (*SD*)	Final Exam Score *M* (*SD*)
Fall 2007		
Attendees (n = 54)	32.0 (3.6)	73.7 (16.6)
Non-attendees (n = 211)	33.0 (2.7)	68.8 (15.6)
Spring 2008		
Attendees (n = 58)	31.6 (3.3)	70.7 (17.5)
Non-attendees (n = 167)	32.0 (3.3)	65.1 (19.9)
Fall 2008		
Attendees (n = 51)	33.5 (2.1)	75.5 (11.0)
Non-Attendees (n = 179)	33.3 (2.7)	70.1 (14.6)

Table 7. Demographics for Subpopulations of Attendees and Non-attendees, Omitting Incomplete Records

	Male (%)	Female (%)	Electrical Engineering (%)	Computer Engineering (%)	Other Major (%)
Fall 2007					
Attendees (n = 54)	85%	15%	55%	26%	18%
Non-attendees (n = 211)	87%	13%	42%	30%	28%
Spring 2008					
Attendees (n = 58)	76%	24%	24%	22%	54%
Non-attendees (n = 167)	85%	15%	23%	18%	59%
Fall 2008					
Attendees (n = 51)	80%	20%	49%	31%	20%
Non-Attendees (n = 179)	88%	12%	50%	35%	15%

tence analysis. For the subpopulation of high and low ACT-Math students, 51 ECE students were omitted as no ACT-Math score was available.

6.2 Self-reported study hours was an unreliable variable

The self-reported study hours turned out to be quite troublesome. First, the surveys in Fall 2007 did not include the study hours. Second, many of the self-reported study hours were not reasonable. Students were instructed to include both time in and out of class; all students have six hours of class each week: three hours of lecture and three hours of laboratory. Yet many students reported spending less than six hours a week on ECE 110, including class, homework, lab reports, studying, study sessions, etc. Since many students apparently misunderstood the prompt, the self-reported study hours may be unreliable. Although the question was carefully worded, it is unclear whether students reported peak hours per week, average hours per week, or simply reported the hours spent the week of the survey was administered. In addition to the inherent unreliability of the data, it was noted that the study hours only had a weak correlation with the other variables of interest, and were not found to have a significant effect in the multivariate regression or ANCOVA analysis of Spring and Fall 2008.

For these reasons, we omitted the self-reported study hours from the analysis. The resulting multivariate regression was of the form:

$$Final \leftarrow B_0 + B_1\, ACTMath + B_3\, Attendance$$

The square of the semipartial correlation coefficient was determined by taking the difference in R^2 for the model including both *ACTMath* and *Attendance* compared to the model including only *ACTMath*. The ANCOVA compared the two models:

$$Final \leftarrow B_0 + B_1\, ACTMath + B_3$$
$$Final \leftarrow B_0 + B_1\, ACTMath$$

By omitting study hours from the analysis, however, the analysis can be applied to a larger number of students in each semester as we have more complete records after omitting this variable.

6.3 Did PLTL participation improve students' exam scores?

To determine whether regular attendance at PLTL study sessions produced higher final examination scores and whether there was a significant difference in the final exam scores of regular attendees and non-attendees, we applied the ANCOVA and linear regression analysis.

For each semester, we applied both statistical analyses to investigate the effect of study session attendance. The number of students in the model depended on the number of students with complete records (omitting the study hours). For a given semester, the number of students was the same in both methods. By inspecting Q-Q plots, we determined that the residuals of the model were approximately normally distributed. We also determined that the ACT-Math scores were not significantly differently distributed between the populations of attendees and non-attendees. The uniform distribution of covariates across the two populations is a key assumption of ANCOVA.

In all three semesters the ANCOVA and multivariate linear regressions suggest a statistically significant influence between PLTL participation and final exam performance, controlling for ACT-Math scores. The results of the multivariate linear regression and ANCOVA are presented in Tables 8 and 9, respectively. In all semesters, final exam scores ranged from 0 to 100 points.

Table 8. Results of multivariate linear regression model

Semester	***ACTMath* Coefficient**	***Attendance* coefficient**	R^2	**Square of Semipartial Correlation Coefficient for *Attendance***
Fall 2007 ($n = 265$)	2.39**	0.86**	0.21	0.04
Spring 2008 ($n = 225$)	1.66**	0.90**	0.11	0.03
Fall 2008 ($n = 230$)	2.24**	0.41*	0.19	0.01

$^{**}p < 0.01$; $^{*}p < 0.1$

Table 9. Results of analysis of covariance method

Semester	**Mean Final Exam Difference between attendees and non-attendees**	**Cohen's *d***	***p*-value of F statistic**
Fall 2007	10.9*	0.68	0.001
Spring 2008	4.8*	0.24	0.03
Fall 2008	5.9*	0.42	0.015

$^{*}p < 0.05$.

The results from Fall 2007 demonstrate a statistically significant relationship between study session attendance and final examination score. For the multivariate linear regression model, the AIC elimination tests did not eliminate the *ACTMath* or *Attendance* variable. This result implies that both factors contribute significantly to the model. The coefficient for *Attendance* is 0.86, so our model predicts that a student scored 0.86 more percentage points on the final exam per study session attended. This coefficient is significantly different from zero, with $p < 0.01$. We therefore conclude that study session attendance had a significant, positive effect on students' final exam scores in Fall 2007. The square of the correlation coefficient (R^2) shows that 21% of the variance in final examination scores is explained by the linear model. The square of the semipartial correlation coefficient corresponding to the *Attendance* variable is 0.04. This measure indicates the improvement in goodness of fit by introducing the *Attendance* variable.

The ANCOVA test for the Fall 2007 population shows that there is a significant difference in final exam scores between regular attendees and non-attendees, after controlling for *ACT-Math* ($p < 0.01$). The *Attendance* coefficient reveals that regular attendees scored 10.9 percentage points higher on the final exam. Comparing this difference with the standard deviation of the final exam scores, this coefficient gives a Cohen's d effect size of 0.68.

For the data from Spring 2008, the results of both tests support a relationship between study session attendance and students' performance on final exams. In the multivariate regression analysis, the AIC did not eliminate the *ACT-Math* or *Attendance* variable from the model. With an R^2 of 0.11, the linear model coefficients are 1.66 for the *ACTMath* variable and 0.90 for *Attendance*. The square of the semipartial correlation coefficient corresponding to the *Attendance* variable is 0.03. Both regression coefficients are significantly different from zero ($p < 0.01$). This result again suggests a positive relationship between study session attendance and final exam scores. Using the Spring 2008 data, the ANCOVA tests also shows a significant difference between the final examination scores of attendees and non-attendees after controlling for *ACT-Math*. The population mean is 4.8 higher for the attendees, giving an effect size $d = 0.24$.

The results of both analyses for Fall 2008 again suggest a relationship between study session attendance and final examination scores. The AIC elimination test on the multivariate linear regression model did not eliminate the *ACTMath* or *Attendance* variables. The outcome of this test suggests that both independent variables contribute to the model. The coefficient of *Attendance* is 0.41, so our linear model predicts that a student scored 0.41 percentage points higher on the final exam per study session attended. This coefficient is significantly different from zero with $p < 0.1$. The square of the correlation coefficient (R^2) demonstrates that 19% of the variance in final examination scores is explained by this model. The square of the semipartial correlation coefficient corresponding to the *Attendance* variable was 0.01.

In Fall 2008, the ANCOVA shows there was a significant difference between the final examination scores of attendees and non-attendees after controlling for *ACT-Math* ($p < 0.1$). The *Attendance* coefficient reveals that regular attendees scored an average of 5.9 percentage points higher on the final examination, giving an effect size of $d = 0.42$.

Overall, the ANCOVA and multivariate linear regression analyses suggest a statistically significant difference between regular study session attendees and non-attendees. These results are robust over all three semesters and consistent between both tests, suggesting a statistically significant relationship between study session attendance and exam performance.

6.4 Did PLTL participation improve persistence?

Improving student exam performance was far from the only goal in implementing PLTL in ECE 110. In addition to student performance on final exams, we also investigated whether regular attendance at PLTL study sessions influenced student persistence (retention) in engineering. We again defined a regular attendee as a student who attended at least six of the eleven or twelve study sessions during the semester.

We analyzed two-way contingency tables for electrical and computer engineering students. Here we defined a persistent student as a student majoring in electrical or computer engineering while enrolled in ECE 110 who then enrolls in another ECE course in the semester immediately following ECE 110.

Table 10 summarizes the results of the persistence rate analysis for the overall population and the subpopulations of interest. We can see that in general our definition of student persistence results in a high persistence rate.

For every sub-population, Cramér's ϕ favors persistence for regular study session attendees. This effect, however, is very slight for the Low-ACT subpopulation. This result is promising, but the significance tests are inconclusive across almost all subpopulations. It is important to remember that the p value is determined by the size of each entry in the two-way contingency table. In this case, the number of regular study session attendees who did not persist is very small. Due to this small group size,

Table 10. Influence of study session attendance on ECE student persistence

Population	Regular attendees	Non-attendees	Regular attendees who did not persist in ECE	Non-attendees who did not persist in ECE	Cramér's ϕ	Exact test, 2-sided p value
All students	121	395	26	98	0.03	0.54
Female	20	44	3	15	0.20	0.07*
Male	101	351	23	81	0.02	1.00
Low ACT	19	62	4	13	0.00	1.00
High ACT	86	298	19	79	0.04	0.48

*$p < 0.1$.

we would not expect the exact test to show significance.

The subpopulation with the largest effect size is female students in electrical and computer engineering. This result was significant at the $p < 0.1$ level using Barnard's exact test. Although far from conclusive, this result is very encouraging as female students are highly underrepresented in ECE. Although the overall population does not show large changes in persistence, encouraging persistence in underrepresented subpopulations (such as female students) is very important. Due to the small sizes of these subpopulations, however, far more data would be needed for a definitive finding.

6.5 What benefits did regular attendees identify? what difficulties did they encounter?

On the second survey, the students who regularly attended the supervised study sessions (SSS) reported benefits of the sessions, providing anonymous feedback. The researchers encoded and categorized student responses for all students who self-reported as attending the study sessions; the responses are reported in Table 11.

Regular attendees identified two different categories of academic benefits. In the first category, students reported that they understood the course material better. In the second category, students reported that they felt better prepared for exams, and that they might have scored better on the exams. Few regular attendees reported both categories of academic benefits. We interpret the two categories as evidence of two motivational orientations [42]: mastery-oriented students value personal understanding, whereas performance-oriented students value external recognition such as scores on examinations. More regular attendees appeared to be mastery-oriented than performance-oriented.

Some regular attendees mentioned that they benefited from access to team leaders and teaching assistants, and others mentioned that they received help from other students. We interpret these differences as evidence that the former students are at a dualistic stage of Perry's model of intellectual development [35], because they did not see other students as sources of knowledge. One student wrote:

> *It benefited me in that I was exposed to test-type questions. It should be noted that without instructor* [*teaching assistant*] *input, the SSS would have lost all value to me.*

In contrast, other students have begun progressing toward higher stages of Perry's model, because they said that they benefited from other students. One student wrote:

> *By attending the SSS regularly, I saw a vast improvement of my understanding of the course material. The fact that the questions used in the sessions were from past ECE 110* [exams] *was beneficial since it was a higher level of understanding required to solve them, but the cool aspect was that I did not have to solve the questions alone, we had groups.*

No students reported as a benefit that they were able to help other students learn. Students did not

Table 11. Categories of benefits for self-reported regular attendees

Benefit	Frequency Fall 2007 ($n = 95$)	Frequency Spring 2008 ($n = 73$)	Frequency Fall 2008 ($n = 75$)	Overall Frequency ($n = 243$)
Access to old exam problems	14%	23%	19%	18%
Extra practice (without saying why it helped)	14%	8%	20%	14%
Better understanding of course material	22%	23%	23%	23%
Better preparation for exams	7%	21%	15%	14%
Improved performance on exams	4%	4%	0%	3%
Met new people, made new friends	17%	0%	4%	8%
Access to teaching assistants	8%	11%	13%	11%
Obtained help from student team members	14%	10%	7%	10%

perceive that by helping other students, they strengthened their own understanding:

> *SSS did not benefit me because my teammates did not come prepared so it seemed like I was not studying anything more. I found myself teaching everything every single time we had a SSS.*

Although we emphasized that students should help each other, a few teams had uncooperative members:

> *I stopped* [attending] *because my group had many talented individuals who did the work by themselves and would not explain it to the rest of us.*

Besides lack of preparation and lack of cooperation, the most common difficulty encountered by regular attendees was irregular attendance by others in their teams:

> *I found it* [the sessions] *helpful, but only 2 or 3 people came regularly in my group.*

On the second survey, students who did not regularly attend the supervised study sessions regularly gave a variety of reasons: some had conflicts with other obligations, some wanted to study at times they chose, some disliked the expectation of weekly attendance, and some decided they did not need the sessions because they felt they could learn the material on their own.

7. Discussion

In all three semesters studied, our analysis provides strong evidence that regular PLTL study session attendance significantly improved the final examination scores of students with moderate effect size. This robust result held up using two linear regression techniques, ANCOVA and multivariate linear regression analysis. This result is encouraging and not immediately obvious, because the primary motivation for implementing PLTL in ECE 110 was the affective benefits of cooperative learning. The ECE 110 PLTL program, however, seems to have a positive effect on student exam performance.

Another interesting aspect was that the quantitative results were robust across both the spring and fall semesters. There are large differences in the demographics between the fall and spring semester populations. In particular, most electrical and computer engineering freshmen enroll in ECE 110 during the fall semester. In the spring semester, the majority of the students are from other engineering majors. The general engineering (systems engineering) curriculum requires students to take ECE 110 in their sophomore or junior year, so many of the students are older and more experienced in the spring. Despite these demographic differences, the effect of PLTL in ECE 110 is similar.

Improving student performance on exams was not the main motivation for implementing PLTL in ECE 110: there are many other potential benefits of cooperative learning, including improved student persistence. Although only one subpopulation of ECE students, female students, showed improved persistence from participating in PLTL, we still believe cooperative learning could improve engineering student persistence overall. For all subpopulations of the engineering students, all of the calculated Cramér's ϕ values were greater than or equal to zero. We recognize that our numbers are too small for conclusive results for some populations. We hope, however, that these numbers may prove useful in a future meta-analysis of peer-led team learning in engineering.

We would also like to comment on the difficulties of working with self-reported study hours. The data collected from the survey were inconsistent. For example, several students reported that they spent only two or three hours per week on the course even though the laboratory session alone, which students are required to attend every week, is three hours long. Even discarding the obvious outliers is insufficient, as students who responded with 5–10 hours could be estimating total time or time in addition to lecture and laboratory. We also do not know whether students were estimating peak or average numbers of hours spent per week. Although the survey question seemed clear, it is not obvious how students interpreted and answered the question. We are therefore skeptical of the self-reported study hours as a measure of student effort. As a consequence, unfortunately, we were unable to control for student motivation or student effort in our analysis.

8. Limitations

When we implemented peer-led team learning (PLTL) for the first time in Fall 2007, we made continual operational adjustments throughout the semester. For example, as the attendance at the supervised study sessions fell, we reorganized small learning teams into new teams. The team cohesion might have suffered as students on consolidated teams learned to work together with different students. We also made improvements between semesters. Experience allowed us to improve our team leader recruiting and training processes. For example, after the experiences of our first semester, we began pairing inexperienced leaders with experienced leaders. These two leaders held their team meetings in the same classroom. The experienced leader was able to mentor the inexperienced leader. In Fall 2008, we began placing registration information, study session problems, and supplementary materials online; this practice allowed all students to access these materials more easily, even if they did not attend study sessions regularly.

This study was also limited because ECE 110 is an introductory engineering course with exam problems and engineering design problems we found well suited to PLTL study sessions. The results discussed here may not generalize to all engineering disciplines at all levels. In particular, the circuit design and digital design concepts taught in ECE 110 naturally make excellent PLTL questions.

Unlike many other implementations of PLTL, participation in the ECE 110 supervised study sessions was optional. Once students elected to participate, they were expected to attend regularly, but students were not required to participate. Students who elected to attend study sessions may have had stronger motivations than other students. Because of scheduling constraints, it is not feasible to make participation a requirement for all students in ECE 110. The analysis in this paper would not be possible without this arrangement, however, as we were able to compare students who took the same exams with the same instructors.

Since the study sessions were optional, the PLTL participants may have been independently motivated. Consequently, self-selection bias may explain the effects seen in this study. By including self-reported study hours, we had hoped to account for this possibility. If students were spending an equivalent amount of time on ECE 110 activities, but PLTL participants were still seeing improvements in exam scores, the study sessions would appear to improve students' performance compared with an equivalent amount of independent studying. The self-reported study hours, however, did not appear to be a reliable measure of student effort and motivation, as discussed above. Motivation could be an important variable that has not properly been taken into account in this analysis. Many other factors may affect the success of our PLTL implementation, including students' educational background and prior experience. Our analysis does not account for these additional variables.

The student population of ECE 110 includes several different majors, age levels, and levels of experience. We deliberately created heterogeneous teams including students with different characteristics such as different numbers of previous mathematics courses. It is difficult to predict how these results would generalize to courses with more homogenous student groups.

9. Conclusions and future directions

We implemented peer-led team learning workshops as optional supervised study sessions in a large engineering course that is required for freshmen in electrical and computer engineering. Students who elected to participate in the study sessions were assigned to permanent learning teams led mostly by undergraduate volunteers. A significant percentage, although not the majority, of students regularly participated in the program. This implementation allowed us to compare students in the same semester and the same course to investigate potential benefits of peer-led team learning participation.

Using two different analyses, we determined that students who regularly attended the study sessions earned higher scores on the final examination than did other students. The results were significant across all three semesters studied, with a moderate effect size. These results held for both spring and fall semesters, which had markedly different student demographics. In our analysis, however, we were unable to account for student motivation, which may influence the results. Participation in the PLTL study sessions did not significantly improve overall persistence in engineering, but female ECE majors who participated in PLTL sessions did show some improvement in persistence. Furthermore, regular attendees experienced social benefits by making new friends, and they reported receiving help from team leaders as well as from other students. This program suggests that implementing cooperative learning teams such as PLTL in an introductory engineering class can result in positive affective outcomes as well as improvement in student exam performance.

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Appendix A: First Student Survey

Your Name:

We are gathering data for a research project to evaluate the effectiveness of supervised study sessions in ECE 110. Please complete this survey even if you have not participated in supervised study sessions. All data on this survey will be kept confidential and will **not** be shared with ECE 110 instructors until after course grades are filed. Your responses will **not** affect your grades or your status as a student at this university.

What is your lecture section?

What is your gender? Female Male

What is your current major? Circle one:
Computer Eng. Electrical Eng. General Eng. Other

ACT-Math Score: SAT-Math Score: (Report highest scores earned)

(Spring 2008 and Fall 2008 only) How many **total** hours per week do you typically spend on **all** ECE 110 activities: lectures, laboratories, Mallard homework, pre-labs, lab reports, reading, studying, supervised study sessions, office hours, etc.?

Typical time per week: hours (round to nearest half-hour)

Did you attend at least half of the ECE 110 Supervised Study Sessions on Sundays?
Circle one:
Yes No

Appendix B: Second Student Survey

We are gathering data for a research project to evaluate the effectiveness of the supervised study sessions. Please complete this survey even if you did not participate in these sessions. All data on this survey will be kept confidential and will **not** be shared with ECE 110 instructors until after course grades are filed. This survey is anonymous: do **not** write your name on this form.

(Spring 2008/Fall 2008 only) Gender: Female Male

What is your current major?
Circle one: Computer Eng. Electrical Eng. General Eng. Other

Did you participate regularly in ECE 110 supervised study sessions?
Circle one: Yes No

1. If you participated regularly in supervised study sessions, explain the benefits to you (academic, social, etc.).
If you began attending these sessions but stopped attending regularly, explain why you stopped.
If you did not participate in these sessions, explain why you did not, and whether you studied with a different group.

2. If you are currently majoring in computer engineering or electrical engineering, tell us whether you plan to continue in ECE, and why or why not.
If you are not majoring in ECE, tell us whether you plan to take elective ECE courses (beyond courses required for your major), and why or why not.

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