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Structured Pairing in a First-Year Electrical and Computer Engineering Laboratory: The Effects on Student Retention, Attitudes, and Teamwork*

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This paper describes a simple technique, structured pairing, for organizing student teams in engineering instructional laboratories. This technique was adapted from pair programming, which was previously found to improve student confidence, satisfaction, and retention in computer science. A study of structured pairing was implemented in a large required course for first-year students in electrical and computer engineering. Six laboratory sections implemented structured pairing, and the other seven laboratory sections operated in a traditional way (i.e., unstructured team interactions). Data were collected from a student survey, two focus groups, and course enrollment records. Structured pairing students reported significantly higher confidence in laboratory tasks and satisfaction with the course and teamwork experiences. Focus group data indicated that structured pairing students experienced reciprocal scaffolding (i.e., students acknowledged that they learned from each other). Short-term retention in engineering did not differ significantly between structured pairing and traditional section students. These findings suggest that structured pairing is a more engaging and motivating alternative to traditional laboratory teaming methods.

Keywords: cooperative learning; pair programming; laboratory; assessment; mixed methods

1. Introduction

Laboratory courses were first introduced in engineering education nearly one and a half centuries ago [1], and they still play a crucial role today [2, 3]. In the laboratory, students work in small teams investigating physical properties, linking theory to practice, and gaining hands-on skills and design experience [2, 3]. Laboratories can also help students develop motivation and persistence in their studies [3]. Recent literature, however, suggests that laboratory courses do not always fulfill these goals, and are too costly and time-consuming [4–6]. As a result, much of the research on improving the laboratory experience has moved towards developing inexpensive and flexible technology such as remote and virtual laboratories [6–8], and comparing these new environments with traditional laboratory environments [9].

Correspondingly, little attention has been paid to student interactions within laboratory teams, and how these interactions affect student outcomes. While the instructional laboratory provides opportunities for team and social learning, laboratory assignments tend to emphasize content- and application-related objectives [5, 10]. In other words, instructors do not always ensure that students work together productively. Cooperative learning has been linked to greater learning, persistence, and affective outcomes [11–15], but care must be taken to meet conditions for effective collaboration [16–18]. Further, successful teamwork and social interaction that stem from cooperative learning are considered their own critical outcomes. ABET, for example, lists "the ability to function on multidisciplinary teams" and "the ability to communicate effectively" among its student outcomes required for program accreditation [19].

Because laboratory work is an essential component of engineering programs, and because engineering students can learn teamwork skills in laboratories, further study of cooperative learning in an engineering laboratory setting is needed. Examples from science education show that cooperative learning can be effective in instructional laboratories when situation-appropriate methods are employed [15, 20, 21]. One such cooperative learning technique, pair programming, has been found to increase student confidence, satisfaction, and persistence in computer science laboratories [22]. Since pair programming is designed to allow two students to develop a computer program using a single computer rather than perform engineering laboratory tasks using a variety of equipment, it

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may require adaptation for successful implementation in an engineering laboratory. This study investigates the effects of structured pairing, an adaptation of pair programming for engineering laboratories, on persistence, attitudes, and experiences of students in an undergraduate laboratory course in electrical and computer engineering.

2. Literature review

2.1 Promoting successful collaborative learning

While collaborative learning generally implies that students work together on common activities, cooperative learning places structural requirements on group work [23]. Most notable are *positive interdependence*, the belief among students that they cannot achieve their goals unless all other students in their group also achieve their goals, and *individual accountability*, the responsibility of individuals to contribute a fair share to the group [16, 17]. Johnson, Johnson, and Smith [16] also emphasize the need for appropriate social skills, opportunities for face-to-face interaction, and ongoing reflection on the group's effectiveness, which they call *group processing*. Cohen [18] adds that the nature of the group task is important and suggests that collaborative learning should be used only for challenging and ill-structured tasks, which no one student could complete in isolation and for which work cannot easily be divided. Laboratory tasks may fulfill these requirements, but engineering students often approach such problems as well-defined [24].

Collectively, the above conditions suggest two elements essential to effective collaborative learning. First, all students must actively participate in the learning activities. Collaboration does not imply a collection of individuals working on independent tasks, but a team working jointly on a common task [18]. When all members participate, each student should have opportunities to learn and develop self-efficacy through mastery experiences with all parts of the task [25]. Additionally, interaction and discourse in these settings can give students opportunities to elaborate on their explanations and justify their claims, which can lead to reflection and reorganization of knowledge [18, 26]. Those who only observe rather than interact with their group or the material tend to learn the least [9, 27].

Second, individuals must support the learning of others. Holton and Clarke [28] use the term *reciprocal scaffolding* to describe the type of interaction that may make collaborative learning effective. In general, *scaffolding* refers to the process of one or more students performing a task with the support of an expert [29]. The expert might model the task, prompt critical thinking and reflection, provide helpful explanations and feedback, or provide a less frustrating environment in which to complete a difficult task. With *reciprocal scaffolding*, students take turns in the expert role [28]. In this way, both students can develop understanding, self-efficacy, and motivation through a guided and supportive experience. Positive experiences helping and learning from others may also lead to positive attitudes toward the content and group work, which has been linked to persistence [30].

2.2 Benefits of collaborative learning in engineering education

Cooperative learning has been successfully implemented in engineering courses for over three decades [31, 32]. In a meta-analysis, Springer, Stanne, and Donovan [13] found that collaborative techniques lead to greater self-esteem, attitude towards content, persistence, and achievement in undergraduate STEM classrooms. In another study, engineering students reported greater opportunities for interaction, discussion, and feedback, as well as improved social and technical skills [33]. Further, the use of cooperative learning approaches in undergraduate engineering courses have produced the most pronounced benefits when collaborative techniques are employed for an entire course [14] or sequence of courses [12].

Some studies demonstrate similar positive effects of cooperative learning in engineering laboratories [34, 35]. Besides these studies, and the overall success of cooperative learning in engineering and other settings, few research efforts have compared effective cooperative learning with unstructured group work in laboratories, especially regarding social and affective outcomes. Felder and Brent [36] indicate that although students may work together in laboratories, the method of grouping may not always lead to effective collaboration. Thus, care should be paid to the method of collaboration implemented in laboratory environments. Kittleson and Southerland [37], for example, found a low level of collaboration between students in the same team in a senior mechanical engineering laboratory.

2.3 Challenges of collaborative learning in engineering laboratories

Many features of undergraduate engineering laboratories can stifle opportunities for productive interaction. Felder and Brent [36] suggest that, in particular, the individual accountability criterion is often violated because instructors reward student work by assigning team grades. Such conditions, in addition to time constraints [38], lack of familiarity or confidence working with laboratory equipment [39, 40], and the routine nature of certain laboratory tasks [40] can lead to ineffective collaboration. Instructors have also noted student reluctance toward cooperative learning in laboratories [35].

Participation is often a problem in engineering laboratories. Free riders, students who do not contribute a fair share of the group's work, may believe their participation is redundant or unnecessary [41, 42], or may be uncomfortable with unfamiliar laboratory equipment and tasks. Conversely, dominant group leaders, especially those with confidence in their ability to complete laboratory tasks efficiently and effectively, may deny others opportunities to participate in order to save time or earn a better grade. Thus, individuals with little experience or confidence may be denied opportunities to contribute or develop self-efficacy and positive attitudes related to the content and group work.

Even when engineering students are motivated to participate in group work, they are often observed employing the divide and conquer method (e.g., [37]): students partition the work and complete the parts individually in order to save time, or they perform tasks with which they are most comfortable. Although all students still participate, there are few opportunities for mastery experiences in all relevant areas, and little opportunity for discussion, interaction, and reciprocal scaffolding.

2.4 Structuring and supporting collaborative learning in engineering laboratories

Assigning roles or scripting interaction between group members is often used to promote positive interdependence, productive discourse, and active participation, and avoid problems such as free riders and dominant group leaders. Scripting techniques such as scripted cooperation [43] and think aloud pair problem solving [44] have proven successful in academic settings such as reading comprehension and physics problem solving. Pair programming has had significant positive results in computer science (e.g., [22, 45–49]) and may be applicable to engineering laboratories. In particular, pair programming has been found to increase student confidence, satisfaction, and performance in introductory computer science courses [22, 46–48], and create a less frustrating and more productive laboratory environment [49]. As a result, pair programming has been used to increase retention among first-year computer science students [22].

In pair programming, pairs of students adopt simple, alternating roles as they sit at the same computer [47]. The students take turns in the role of the *driver*, who types the specification or program code, and the *navigator* or *reviewer*, who oversees the driver's progress. Students switch roles at moderate intervals, about every twenty minutes, so they can gain experience with each role while not growing weary of either role. Though the two roles may seem unequal, with the driver acting as the "leader" of the pair, all key decisions are made by consensus. The navigator role becomes important for identifying errors and thinking reflectively about the task, team process, and one's own learning.

Pair programming may be effective because it satisfies the five criteria described by Johnson and his colleagues [16]. The simple, distinct roles promote positive interdependence and appropriate use of collaborative skills. Further, situating two students at the same computer promotes face-to-face interaction, and giving students joint decision-making responsibility aids group processing. Requiring students to act as both the hands-on, action-oriented *driver*, and the goal-focused, reflective *navigator*, gives each student individual accountability. More importantly, these roles are similar to roles students naturally take in group and team contexts [50]. Thus, students are less likely to ignore their roles, as some have done with other role distributions [51]. Switching roles at moderate intervals further ensures that both students practice and develop all necessary skills.

Since pair programming and similar student pairing techniques [43, 44] have produced favorable outcomes, it is reasonable to hope that the pair programming technique could be adapted to other learning contexts. In this study, we investigated a modified version of pair programming called *structured pairing* in an electronics laboratory.

In structured pairing, students are organized in teams of two (or sometimes three), with well-defined roles. One student is the *driver*, who performs the hands-on laboratory work, such as building circuits and connecting and adjusting laboratory equipment, and the other student is the *navigator*, who keeps the team on task, asks metacognitive questions, checks for errors, considers alternative solutions, consults resources, and records all measurements. The students switch roles at section breaks in the laboratory procedures, three or four times per three-hour laboratory period. All major decisions are made as a team. Within three-person teams, two students act as navigators and one acts as the driver, since one student may dominate the hands-on work in a two-driver team.

Students often work in teams in engineering laboratories [2]. Thus we could not compare individuals with structured pairs, as most studies of pair programming have done. Instead, we compared the effects of structured pairing with the commonplace method of traditional pairing (i.e., unstructured group work). We investigated three research questions that compare structured pairing with traditional pairing in an engineering instructional laboratory:

(1) To what extent does structured pairing improve student retention in engineering?
(2) To what extent does structured pairing improve students' confidence, course satisfaction, and attitudes toward engineering and teamwork?
(3) How does structured pairing affect the student laboratory experience?

3. Implementation and investigation of structured pairing

3.1 Setting and participants

This study was conducted in the context of an electrical and computer engineering instructional laboratory course (ECE 110) during the Fall 2009 semester [52]. Offered every semester, this course is required for first-year students majoring in electrical engineering or computer engineering, and for more advanced students in industrial engineering and general engineering.

All students attended three one-hour lecture sessions and one three-hour laboratory session each week. In the laboratory students completed ten weekly assignments with topics such as resistors, diodes, transistors, and digital logic. The laboratory sessions complemented theory and problem-solving strategies presented in the lecture sessions. The laboratory also aimed to build students' practical knowledge of circuits, digital logic, and measurement equipment. The laboratory assignments culminated in a four-week design project to create an autonomous vehicle.

During the Fall 2009 semester, the course offered 13 laboratory sections comprised of 20 to 28 students. Six of these sections were "structured." Students in the structured sections were instructed to complete all ten weekly labs and the four-week design project following the structured pairing protocol. The remaining seven sections were "traditional." Students in traditional sections were allowed to organize their work freely. Each section was overseen by two graduate or advanced undergraduate teaching assistants. Though specific teaching assistants differed, their overall experience was comparable for both groups. Aside from the implementation of structured pairing, all sections were taught in the same fashion and covered the same topics. Further, all students were also briefed on structured pairing and informed whether their section was a structured pairing section or a traditional section.

Of the 326 students enrolled during the Fall 2009 semester, 240 students (126 from structured sections and 114 from traditional sections) consented to participate in the study. In order to determine whether the structured and traditional groups were academically and demographically similar, we compared their course final exam scores using an independent samples t-test and the percentage of women, underrepresented minorities, and students who passed the course (with a grade of C or better) in each group using Fisher's exact test. There were no statistically significant differences either academically or demographically (see Table 1).

3.2 Training for structured pairing

Teaching assistants (TAs) facilitated all ECE 110 laboratory sections. Although the teaching assistants were primarily responsible for introducing laboratory content, reviewing applicable engineering knowledge, and helping students perform the laboratory activities, the TAs also ensured that students followed the roles of driver and navigator and switched roles at appropriate points in structured pairing sections. All TAs were briefed and trained on structured pairing prior to the first course meetings. This information included an overview of the technique, the purpose of the study, the theoretical and research basis for its implementation, and advice for ensuring students followed the procedure. TAs also discussed the operation of structured pairing section during their weekly meetings.

The switch points were determined at the beginning of the week and written on whiteboards around the laboratory by TAs. Switch points were selected such that each segment would take about thirty minutes to complete and all segments contained similar activities. TAs reported that students followed the structured pairing procedure with few operational questions.

3.3 Comparison of structured and traditional laboratory pairing

To compare the structured pairing and traditional

Table 1. Academic and Demographic Information of Participants

	Structured (N = 126)	Traditional (N = 114)
Average final exam score (out of 100)	68.7	68.1
Underrepresented minorities	12 (9.5%)	5 (4.4%)
Women	7 (5.6%)	12 (11%)
Students who passed the course (C or better)	102 (81%)	89 (78%)

Note: None of these differences were statistically significant, $p < 0.05$.

sections, we collected three types of data: course and curriculum enrollment records, survey responses with closed-ended items, and focus group interviews with students from both structured pairing and traditional sections. In sections 4–6 we present the data collection and analysis methods and results for each of the three sets of data.

4. Effects on student retention

We collected and analyzed College of Engineering enrollment data to answer the first research question: To what extent does structured pairing improve student retention in engineering?

4.1 Data collection

We obtained enrollment and demographic information on consenting students from the College of Engineering. We identified the courses that students took the semester after they completed the ECE 110 course. In the College of Engineering, students who intend to continue in an engineering major would normally take another engineering-related course in the following semester. We defined an engineering-related course as a technical course offered in engineering, computer science, or physics, but not in mathematics, since mathematics is required for many majors outside engineering. In addition, we obtained records of students' declared majors six months after they completed the ECE 110 course. We did so to allow students enough time to change majors while mitigating the effects later courses or experiences may have on students' decisions to switch majors.

4.2 Data analysis

We compared the proportions of structured pairing and traditional section students who took engineering-related courses the next semester and who remained as engineering majors six months later. Since the data were categorical, we used Fisher's exact test. We selected $\alpha = 0.05$ to indicate a statistically significant difference.

4.3 Results

Table 2 shows the percentages of students who majored in engineering six months after completing the ECE 110 course as well as percentages of students who took an engineering-related course in the semester after they took the introductory laboratory course. Comparison between structured pairing and traditional students resulted in no statistically significant differences.

5. Effects on student attitudes

We developed, collected, and analyzed end-of-semester surveys to answer the second research question: To what extent does structured pairing improve students' confidence, satisfaction, and attitudes toward engineering and teamwork?

5.1 Data collection

During the final session of each laboratory section, the teaching assistants administered anonymous paper-based surveys. We chose to distribute surveys during the final session in order to allow students to reflect on the entire 14 weeks of the course. During this session, students demonstrated their vehicles and then completed course and instructor evaluations. Because of time constraints, students in two laboratory sections, one structured pairing and one traditional, did not complete the survey.

The survey contained 40 items [53]. Thirteen items were intended for course management purposes and were not included in this study. The remaining 27 items included Likert-scale items focusing on confidence, course satisfaction, comfort with basic laboratory tasks, attitudes towards electrical and computer engineering, desire to persist within electrical and computer engineering, and teamwork experiences. To promote content validity, these 27 items were built upon items in previous studies of pair programming and engineering student attitudes/retention. Some of the survey items reflect student attitudes that Besterfield-Sacre and her colleagues [30] found to correlate with retention. Others were adapted from surveys used by McDowell and his

Table 2. College of Engineering Enrollment Data

	Structured (N = 126)	**Traditional (N = 114)**
% of students majoring in engineering after 6 months	88.9	86.8
% of students majoring in engineering after 6 months among those who began course as engineering majors	89.8	90.7
% of students who took an engineering-related course in the next semester	93.7	93.0
% of students who took an engineering-related course in the next semester among those who began as engineering majors	93.2	93.5

Note: None of these differences were statistically significant, $p < 0.05$.

Table 3. Items Loading to Each Factor

Factor	Construct	Item numbers	Eigenvalue	% Variance Explained
1	Comfort with basic laboratory tasks	10–14, 17	10.71	41.18
2	Attitude toward collaboration	18–21	2.54	9.78
3	Attitude toward ECE	2, 8, 9, 26, 27	1.91	7.35
4	Effective collaboration	1, 15, 16, 22–24	1.25	4.79
5	Satisfaction	4–7, 25	1.04	4.00

colleagues in their pair programming studies [22, 46]. For each item, the student's response could range from 1 (not at all confident, completely dissatisfied, or strongly disagree) to 5 (extremely confident, completely satisfied, or strongly agree). The survey was reviewed by a survey design expert and pilot tested to ensure face validity.

5.2 *Data analysis*

We received surveys from 104 structured pairing and 109 traditional section students. Most students completed the entire survey. A few individual item responses, however, were excluded from the analysis because students either left these sections blank or responded with irrelevant answers. For example, one student responded "72," "yes," and "no" on three consecutive Likert-scale items. After the blank and irrelevant responses were removed, there were 103 complete structured pairing surveys and 107 complete traditional section surveys.

We performed an exploratory factor analysis on the 27 survey items using *Statistical Package for the Social Sciences (SPSS) 18*. The purpose of this analysis was to identify constructs of the survey (i.e., sets of questions linked to similar concepts), and ultimately to gauge student attitudes beyond their specific item responses. We used oblimin rotation with a delta value of 0 because we expected a moderate degree of correlation between the factors. For example, course satisfaction may be linked to desire to persist. By considering only factors with eigenvalues above 1, we found a five-factor model that demonstrated consistent and meaningful constructs. This model explained 67.1% of the total variance in survey responses. In Table 3, we present the constructs present in the five factor model along with corresponding items.

As evidence of the validity of the survey instrument, each factor includes a coherent set of items. Factor 4 (effective collaboration) includes the most diverse collection of items. Three items (22–24) focus on level of effort and participation by the student and his or her team members. The remaining three items (1, 15, 16) focus on general laboratory skills and wiring tasks. Most likely students perceived the complex wiring tasks to be team tasks, and thus aligned wiring tasks with collaborative efforts. These tasks tended to be difficult and require significant discussion and participation among all team members, compared with the other laboratory tasks included in Factor 1.

Notice that item 3 was omitted. Item 3 regards student confidence in their vehicle's performance in the final design project. Since some students had demonstrated their vehicles and received their performance grades before they took the surveys, item 3 does not accurately indicate student confidence. Since the factor loadings for all other items were above the common threshold of 0.3 [54], we retained the remaining items (see Table 4).

In Table 4 we present the factor loadings for each response in relation to the five factors. For items that had factor loadings above the cutoff of 0.3 for multiple factors, we selected the factor based on greater factor loading. Overall, the survey demonstrated strong reliability (Cronbach's alpha = 0.94). Additionally, all individual factors demonstrated strong reliability with Cronbach's alpha values above 0.80.

We averaged each student's responses to the survey items within each of the five factors, and compared factor averages of students in structured pairing and traditional sections to determine structured pairing's effect on each factor using an independent samples t-test. Since we were testing multiple outcomes, we applied the Bonferroni-Holm procedure to reduce the probability of a type I error. For this analysis we used only the surveys of the 59 structured pairing students who reported using structured pairing at least 50% of the time during their final project (this was reported on one of the 13 survey items not used for statistical analysis). We assumed that these students operated under structured pairing throughout the semester. All factors were within acceptable limits of skewness and kurtosis (+/− 2) except factor 2 (positive attitude toward collaboration). We further tested the assumption of normality of variances between the two samples on each factor. Factors 3–5 violated this normality assumption, and thus we performed an unequal variances t-test instead of the traditional Student's t-test to minimize potential for type I error [55].

5.3 *Results*

Table 5 compares the average response of struc-

Table 4. Factor Loadings above 0.4 of Each Item for the Five-Factor Model

Item	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
1. Confidence in laboratory skills	0.374			**0.472**	
2. Confidence in ECE knowledge	0.351		**0.395**		
3. Confidence in final design [Omitted]					
4. Satisfaction with lab portion					**0.885**
5. Satisfaction with course overall					**0.802**
6. Satisfaction with ECE program					**0.762**
7. Pleased with course lab experience					**0.670**
8. Electrical engineering is exciting field			**0.543**		0.341
9. Computer engineering is exciting field			**0.746**		
10. Comfort measuring voltages, currents, and resistances using digital multimeter	**0.741**				
11. Comfort capturing signals w/oscilloscope	**0.859**				
12. Comfort reading the frequency, period, and peak-to-peak voltage of a periodic signal using the oscilloscope	**0.817**				
13. Comfort setting up linear circuits	**0.649**				
14. Comfort designing circuits using simple logic elements	**0.505**			0.446	
15. Comfort wiring circuits using TTL logic gates from an existing design	0.349			**0.626**	
16. Comfort wiring circuit using TTL logic gates of own design	0.361			**0.580**	
17. Comfort debugging circuits that include TTL logic gates	**0.482**			0.422	
18. Enjoyment working with lab partner(s)		**0.604**			
19. Comfort working with a partner or group in a laboratory setting		**0.866**			
20. Comfort working with a partner or group in a non-laboratory setting		**0.888**			
21. Willingness to work with a partner or group in future engineering laboratories		**0.804**			
22. Participated in lab to the best of ability		0.314		**0.335**	
23. Had an equal part in group's success				**0.682**	
24. Everyone in group did fair share		0.301		**0.697**	
25. Proud of the work done in lab					**0.373**
26. Plan to take more ECE courses			**0.777**		
27. Plan to continue ECE studies (or transfer into ECE)			**0.762**		
Cronbach's alpha	0.89	0.86	0.82	0.86	0.85

Bold values indicate the factor for each item.

tured pairing and traditional section students within each factor. Compared with students in traditional sections, structured pairing students reported greater levels of comfort with laboratory tasks, effective collaboration, and satisfaction. Effect sizes (Cohen's *d*) for all factors were between 0.3 and 0.49, indicating small positive effects of structured pairing on all factors, according to guidelines by Cohen [56].

6. Student experiences

The quantitative results indicated that structured pairing students were more satisfied with their laboratory experiences, participated in effective collaboration, and were more comfortable conducting basic laboratory tasks, but did not persist in greater numbers and were no more positive towards collaborative learning or ECE. We conducted focus

Table 5. Average Responses within each Factor for Structured and Traditional Students

Factor	Number of items	Structured (N = 59)	Traditional (N = 106)	Effect Size (d)
1. Comfort with basic laboratory tasks	6	**4.29***	3.99	0.39
2. Positive attitude toward collaboration	4	4.59	4.39	0.30
3. Positive attitude toward ECE	5	4.19	3.93	0.34
4. Effective collaboration	6	**4.39***	4.04	0.49
5. Satisfaction	5	**4.16***	3.82	0.47

* Denotes statistically significant difference with Bonferroni-Holm correction applied, $p < 0.05$.

groups with both structured pairing and traditional section students in order to add context to these findings and answer the third research question: How does structured pairing affect the student laboratory experience? We selected focus groups to allow students to respond to each others' comments and to guide the discussion around common themes without overly structuring discussion.

6.1 Data collection

After the semester had ended, we invited via e-mail all students who had completed the course to participate in two focus groups. Ten students from traditional sections participated in one focus group, and seven from structured pairing sections participated in the other. No volunteers were excluded from participating. The focus group interviews were semi-structured. We asked both groups the same six base questions and asked follow-up questions when relevant. We asked questions related to laboratory experiences, particularly teamwork, division of labor, laboratory tasks, lab partner relationships, and structured pairing. See appendices A and B for the lists of questions asked to both groups. The recorded audio from each focus group was transcribed for analysis.

6.2 Data analysis

We analyzed these transcripts in order to identify themes of student perceptions, experiences, and attitudes in lab. Since there is little qualitative research in the area of collaborative learning in engineering laboratories, we had no a priori expectations for the results. We selected an open-ended content analysis approach (Patton, 2002) because of its emphasis on inductively and deductively building interpretations.

First, we (the two authors) independently read through the transcripts and marked them with notes referring to important passages. We then created a list of codes referring to recurring and important themes. We read through the transcripts again and independently marked passages that demonstrated one or more of the codes. We then cross-checked the independent codings at an agreement rate of 95%. We reconciled each instance of disagreement in our codes to ensure reliability of analysis. From the reconciled transcript coding we searched for any differences in student perceptions, experiences, or attitudes among structured pairing and traditional students. Each assertion about the data was strength-tested. Only assertions with significant support from the data were included.

6.3 Results

After the coding process, various themes emerged from the student dialogue. A preliminary discussion of some of these themes was previously documented [57]. In this study, we focused on themes related to team procedure and outcomes. Assertions were supported by student quotations. The students were given pseudonyms to protect anonymity. Traditional students were given names beginning with letters A–K. Structured pairing students were given names beginning with letters T–Z.

Task Distribution. Most students reported performing the same number of laboratory tasks and devoting the same effort as their partners. Traditional section teams gravitated towards the divide-and-conquer technique. Some students, such as Alex, took the conventional approach: each student performed the task with which he or she was most comfortable.

> **Alex**
>
> *My partner did a lot of the wiring and stuff like that. And I kind of oversaw what he was doing and if he had some trouble I helped him. And I did like other stuff in the meantime. And I... tried to get most of the answers in the lab while we [were] working with the objects.*

Other traditional teams distributed the tasks by convenience. Students would perform tasks based on mood or proximity to objects. Although students would alternate as leader, reciprocal scaffolding was not evident.

> **Fred**
>
> *It was just: whoever was closest to this cable, go and get it. Whoever is closest to the button, push it. And kind of during the final design challenge . . . if you have an idea how to make this circuit work, you go and try it. If it fails, then we would start from scratch. Or if it works, good job, now let's try and put it together with this. We usually alternated who would take the board home for the week when we were doing the final design challenge. . . It was pretty much just whoever has an idea, try it and see if it works.*

Structured pairing students did not use the divide-and-conquer technique, but neither did they rigidly adhere to the structured pairing protocol. While most teams followed the protocol during the first half of the semester, some adopted alternative methods of working together by the end of the semester. All students indicated that time constraints adversely affected their work, especially as laboratory exercises became more complex and the final design project commenced. Because students were not able to finish their laboratory assignments in the allotted three hours each week, they adopted methods they believed to be more time-efficient. Some structured pairing students dealt with these time constraints by specializing, or allowing each student to perform the laboratory tasks that he or she was best or fastest at, while the other team member(s) acted as navigator(s).

Xavier

The only major reason [structured pairing] was really hard to implement towards the end of the semester was that we found it just quicker to specialize . . . It's a lot more efficient as far as time, which is definitely a scarce resource in lab.

Other teams dealt with the time constraints by employing a technique that we call *natural switching*. As in Miyake's observations of dyads [50], teams operating under a natural switching framework still act within the roles of driver and navigator, but they switch roles at points they choose rather than at the prescribed switching points. Umberto described one such example.

Umberto

We discovered that some of the labs took quite a long time, and we kind of weren't learning everything we should be because we weren't finishing the labs. We ended up, like Vance said, there were like natural switching points. So we kind of gravitated towards our roles. So one of us would be wiring, the other person would be describing like how this specific wiring is supposed to be done, like what the concepts are behind it. Usually that person, whoever was wiring, would stay with that until we switched to a completely different concept.

In contrasting Umberto's experience with Alex's experience, it is worth noting the difference in roles between the students not working on wiring tasks. In Umberto's (structured pairing) example, the non-wirer engaged the wirer in a conceptual discussion. In Alex's (traditional) example, the non-wirer was simply checking for mistakes and finding answers.

Though many students experienced an equal division of labor, students reported instances of free riders in both structured pairing and traditional sections. Some free riders demonstrated indifference towards laboratory work, while others lacked confidence. Regardless, free rider problems were usually resolved by the end of the semester and some were mitigated within a team of three rather than two. Kevin provided an example.

Kevin

There was another guy in our lab section who didn't, couldn't find a partner, so he came in with us and, well, like I was saying earlier, he was the one who didn't do a lot of work for a lot of the lab periods and I didn't get along that well with him until pretty near the end when he started actually doing some of the work. So I think by the end we were working pretty well together.

Willie and Zane from structured pairing sections also worked with free riders. Without reliable partners, they were forced to seek assistance elsewhere or to complete the labs themselves. Willie enjoyed the arrangement. Zane simply accepted it.

Willie

My lab partner pretty much let me do everything. So it was more like I was dominating and I was the one who was doing all of the individual work. . . . It's just that he openly admitted to me that he's not comfortable in the laboratory.

Zane

In the beginning, well the TA specified the whole alternating, like the driver and the other roles. And we tried to follow that. But me and my lab partner just, he just kept repeatedly telling me, "No, no, you do it. You do it." I mean, it's a timed lab and some of the earlier labs took the whole time. And sometimes we didn't even finish. So, for the sake of time, I had to put up with him and just do it myself.

Since Willie and Zane did not follow the structured pairing protocol in their teams, they do not accurately represent structured pairing students. We include these cases to illustrate that no instructional technique can be effective if students do not follow it. Ensuring student participation is key.

Reciprocally-Scaffolded Learning. The difference in task distribution may have affected teammate relationships. Outside of Willie and Zane, who partnered with free riders, the structured pairing students generally enjoyed working with their partners. They not only felt they were part of productive teams, they also believed that their teammates were valuable to their education, helped them learn, and contributed intellectually within the role of navigator.

Thomas

I was lucky to really get a good partner. . . he sort of knows more about [logic] and wiring stuff more than I do. And working with him actually taught me how to do stuff better and how to learn quicker.

Traditional section students also tended to enjoy working with their partners. Many felt their partners and teammates committed adequate effort, and some even befriended their partners. Unlike structured pairing students, however, none of the traditional section students described experiences where their partners helped them learn. Nor, as Alex's comment in the previous section indicated, did they contribute intellectually when not performing driver tasks. Sometimes negative or frustrating relationships emerged. Traditional section students reported everything from unproductive or uninterested partners to partners who would regularly leave the laboratory early without cause. Hal described his partner as an example.

Hal

There wasn't really a conflict resolution because my lab partner would often leave an hour early and I'm not sure if he really cared about the outcome of the lab. So it really just came down to me finish. I mean like, on the two occasions that he actually stayed. . . I finished [the lab] and he asked his friends for their answers, so it didn't really work out.

In addition to better teammate relationships, structured pairing students also reported productive relationships with neighboring teams. Both structured pairing and traditional section students often reported waiting to receive help from the teaching assistants who were helping students on other teams. While traditional section students described no solution to this problem, structured pairing students sought help from and gave help to neighboring teams in their sections. Xavier discusses one such relationship.

> **Xavier**
>
> *My lab partner was friends with the group next to [us]. [When] there were some difficult concepts. . . we would bounce ideas off each other as to what would be going right or going wrong and trying to come to a solution and it benefited both [of] our groups.*

Ultimately, the primary difference between structured pairing and traditional section students was adequacy as a member of the team. Structured pairers often had partners capable of helping during the design project, while traditional section students often did not. Both structured pairing and traditional section students claimed that while structured pairing may be cumbersome in certain situations—especially with time constraints—they believed such a technique would produce better lab partners later in the semester.

> **Joe**
>
> *Yes, [structured pairing] would take some patience on the person who learns the material faster. However, that patience will pay off when it comes to the final design project, [when otherwise] you [would] have no partner. Maybe you were fortunate enough to have a partner who was motivated and willing to. . . learn or work with you. But by that stage in the final design project, you're so deep into the material and wiring, working with the oscilloscope and multimeter that it's too late to actually go back and start delegating and showing them how a multimeter works or how an oscilloscope works, or that an oscilloscope has two readings of voltages and how to . . . reformat [the display]. It's just, it's trying to go back from lab one and reteach the whole lab again, when that can be fixed with, yes, granted, a little extra time of structured pairing. That would kind of make it more of a seamless transition when you reach the final design.*

7. Discussion

7.1 Student attitudes, experiences and retention

On the whole, the results of this study were positive. Structured pairing students reported significantly greater confidence in laboratory skills, collaborative experiences, and satisfaction with laboratory experiences than traditional section students. The focus group results also indicated that structured pairing teams experienced joint participation, conceptual discussions, and reciprocal scaffolding, which are linked to both motivational and learning outcomes [18, 25, 26]. These results suggest that structured pairing could benefit students in other engineering laboratory settings.

The results, however, were not all positive. Structured pairing did not appear to affect student retention in engineering. Structured pairing students continued as engineering majors and took engineering-related courses at about the same rates as traditional section students. The enrollment data indicated that 93.0% of traditional section students took engineering-related courses the semester after the laboratory course and 86.8% were engineering majors six months after taking the course. Compared with corresponding figures, 62.2% and 33.8%, for students who worked alone in the key pair programming study by McDowell and colleagues [22], there was little room for improvement of student retention after the first semester. The survey results demonstrated a small positive effect size for the mean difference between structured pairing and traditional groups on *positive attitude towards ECE*; the difference in attitude might indicate a greater likelihood to persist, but the difference was not statistically significant at the 0.05 level with the Bonferroni-Holm correction. The effects on confidence and satisfaction might increase long-term retention (i.e., persistence to a degree), even without increasing short-term retention (i.e., persistence through the next semester).

Structured pairing students reported stronger collaborative experiences both on the survey (Factor 4) and in the focus groups, but did not indicate significantly different attitudes towards collaborative learning (Factor 2). One potential explanation for this finding is that students in this study already had a positive view of collaborative learning, and thus had the intervention had little room for improvement. Students rated *positive attitudes towards collaborative learning* the highest of any of the survey factors.

7.2 Implications of results

Beyond retention in engineering, the survey and focus group results indicate that structured pairing students may be better prepared to complete their engineering programs. Students who followed the structured pairing protocol reported greater comfort in fundamental laboratory skills and more competent lab partners. In the focus groups, structured pairing students reported reciprocally-scaffolded experiences with laboratory tasks, whereas traditional section students reported no such experiences. Because structured pairing students gain increased experience and comfort with the basic laboratory tasks, they are likely to be better prepared, through stronger laboratory skills and greater self-efficacy, for future laboratory courses and other situations where they will need the hands-on skills that they should develop in the introductory course.

In addition to hands-on work, team projects are becoming more common in engineering and technical courses and are key to engineering practice. The structured pairing students in this study reported better team experiences than traditional students and demonstrated effective teamwork skills. Some may argue that traditional teaming methods better simulate the teamwork students will experience in industry and better prepare students to deal with problematic teammates, but productive experiences, especially early in their engineering training, can be crucial to successful future teamwork. Pair programming, the basis for structured pairing, was modeled on successful team practices in industry [47]. Thus teamwork skills developed through structured pairing may prepare many students for successful team experiences during their careers. Further, developing healthy team behaviors, such as building positive and supportive relationships with their lab partners and other classmates, can help structured pairing students to form strong teams in the future and potentially alter the teamwork landscape of free riders, dominant leaders, and divide-and-conquer task distribution.

7.3 Notes on structured pairing implementation

During the structured pairing focus group, students stated that they did not always follow the structured pairing protocol. Instead, two of the seven students indicated that their teams had stopped following the structured pairing protocol by the end of the first laboratory session. One student, whom we identify as a dominant leader, was paired with a free rider, and he was pleased with the arrangement until he needed his partner's help for the final design project. The other student was displeased with his free riding partner throughout the semester, but succeeded by seeking support from other students. In particular, he developed a relationship with a student from another section during optional practice sessions.

The above free rider examples represent the situations that structured pairing was developed to avoid. In consultation with some of the course TAs, we identified three techniques lab facilitators can use to help ensure student participation in structured pairing. First, it is important to discuss and demonstrate the potential value of following structured pairing (e.g., better laboratory and teaming experiences, more effective collaboration) during the first lab session. Second, lab facilitators should intervene with any team they observe disregarding the driver and navigator roles. One simple way to identify these teams, especially in laboratory environments where the facilitator is consistently engaged with students, is to ask which student is the current driver during every consultation. Third, make sure the student workspace is set up so that students can easily access all relevant equipment and observe all work products and measurement devices. In addition to actions lab facilitators can take in the laboratory environment, instructors should identify tasks that are sufficiently complex to require attention from all students in a team, as research suggests that these tasks encourage more effective collaboration [18].

The remaining five students indicated that their teams followed structured pairing for part of the time, but also adopted a technique they dubbed *natural switching*, which resembles Miyake's findings [50]. Instead of switching at the prescribed switch points, natural switching teams alternated roles when they felt it was more natural to switch. For example, they would switch roles when one person "got an idea and went with it." These students indicated that all team members shared roughly equal time as driver and navigator, performed the functions of those roles sufficiently, and thus seemed to experience reciprocal scaffolding. Natural switching students also indicated that they were generally pleased with their laboratory experiences, unlike the two students who hardly switched at all.

These results indicate a tradeoff related to structured pairing switch points. When we selected the switch points in the laboratory procedures, we attempted to allow each student to share equal time and responsibility as driver and have them switch roles when transitions were natural (e.g., when they were asked to build a new circuit). The focus group results, however, suggest that students prefer to switch roles when topic-divergent suggestions [50] are made. Allowing students to operate without set switch points could increase buy-in, and potentially productivity, among students but could also limit the range of laboratory activities each student experiences and enable free riders and dominant leaders. The results of this study indicate that even natural switchers derived benefits from their brief formal experience with structured pairing, so it may be an effective compromise for instructors who wish to implement cooperative learning but are uncomfortable applying too much structure to teamwork. Instructors might also set appropriate switch points for the first few lab sessions and consult with their students to identify any modifications that may be beneficial in future sessions.

8. Limitations and future work

This study was conducted in one offering of one course at one university in the United States. The results could have been affected by the characteristics of the course and the demographics of the students, who were mostly traditional-aged first-year full-time residential students. With so few female and minority students, we could not find statistically significant differences for underrepresented groups. Thus, further research is needed to understand structured pairing's effect along different demographic variables.

Since this study investigated only short-term retention effects, further study of structured pairing should be conducted to determine long-term effects. If students experienced a series of laboratory courses that use structured pairing, retention in engineering could improve. Additionally, a long-term study might provide sufficient time to demonstrate the effects of the attitudinal changes and teamwork and experience outcomes from structured pairing. For example, how does the initial structured pairing experience affect students' teamwork experiences in later courses?

Further study should also be conducted in additional engineering laboratory courses to determine the effect of structured pairing on students in other contexts, especially those with lower retention rates than reported in this study. One particular area of interest would be virtual or remote laboratory environments with different teaming structures than traditional on-site laboratory courses. Future studies might also investigate specific effects of structured pairing on student learning, since other cooperative learning techniques have improved student learning in a variety of educational contexts in a variety of ways [11, 13].

9. Conclusions

Structured pairing is a simple procedure, adapted from pair programming, for organizing student teams in laboratory settings. In this study, structured pairing was found to increase student confidence in laboratory skills and satisfaction with laboratory and team experiences. Structured pairing students reported equitable, helpful, positive, and reciprocally-scaffolded team behaviors. Further, we found no negative effects on retention, course grades, or desire to persist or work in teams. Beyond these outcomes, structured pairing is a simple way to introduce cooperative learning into engineering laboratories without disrupting standard course operation. It requires no additional instrumentation, only brief training for students and instructors, and additional monitoring by laboratory instructors. Because structured pairing produces positive outcomes and is easy to implement, we recommend that laboratory instructors consider incorporating structured pairing into their courses.

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Appendix A

Questions Asked During Traditional Sections Focus Group

(1) Please state your major, your year in school, and the size of your ECE 110 lab group.
(2) What lab task were you most comfortable with?
(3) What lab task were you least comfortable with?
(4) What was the best part of working in your lab group; what did you enjoy most working with your partners?
(5) Was everyone happy with the number of people in their lab group?
(6) How well did you get along with your partners?
(7) How did you resolve conflicts or disagreements with your partners?
(8) Comment on the division of labor in your group.
(9) If you had to do the labs all over again, would you prefer to be in a structured pairing section or would you prefer to be in the standard section where you could divide up the labor however you liked and why?
(10) A number of you have talked about whether your partner did the work or did not do the work. I'd just like you to explain what does "doing the work" mean or look like, what are tasks that you consider "doing the work"?
(11) You've explained what "work" looks like and so not doing work would then be not contributing. I don't want to put words in your mouth, but just briefly, what does it mean to not do work?
(12) What does a "good" partner look like?
(13) If you could change any one, single thing about your ECE 110 experience, what would that be?
(14) What was your favorite part about the ECE 110 lab?

Appendix B

Questions Asked During the Structured Pairing Focus Group

(1) Please state your major, your year in school, and the size of your ECE 110 lab group.
(2) What was your most comfortable lab task?
(3) What lab task were you least comfortable with?
(4) What was the best part of working in your lab group?
(5) How well did you get along with your lab partners?
(6) How did you resolve conflicts or disagreements with your partner or partners?
(7) How closely did you actually follow the structured pairing protocol that was outlined by your TA's at the beginning of the lab?
(8) A lot of you mentioned that [structured pairing] was either time-consuming or cumbersome and that's why you ended up dropping it towards the end of the semester. What specifically did you find time-consuming about it or cumbersome?
(9) Describe your ideal lab partner.
(10) Given the opportunity to change structured pairing, what would be one thing you would change about it?
(11) What was your favorite part about the ECE 110 lab?

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