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Partner Selection and Group-Based Curriculum Design for Engineering Laboratory Courses

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Abstract

Providing engineering students with hands-on experiences in physical laboratories is a critical factor in producing well rounded graduates. Additionally, engineering students need to gain as much experience working on teams as possible, so they are prepared for the teaming environment that is prevalent in industry. While implementing a group-based course design might be more difficult on the instructor, it provides greater benefit to the students and reduces laboratory equipment cost and support staff. The details of how groups are structured and selected plays a major role into how effective the group-based course design will be. Allowing students to self-select their group is by far the easiest on the instructor and one would naturally think it would also be the most popular method for the students. Educators often make the assumption that students will be happier when they are given more autonomy, but in this study that was found not to be the case. When a self-selection system was replaced with the system explained in this paper the course was greatly improved. Many of the issues with self-selection and other common group selection methods are overcome with a novel group shuffling process that is proposed in this study. This study is implemented in an analog electronics laboratory course with 2-person groups, but many of the ideas could be implemented in other settings. A vital part of any group-based course design should be a method to motivate the students to do their best in the group. This study details a group evaluation method that serves as an exceptional motivational tool for the students. Anonymous course evaluation data was used to show how the students perceived the effectiveness of the group selection process and the group evaluation tool.

I. Background

There are many different types of engineering laboratory courses. Historically, a lab course involves students going to a defined space with fixed equipment that is used for hands-on experimentation. Allocating space for physical labs is usually a challenge, but it might be even more difficult to purchase and maintain the equipment in physical labs and provide adequate teaching support. In recent years, virtual labs have been used as a cheaper alternative to physical labs [1],[2]. While virtual labs are more cost effective than physical labs, they do not offer the same type of experience and benefits to students. When students are able to get their hands-on physical systems and tinker with them, it brings a greater understanding than the sort of experimentation done in most virtual labs. It is also much easier to do meaningful projects in a physical lab, and having a project-based approach to ECE courses has shown to play a vital role in increasing students' interest in the subject matter [3],[4].

Another important benefit of working in physical labs is that it is easier for students to work together in groups. Working in groups also provides cost savings because both equipment and support staff can be reduced, but the more important reason for implementing groups is the benefits to the students by helping them develop teamwork and communication skills. These so-called soft skills are often just as important as the technical skills and abilities gained in lab courses. Engineering students need to gain as much experience working on teams as possible, so they are prepared for the teaming environment that is prevalent in industry.

When implementing groups in a course, the group selection process is a vital aspect that people often overlook. The number of people to put in a group is the first question that needs to be answered. For this study, two-person groups are used because it works best for the type of course it was implemented in. However, the methods used in this paper could also be applied to larger groups. Additionally, research studies involving larger groups will also be reviewed because many aspects are also applicable to 2-person groups. Once the number of students in each group is determined, a method to put them into different groups is needed. Due to its ease in implementation, allowing students to self-select their groups is a popular way of distributing the students into groups. Self-selection is by far the easiest on the instructor and one would naturally think it would also be the most popular method for the students. Educators often make the assumption that students will be happier when they are given more autonomy, but in this study, self-selection was shown to be ineffective and filled with problems. One problem with students self-selecting their lab partner is that there will always be students that do not know very many people in the course and have trouble finding someone and the whole idea of going out and finding their own lab partner is very difficult for them. Another issue with self-selection is that students naturally tend to partner with one of their friends and if they end up being a bad lab partner it ruins their experience and sometimes even their friendship.

Determining new grouping strategies that avoid self-selection has been studied by several researchers. One interesting approach is to group team members based on student interests or desired learning topics. One example proposed at North Carolina State University is selecting groups based on a first-come first serve approach using the online tool Expertiza. This tool allows students to select their own teammates and group members based on a learning topic. This approach works by having students select a topic and then search for teammates with similar interests in that topic. The main disadvantage was that teachers had to entice students to form teams of a particular size [5]. An improved method was attempted in a software engineering course which used an automated process based on asking each student to rank topics in order of preference and recording the topic "bids." Student bids are mapped to an *n*-dimensional vector and Hierarchical *k*-means clustering algorithm that recursively splits the students into teams [6]. While using the studies that used learning topics to set groups had some level of success, the implementation effort required by the instructor was substantial.

Another study at the US Military Academy, that is very applicable to this paper, discusses the effect of replacing individual exercises with randomly assigning teams of two [7]. This study highlighted the benefit of removing the artificial laboratory time constraint by making the equipment available on a full-time basis. The trial claimed there was improved student camaraderie, particularly at the sophomore level, where students are largely unfamiliar with one another. The open lab concept also helped overcome inefficiencies caused by personality or scheduling conflicts. The weakness of the group process was the need to give a team grade rather than individual scores. A "snapshot" of individual performance was limited to ten minutes in this study, but it was concluded that the sense of fairness in an individual grade was elusive and therefore not assigned. The lack of individual grades was claimed to be partially offset by demonstrating laboratory concepts in normal course examinations. It was inferred that students who performed poorly on the examinations were likely the same ones who contributed little to their team's effort in the laboratory exercises. This US Military Academy study highlights the importance of having an ample number of individual components in the grading structure when implementing a group-based course design. Section II shows how keeping a balance of group and individual work was accomplished in this paper.

The US Military Academy study [7] also analysed senior-level design team selections using a combination of student preferences for team members, student preferences for projects and instructor selections. The students could nominate up to two other students for their design teams. It was found that many students did not list the same team members for all three project choices which was argued to be an indication that skills and background were a factor in their choices, instead of only choosing partners based on outside relationships. The study cited the most difficult part of the teaming process was to complete the design teams with the pool of unassigned students based on a variety of considerations such as past academic performance, individual skills, choice of project, team leader personality, and advisor opinion or preference. Designing a group-based system where there are no students left at the end that no one wants to be in a group with is an important consideration in the system created in this paper.

A study out of Purdue University researched the idea of using self-formed teams around a voluntary leader [8]. At the end of the course, the 35% of total course points were apportioned internally by the team members. Interestingly, the only stipulation is that they were not allowed to divide points evenly among team members and they were required to justify the apportionment. Some interesting group dynamic issues were documented in that study. One group had older conscientious students working independently with very little deference to individual ideas. An issue of one leader with three non-performing students occurred. At the other end of the spectrum there were hard working students mixed with somewhat weaker students, but difficulties were not so apparent and there were no reported arguments. The end of the study concluded that assigned groups may be preferred. It suggested basing the selections arbitrarily on GPA, last-name or by using a personality test. It was concluded that arbitrary groupings would avoid like-with-like groupings, which would increase the likelihood of producing a mixture of abilities and minimizing the situation of having "leftovers" of a high proportion of weaker or less dynamic students. Using randomness in the group selection process is also a method that tends to even out ability levels and is a key aspect in this paper that will be described in Section III.

One glaring downside to implementing a group-based course design is that if it is not structured and implemented wisely the instructor may spend more time dealing with team interaction problems than with technical problems [9]. The goal of this paper is to provide a solution that gives the most possible benefit to the students, while not becoming a burden on the instructor. The group selection process is described in detail in Section III. One final thing that was learned during this study is that no matter what group-based system that is deployed, it will not work effectively unless there is some sort of motivation for the students to be a good team member. This paper provides an extensive group evaluation method in Section IV that serves as a motivating factor for students to excel in their groups.

II. Course History of ECE3873 – Electronics Lab

Before explaining the details of the project-based course design that was developed in this work, the laboratory course that it was implemented in will be discussed. One of the most rigorous and time intensive ECE courses at the University of Oklahoma (OU) is ECE3873 – Electronics Lab. The following is the course description: *electronic analog circuit design, simulation, construction, debugging and measurement of circuit performance quantities using advanced instrumentation techniques; circuit reliability theory; independent design skills development and technical writing*. This course has a lecture section that all students attend and smaller lab sections that contain approximately 20 students in each. ECE3873 has the following four prerequisites: *ECE3723 – Circuits II*, *ECE3773 – Circuits Lab*, *ECE3813 – Introduction to Electronics*, and *ENGR2002 – Professional Development*.

ECE3723, ECE3773, and ECE3813 are typical courses that are taught in nearly every ECE curriculum. A major portion of ECE3723 – *Circuits II* is to build on the knowledge learned in the first circuits course that OU-ECE students take (ECE2723) by extending the circuit analysis theory into the frequency domain. ECE3813 provides a basic theoretical understanding of diodes, transistors, and operational amplifiers (Op Amps). ECE3773 is a basic lab course that teaches the students how to build basic circuits on a breadboard and how to use a power supply, multimeter, function generator, and an oscilloscope. In ECE3873, the students combine the practical lab knowledge they gain in ECE3773 with the theoretical concepts learned in ECE3723, ECE3813, and other previously taken ECE courses to be able to design and construct complicated analog electronic projects.

The prerequisite that OU includes for its analog electronics lab (ECE3873) that is unique, when compared to other ECE programs, is the course called *ENGR2002 – Professional Development*. The reason this course was selected for a prerequisite for ECE3873 is that it focuses heavily on building teamwork and communication skills. These topics help students understand how to work with other people and are critical to the successful implementation of the group-based course design that is proposed in this paper. Reference [10] goes into more detail about ENGR2002 and shows that it is an effective way to teach engineers the soft skills that are desperately needed in industry and required for ABET accreditation.

Table I shows the schedule for ECE3873. The first column shows that the students change groups four times during the duration of the course. The students work on the Robot

Design Challenge in the final group pairing. The robot design is a tradition in ECE3873 that involves the design of an analog robot from scratch that competes against the other students' robots in the course. This robot project is so well thought of that the vast majority of the ECE juniors that take the course respond positively (4 or 5 response on a 5 point Likert scale) to the following anonymous course evaluation statement: "*The robot project was the best learning experience I have had so far at OU.*" Specifically, in the Fall 2019 semester, 71.4% of the 28 students that completed the evaluations responded positively to this statement.

Table I – ECE3873 Schedule

Group #	Week #	Lab
1	1	Introduction Lab
	2	Diodes Lab
	3	Basic MOSFET Lab
2	4	Advanced MOSFET Lab
	5	BJT Lab
3	6	Basic IC Amplifier Lab
	7	Advanced IC Amplifier Lab
	8	555 Timer Lab
4	9-15	Robot Design Challenge

In addition to the group work that is shown in Table I, there is also an individual final design project and individual exams and quizzes. The course is structured such that the individual work makes up half their grade. The grade breakdown for ECE3873 is shown in Table II.

Table II – ECE3873 Grade Breakdown (50% Group and 50% Individual)

Percent	Grade Item
25	Group Labs done in weeks 1 to 8
15	Group Robot Design Challenge
10	Group Evaluations (Discussed in Section IV)
10	Individual Quizzes (6 preparation quizzes and 2 hands-on quizzes)
15	Individual Final Design Project
25	Individual Final Exam

This paper is focused only on the course design strategies related to student groups, so the many novel course design elements and explanations of the assignments will not be discussed in great detail, but only what is necessary to provide context to this study.

III. ECE3873 Group Selection Methodology

Before the first day of class each student is paired with another student using an auto-group generator tool that is available in the Canvas learning management software platform that is used at OU. The students sit with their partner in the Monday night lecture period according to a seating chart that changes each time the group pairings change (as shown in

Table I). When the seating chart was first implemented in ECE3873 there was a concern that the students would disapprove because there is typically not that level of restriction in a junior-level college class. On the contrary, it turned out that the students liked the set up because it made the course more structured and helped them with the logistical challenges of working with new partners throughout the semester. The Monday night lecture section is the time that the information and background theory the students need for the lab exercises for that week are explained. The students have a dedicated lab section that is at a set time later in the week, but the lab is also accessible at all hours using their student ID.

After the first three labs, the students are switched to a new lab partner in week 4 and then again in week 6. Each student works with three different lab partners during the first half of the course. This 8-week period is called the "Learning from the Labs" portion of the course. After week 8, the final group pairing is set, and the students apply the knowledge they learned from the first 8 weeks to produce an analog robot. The students complete a peer evaluation at the end of their time with each lab partner (details are shown in Section IV). The first three lab partners are selected using a random group selection algorithm that assures the students do not work with the same person twice. The fourth lab partner pairing is determined from a survey that is incorporated into the 3rd peer evaluation. In this survey, the students list their preference for the 4th lab partner by prioritizing the following five options:

- Work with their 1st lab partner
- Work with their 2nd lab partner
- Work with their 3rd lab partner
- Work with someone they have not worked with before
- Work alone

A program was created to analyze the survey results and give each student their highest possible preferences when selecting their 4th lab partner.

There are many reasons why the group shuffling policy was implemented in this course. First and foremost, it gives the students more experience working with different people and that is a very valuable skill for engineers. Working with more people also increases a student's network and that is widely believed to be a key to success. ENGR2002 (one of the prerequisite courses to ECE3873) also implements a group shuffling policy with larger sized groups and it was found to be very effective in that course [10]. Since the students have taken ENGR2002 and are accustomed to group shuffling, it provides scaffolding for the group-based structure in ECE3873.

In a difficult lab course like ECE3873 one of the biggest concerns is getting lab partners that have a mismatch in abilities or performance. In these mismatch situations there is often the problem of one student relying too heavily on the other student and not learning the material well. Since their partner changes throughout the semester with the group shuffling system, it reduces the likelihood that someone can rely on their partner without learning concepts for themselves. Before implementing the shuffling system in ECE3873 several years ago, the students were allowed to self-select their lab partner and stay with them the entire semester. Observing so many instances of having one student carried by their lab partner and not learn the material well enough to pass the final exam was one of the biggest reasons a change was made. Surprisingly, from past observations in ECE3873, the student that was getting carried by their partner usually did not want to be carried. Far too often the problem was that their lab partner was not a team player and just wanted to do everything themselves because they thought they could do it faster. Being in a dysfunctional situation like that for a whole semester is miserable for students. There are numerous other reasons why having to stick with one student for the whole semester is not an ideal scenario. Some of these are personality clashes, scheduling conflicts, different work ethics, and differences in tolerance to procrastination.

Another important reason that the group shuffling process was implemented for ECE3873 was the problem with sections that have an odd number of people. Under no circumstance would a three-person group work in ECE3873 because the hands-on experience would be diminished, so the only alternative when there was an odd number of students in a section was to have one student work alone all semester. With the group shuffling method, they would only have to work alone for a small portion of the course. Overall, the group shuffling policy offers the numerous benefits that come along with students working with more people, while at the same time mitigating many of the negative outcomes that can occur when using a curriculum design where partners self-select and/or stay together the whole semester.

IV. Group Evaluation

Creating strategies to minimize the number of students that do not contribute adequately to the group is the biggest challenge in designing a group-based course curriculum. An effective strategy to motivate students to contribute in their group is to implement a peer evaluation system where the students evaluate their group members and themselves. Including a self-evaluation is a critical aspect of the group evaluation because it provides them an opportunity to reflect on their performance and see where they can improve. From years of experience in analyzing group evaluations, students tend to be honest on self-evaluations and are sometimes even harder on themselves than they are on their group members.

The group evaluation system in ECE3873 has the following four categories for the self-evaluation and the peer evaluation. These categories attempt to embody what it means to be a good group member. The following explanations of these four items are written from the perspective of evaluating their group partner, but they are also applied in the self-evaluation by changing the pronouns *they*, *themselves*, and *you* with *I*, *myself*, and *them* respectively.

- **Professionalism** – They showed up on time for scheduled meetings and showed a willingness to work with their partner on times to meet. They acted in a professional manner at all times.
- **Competency** – They acquired the knowledge needed to adequately contribute to the group. A question you might ask in determining this score is: “If they had to do it by themselves, would they be able to pull it off or would they have a major problem doing it?”
- **Effort and Attitude** – They worked hard to try to do at least half of the work and maintained a positive attitude.

- **Teamwork** – They tried to make the project a 2-person project instead of making you do all of it or trying to do it all by themselves.

A score from 0 to 2 is given for each of these items for the peer evaluations and self-evaluations. The scores are averaged for each category and then added to make a total of 16 points. Students are encouraged to use fractional numbers when they enter their scores instead of just entering 0, 1, or 2. However for the last 2 points of the group evaluation there is an item called "overall" where the students evaluate their partner by asking themselves "Did I have the kind of positive experience working with this person that they are someone I would like to be paired together to do the robot project with?" For this item there are only three possible scores they can choose: yes = 2, maybe = 1, no = 0. So, each group evaluation is worth 18 points (10 points for the peer evaluation and 8 for the self-evaluation) and the average of the evaluations from the four pairings are averaged and worth 10% of the grade in the course. The students are warned to make the peer evaluation confidential and if students are discovered to be discussing them with each other they will get a group evaluation grade deduction. By shuffling the groups and not disclosing the group evaluation grade until the end of the semester the students do not know which people might have given them a bad peer evaluation score if they end up with a bad overall grade. Keeping the anonymity of peer evaluations is a critical aspect because it emboldens people to be honest on them without repercussions.

The peer evaluation and self-evaluation were implemented using a custom-designed Canvas survey tool so that the data can be downloaded and processed by a program that does statistical analysis on the responses. If there is a discrepancy that is greater than 20% between the self-evaluation and the peer evaluation of their group partner for any of the four categories shown above, then it will be flagged and teaching assistant (TA) or instructor observations *might* be used in some situations to throw out the score that appears to be wrong. For example, if someone gives themselves a 2 on the professionalism category, but their partner gives them a 1.5, then the average grade of 1.75 should be given. However, since there is a discrepancy greater than 20% that grade would be flagged, and the facts would be analyzed to decide how to proceed. If it was clearly observed that they frequently didn't show up for lab or were always late, then we would throw out the self-score of 2 and the professionalism score would be a 1.5. If there is not a clear reason for throwing out one of the grades, then the average is used. This discrepancy flag system provides a mechanism to increase the fairness and accuracy of the grades. It provides a safeguard against someone being overly critical of their partner on the peer-evaluation and a way to stop an undeserving student that tries to pad their grade by exaggerating how well they did in the group on the self-evaluation.

V. Results

When considering how to form groups it is a logical assertion that most students would much rather pick their own lab partner (i.e. self-selection) and stick with them the whole semester, so if they were asked whether they thought the shuffling group process was a good idea, the result would be assumed to be negative (i.e. a Likert average score less than 3).

Using a 5-point Likert scale survey in the anonymous course evaluations, the students responded to the following statement regarding the group shuffling process:

"*In the end, I think the structure that was used to rotate lab partners was a good idea.*"

Table III shows the responses to this question over the last four semesters. It is important to note that the students are aware that the instructor does not see the results from the anonymous course evaluations until after the grades come out, so there should not be any "professor pleasing" bias in the data. The *N* column shows the number of students that filled out the evaluations and the *Total* column shows how many students were in the course each semester. The ratio of N to Total depends largely on how many times the students were reminded to fill out the evaluations in that particular semester. There is no mechanism to force students to complete the course evaluations at OU, so getting only a subset of the students is a normal situation. The *% 1 or 2* column shows the percentage of the responses that were negative and the *% 4 or 5* column shows the number of responses that were positive. The neutral responses (i.e. 3) can be determined by adding the positive and negative responses and subtracting them from 100.

Table III – Group Shuffling Process Favorability Data

Cohort	N	Total	AVG	% 1 or 2	% 4 or 5
Spring 2018	45	66	3.93	8.88	71.12
Fall 2018	56	58	4.04	8.93	78.57
Spring 2019	38	59	4.26	5.26	84.21
Fall 2019	28	56	4.50	0	96.43
Total	167	239	4.14	6.58	80.84

This data shows that the students overwhelmingly thought the group shuffling method was a good idea. The data also shows that the average response score increased each semester. This can be explained by the improvements that have been made to the process each semester. The two biggest changes that were implemented were the seating chart policy that was introduced prior to Spring 2019 and the total number of partners was reduced from five to four beginning in Fall 2019. Having four different groups appears to be the optimal number in this course because it allows the students enough time together to develop as a team, but still allows the shuffling methodology to work properly.

The students were also asked to respond to the following statement regarding peer reviews in the anonymous course evaluations:

"The peer review process for the robot project and the other labs motivated me to do my best."

The responses to this question over the last four semesters are shown in Table IV.

Table IV – Motivational Effect of Peer Reviews Data

Cohort	N	Total	AVG	% 1 or 2	% 4 or 5
Spring 2018	45	66	3.71	11.11	60
Fall 2018	57	58	3.56	15.79	56.14
Spring 2019	38	59	3.66	18.42	60.53
Fall 2019	28	56	4.07	3.57	71.43
Total	168	239	3.71	13.09	60.72

To be clear, the group evaluations are referred to as "peer reviews" in the syllabus, so from the students' perspective this data refers to the entire system of performing both the self-evaluation and the peer evaluation. It is clear from the data that the students feel the group evaluations increase their motivation. Another important detail of the group formation structure that motivates students to be good group members is the survey to select their 4th lab partner. The students know that if they are not the type of group member that causes people to pick them as a high priority on their robot partner preference, then they will likely not get one of their top choices and might end up with someone else that no one selected as a high priority. This motivation is something that many of the students might not have taken into account when they responded to the generic statement about the peer review process's effect on motivation, but the motivational benefits have been observed to be profound. It is similar to the dynamic where a student tries to impress their boss on an internship in hopes they can get a full-time job offer.

VI. Conclusions

This paper shows an effective way to design a group-based curriculum for engineering lab courses that meet in physical lab spaces. The students are motivated to be a good team member through a group evaluation tool and a group shuffling process that rewards students that do a good job. While this study focused only on groups of two people, the process could also be implemented with larger group sizes. While teaching a course with a group-based structure is often more work for the instructor, it provides a great benefit to the students and reduces operational and support cost. Engineering students need to gain as much experience working on teams as possible, so they are prepared for the teaming environment that is prevalent in industry. For this reason, educators should try to incorporate a group-based course design that includes ample individual assignments whenever it is possible. It was found that a 50/50 model, where half of the grade came from group work and half came from individual work functioned well in ECE3873.

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