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A Novel Approach to Purposeful Team Formation

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Abstract

This evidence-based research paper presents a new approach to team formation in engineering courses. Teamwork plays a pivotal role in active learning and holds the potential to enhance the inclusivity and equity of educational environments. However, engineering students hailing from diverse backgrounds with varying skills, experiences, and learning preferences pose challenges in forming balanced and cohesive teams. While some students exhibit strong preferences for team members, others are open to diverse collaborations. Accommodating these preferences during team formation is a complex task.

This paper discusses a novel approach to team formation, shifting from random, self, and student feature-based selection to purposeful grouping to maximize new connections between students. An example is provided to demonstrate the different team formation variations:

- Maximizing New Connections: Encouraging students to collaborate with as many unfamiliar peers as possible.
- Pre-assigning Students: Satisfying students' strong preferences or need to be on a specific team.
- Balancing Teams: Consideration of specific student characteristics, such as forming diverse teams.
- Forcing Teammates: Ensuring specific students collaborate on a team as needed.
- Averting Teammates: Allowing students to express their preferences to avoid certain teammates.

By intentionally constructing teams to circumvent pre-existing intra-team connections, this method significantly fosters the formation of novel connections and therefore enriches the learning experience for students. Examples of how to implement the approach using a spreadsheet and a freely available solver plug-in are presented, including different team formation scenarios.

In summary, the presented team formation method opens new avenues for engineering education, offering a practical strategy to enhance teamwork, foster inclusivity, and expedite network expansion among students. Since the method is based on mathematical optimization, it eliminates biases and is therefore ideal for engineering educational research projects.

Key Words: Collaborative learning, team formation, social networks in education, mathematical optimization

1. Introduction

In engineering education, teamwork plays a vital role in shaping the educational experience and preparing future engineers for real-world challenges. Collaborative efforts and effective communication within engineering teams not only enhance problem-solving skills but also foster innovation and creativity in finding solutions to complex engineering problems. Engineers rarely work in isolation in the professional environment. They are frequently part of multidisciplinary teams where collaboration is vital for problem solving and project completion. In addition to technical expertise, engineering demands strong interpersonal, leadership, and conflict-resolution abilities. In the classroom, teamwork fosters the development of technical as well as soft skills that are essential for success in the workplace [1], [2]. Teamwork also exposes college students to diverse viewpoints and concepts, fostering creativity and ingenuity [3], [4]. It helps students appreciate the variety of ideas from others and encourages them to think critically and challenge their own beliefs. This prepares students to effectively collaborate with people from various cultures and backgrounds [5]. Teamwork usually involves active learning and engagement between students. Students often learn better when they can discuss concepts, debate ideas, and solve problems collaboratively, rather than passively listening to lectures or just solving a problem by themselves [6], [7]. Working in teams requires students to be responsible for their part of the work and accountable to their team members. This sense of responsibility and accountability is crucial in college and, of course, later in their professional lives. Working in a team during an engineering student's academic career fosters early network building and can strengthen their sense of identity within the major and the university. It's common for alumni to say that they remain in touch with the friends they met during their undergraduate years in college. Lastly, all accredited engineering programs must incorporate teamwork into their curriculum since the Accreditation Board for Engineering and Technology (ABET) mandates under Criterion 3 that student outcomes include "an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives." [8]. In summary, teamwork in engineering education is not just a pedagogical tool but a fundamental aspect of preparing students for the realities of the engineering profession, where collaboration, communication, and diverse perspectives are key to success.

One of the challenges when implementing team-based pedagogies is how to assign students to teams. The objective is to form balanced, cohesive, and high-functioning teams. Some team-based pedagogies have mechanisms incorporated to address issues such as when one or more students perform all of the work in a team while another student performs little to no effort but reaps the benefits, i.e., grade, of the team [9]. The following is an overview of typical team formation methods:

<u>Random assignments:</u> The instructor randomly assigns students to teams. This is a quick and easy method, but it can result in unbalanced teams in terms of skills, motivation, and cohesiveness, as well as a negative team experience [10].

<u>Self-selection:</u> Instructors let students choose with whom they want to be on a team. Self-selection can lead to a better team experience for students, better group dynamics, and perceived better learning [10]–[13]. Self-selection, however, can reinforce cliques, limit diversity in teams, and may not encourage students to work with new peers.

The following methods can all be categorized as team formation by instructor [14] - [16]:

Skill Assessment: Teams are formed based on the instructor's assessment of students' skills and abilities. This method can create balanced teams in terms of abilities and skills, but since it is based on only certain skills and/or abilities, it may also lead to the formation of homogeneous groups lacking diversity or other important factors such as teamwork, communication, and leadership capabilities are overlooked.

Heterogeneous Grouping: Instructors deliberately create teams with diverse skill sets, backgrounds, or academic performance. This method encourages learning from peers, diversity of thought, and can mimic real-world work environments. To avoid conflict or imbalanced workload distribution, heterogeneous teams may need additional management by the instructor after team formation.

Personality-Based Teams: Instructors assign students to teams based on certain personality traits to form teams with balanced personality types. This can lead to well-functioning teams with a mix of leadership styles and interpersonal dynamics. However, to assess personality traits, some form of personality test or inventory must be applied. Issues with these tests or inventories can include reliability and validity, as well as the potential for bias and cultural differences to affect results.

Role-Based Assignment: Instructors form teams by roles, e.g., team manager, project coordinator, technical lead, etc. This method ensures the assignment of roles across teams and can match students to roles suited to their strengths. However, it can lead to pigeonholing students into specific roles and limiting their experience in other areas.

Beyond the methods described above, there are other less common approaches to team formation, and it is not uncommon for methods to be combined. Tools like CAMTE Team-Maker [17] are available, which use a max-min heuristic to create teams based on various criteria set by instructors. However, our proposed strategy offers a novel approach. It is grounded in a mathematical model designed to optimize team assignments, with a primary focus on maximizing new connections between students while also accommodating other team formation considerations.

2. Methodology

A novel approach to team formation in engineering courses involves first determining who knows who in a given course and then optimizing team allocations using a mathematical model. The details about the mathematical model are described in [18] and are not repeated here. The emphasis is on the use of this new technique in engineering education for team creation, as well as understanding its advantages and disadvantages.

Next, we describe the steps to implement the approach in any engineering course. We illustrate the implementation with a small class of 12 students. The small class size example illustrates the procedure better and is easier to follow than using a larger class size example.

3. Implementation

The first stage is to identify any existing relationships between students in a course. This can be accomplished with a simple survey asking students who they know in class. A course matrix, for example, can be created in a spreadsheet, and students are asked to enter 1 in a cell when they know a classmate. An example is shown in Figure 1.

#		1	2	3	4	5	6	7	8	9	10	11	12
	Names	Emily	Michael	Olivia	Ethan	Sophia	Daniel	Ava	Lucas	Mia	Alexander	Isabella	William
1	Emily	x		1			1			1			
2	Michael		x		1	1			1				
3	Olivia	1		x			1					1	
4	Ethan		1		x			1			1	1	1
5	Sophia		1			x		1			1	1	
6	Daniel	1		1			x		1			1	
7	Ava				1	1		x	1				
8	Lucas		1				1	1	x				
9	Mia	1								x			
10	Alexander				1	1					x		
11	Isabella			1	1	1	1					x	
12	William				1								x

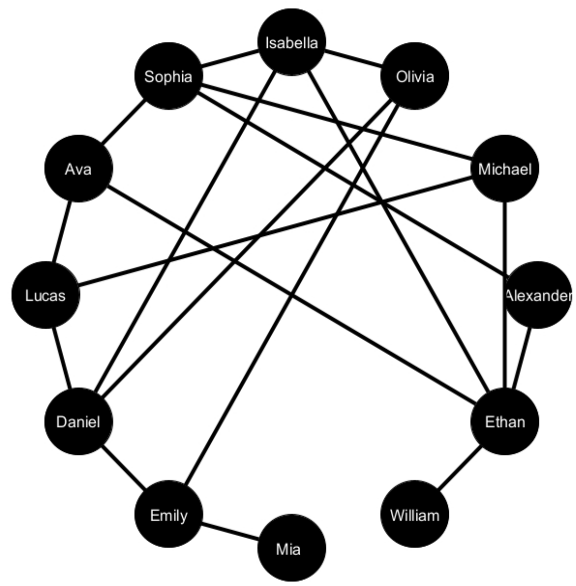

Figure 1: Example of a class connectivity matrix before team formation.

The class connectivity matrix shown in Figure 1 serves as the input to the mathematical model. For small class sizes up to 31 students, this can be accomplished using MS Excel and the freely available OpenSolver plug-in [19]. For larger class sizes, commercial solvers may be used. The template spreadsheet used for the examples presented here is available from the authors upon request, including a user guide with step-by-step instructions [20]. Here, we will present the results. The following scenarios are used to demonstrate the application of the model using the example class in Figure 1:

I. Maximizing New Connections: team size of 3 students per team (4 teams total)

II. Pre-assigning Students to Teams: Emily in team 1, Isabella in team 2, Mia in team 3

III. Balancing Teams: 2 female students per team (Emily, Olivia, Sophia, Ava, Mia, Isabella)

IV. Forcing Teammates: Michael and Alexander on a team and Mia and Ava on a team

V. Averting Teammates: Emily does not want to be on the same team as Olivia; Isabella doesn't want to be on a team with Daniel or Ethan; Ethan doesn't want to be on team with Michael, Alexander, William

I. Maximizing New Connections

The objective is to maximize the potential for students to make new connections, to get to know new people, and to increase their academic social network. In our example class, we see that Mia and William only know one other student in the class, whereas Ethan knows five other students in the class already. In order to demonstrate the capabilities of the optimal solution for team assignments, we will compare the results with those obtained from a random team assignment. As an illustration, we will allocate the 12 students randomly into four teams, as shown in Table 1. The results for the optimized team assignments are shown as well in Table 1.

Table 1: Random and optimized team assignments.

	Random Assignment	Optimized Assignment
Team 1	Ava, Isabella, Ethan	Lucas, Mia, Alexander
Team 2	Emily, Mia, William	Emily, Michael, Isabella
Team 3	Lucas, Daniel, Olivia	Ethan, Sophia, Daniel
Team 4	Alexander, Michael, Sophia	Olivia, Ava, William

Figure 2 shows a graphical representation of the random team and optimized team assignments. Initially, there were 18 connections between students in the class, denoted by the black solid lines in Figure 2. Based on the random team assignment, there are five new potential connections, denoted by the red dashed lines in Figure 2. The optimized team assignments show 12 new potential connections, demonstrating that the method effectively maximized the opportunity for students to meet students they had not previously known. The maximum number of new connections for a single team of N students is N(N-1)/2. For a team with three students, the maximum number of new connections is 3. Since we have four teams in our example in Table 1, the maximum number of possible new connections is indeed 12 which is a 60% increase over the initial connections.

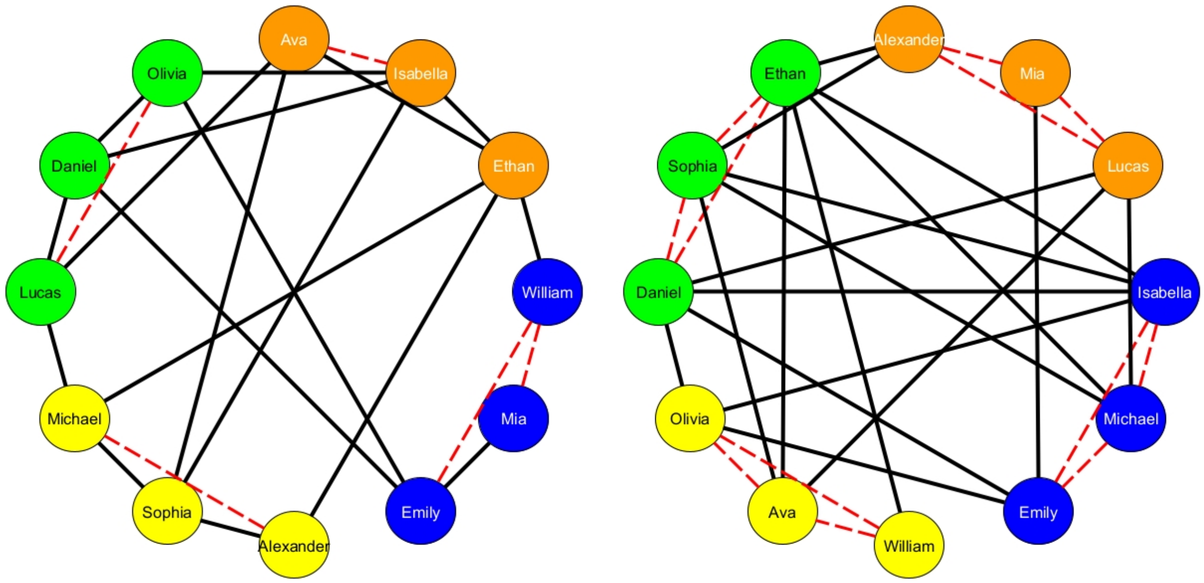

Figure 2: Random team assignments on the left; optimized team assignments on the right.

II. Pre-assigning Students to Teams

Sometimes specific students require placement on a particular team. For example, in the context of senior design projects, it may be necessary for a student to join a team that is sponsored by a company. This requirement could arise from the student's prior internship experience with the company, which has now presented a chance for a team of senior design students to collaborate on a project. Let us assume we have the following requirements: Emily has to be in team 1, Isabella has to be in team 2, and Mia has to be in team 3. Our previously optimized solution would not work because Emily and Isabella are on the same team, as shown in Table 1. This requires us to add new constraints to our model and re-run to solve for optimized team assignments. The results are shown in Table 2 and Figure 3.

Table 2: Pre-assigning students and optimized team assignments.

	Pre-assign Students
Team 1	**Emily**, Ethan, Lucas
Team 2	**Isabella**, Alexander, Michael
Team 3	**Mia**, Ava, Olivia
Team 4	William, Daniel, Sophia

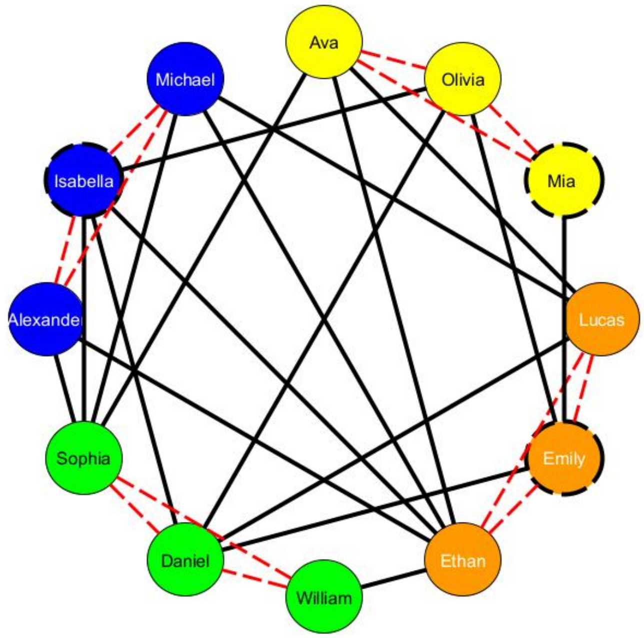

Figure 3: Optimized result when pre-assigning Emily, Isabella and Mia to teams 1, 2 and 3 respectively.

As Figure 3 shows, the optimized team assignments resulted in 12 new potential connections, demonstrating that the method effectively maximized the opportunity for students to meet students they had not previously known, even with the constraints of pre-assigning Emily, Isabella and Mia to specific teams.

III. Balancing Teams

Team assignments may necessitate the consideration of specific student characteristics, such as forming diverse teams based on factors including students' majors, skills, personal backgrounds, genders, socioeconomic standings, and underrepresented minority (URM) status, just to name a few. Research has shown that when students engage with diverse peers, these interactions frequently result in learning, cognitive growth and better learning outcomes [21-24].

Let's consider a scenario where we aim to achieve gender balance in teams. We now add the constraint that each team should have at least two female students. In our example class, we know that there are six female students (we assume that Emily, Olivia, Sophia, Ava, Mia and Isabella identify as female), and therefore it is not possible to have two female students per team when there are four teams. So, we will adjust to having three teams with four students each and add the constraint that each team has two female students. The optimized team assignment (maximizing new connections between students) is shown in Table 3 and Figure 4.

Table 3: Optimized team assignments with two female students per team.

	Balanced Teams Two female students per team
Team 1	Sophia, Mia, Ethan, Daniel,
Team 2	Emily, Isabella, Lucas, Alexander
Team 3	Ava, Olivia, Michael, William

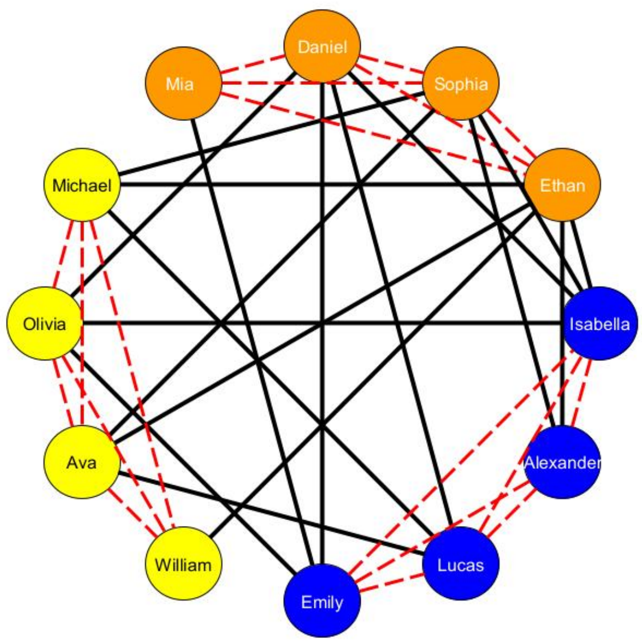

Figure 4: Optimized result when balancing teams by gender with two female students per team.

As shown in Figure 4, the optimized team assignments resulted in 18 new potential connections. Again, it demonstrates that the model found a solution that maximizes the opportunity for students to meet students they had not previously known while balancing the teams to have two female students per team.

<u>IV. Forcing Teammates</u>

In some circumstances, two or more students must or want to work together on the same team. This can be due to the project's nature (e.g., industry collaboration, senior design project) or to unique student circumstances. Let’s assume we asked our students in our example class with whom they want to work together, and as a result, Michael and Alexander want to be on a team and Mia and Ava want to be on a team. Including these constraints in our model, the results are shown in Table 4 and Figure 5.

Table 4: Optimized team assignments with forcing teammates

	Forcing Teammates	
	Four Teams	**Three Teams**
Team 1	**Michael**, **Alexander**, Olivia	**Michael**, **Alexander**, Emily, Isabella
Team 2	**Mia**, **Ava**, William	**Mia**, **Ava**, Daniel, William
Team 3	Emily, Lucas, Isabella	Olivia, Sophia, Ethan, Lucas
Team 4	Ethan, Sophia, Daniel	

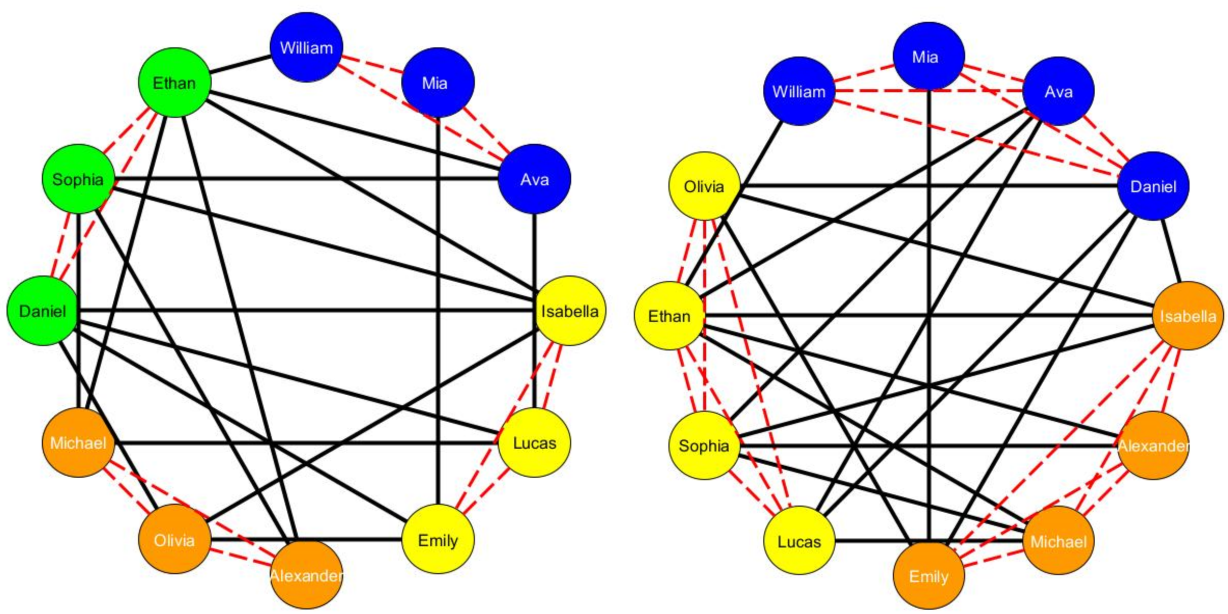

Figure 5: Optimized team assignments forcing teammates.

As shown in Figure 5, the model optimized team assignments with the constraint of having Michael and Alexander on a team and Mia and Ava on a team. Two cases are presented, one with four teams and one with three teams. Both cases resulted in team assignments with the greatest number of new potential connections conceivable: 12 new connections for the four teams' case and 18 new connections for the three teams' case.

<u>V. Averting Teammates</u>

Averting teammates is the inverse of forcing teammates. Sometimes students express a desire not to be on a team with a specific student or students. For a variety of reasons, instructors may choose to avoid pairing certain students as well. Let's assume we got the following feedback:

Emily does not want to be on the same team as Olivia; Isabella doesn't want to be on a team with Daniel or Ethan; Ethan doesn't want to be on team with Michael, Alexander, William. Applying the constraints to the model and solving gives the results shown in Table 5 and Figure 6.

Table 5: Optimized team assignments with averting teammates.

	Averting Teammates
Team 1	Emily, Michael, Isabella
Team 2	Olivia, Lucas, Alexander
Team 3	Daniel, Ava, William
Team 4	Ethan, Sophia, Mia

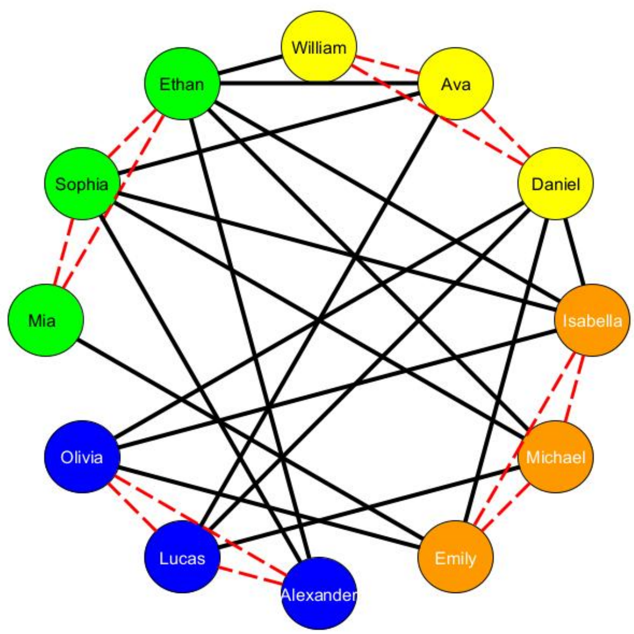

Figure 6: Optimized team assignments with averting teammates.

As shown in Figure 6, the model discovered optimal team assignments that maximize new potential connections between students (12 new connections) while preventing students from being placed in teams with students they do not want to be with.

5. Discussion

The challenge for instructors who are using collaborative pedagogies or teaching courses with group work is how to assign students to teams. The novel approach presented here has the objective of assigning students to teams to maximize the students' opportunities to get to know other students they do not know. Engineering students hailing from diverse backgrounds and experiences pose challenges in forming balanced and cohesive teams. While some students exhibit strong preferences for team members, others are open to diverse collaborations. Based on project requirements or instructor needs, there are other factors that would need to be considered to form teams. The new approach can account for all these factors by adding constraints to the model.

The presented method for team formation offers several advantages. It can easily be implemented by anyone using a spreadsheet approach and a freely available solver plug-in [20]. This method promotes an unbiased team formation approach, ensuring fairness and objectivity. It is especially effective in expanding students' social networks by maximizing new interactions; students are encouraged to collaborate with as many unfamiliar peers as possible, thereby broadening their academic and social horizons. Furthermore, the procedure is versatile, accommodating various constraints such as pre-assigned students, balanced team compositions, and specific preferences for team members. It also supports the formation of diverse teams, allowing instructors to define and apply their own criteria for diversity. By facilitating repeated team reformation throughout a term or across different courses, this method significantly enhances students' social networks, fostering long-term connections. Additionally, the objective nature of this team formation method can enhance inclusivity and equality, offering a robust alternative to subjective methods like self-selection.

While the presented method for team formation presents several benefits, it also has some limitations. The spreadsheet approach using the OpenSolver plug-in is effective in yielding results within a reasonable time frame for class sizes up to 31 students. For larger classes, alternative computational methods and possibly commercial solvers may be required, though dividing the class into smaller sections of 30 students each can be a workaround. However, this may compromise the optimization of results, even though it still offers improvements over traditional team assignment methods, particularly in terms of fostering new student connections. Another limitation is that an excessive number of constraints can render the problem unsolvable. This issue is further compounded in classes where social networks are already dense or complex, leading to unavoidable situations where students may end up on teams with peers they already know. The accuracy of input values, which are based on the student survey assessing mutual acquaintances, is dependent on response rates. Low participation can lead to inadequate data, potentially placing students in teams with known peers due to incomplete survey information. Therefore, it is important to encourage complete and accurate survey participation. Lastly, there is a risk of introducing bias through inappropriate constraints set by instructors. Factors such as demographic data, socioeconomic status, and underrepresented minority (URM) status require careful consideration to avoid unintentional biases.

The first implementation of the novel approach within college courses yielded a notable increase in the formation of new interconnections among students [18]. The presented study conducted a comparison between four control classes comprising a total of 95 students and an experimental group consisting of six courses with a total of 158 students. In the experimental group, team assignments were optimized using the new data-driven approach. The findings show that implementing the data-driven approach resulted in a twofold increase in the number of new connections between students, indicating that students had the opportunity to interact and become acquainted with twice as many peers as they would have with self-selected team assignments.

6. Conclusion

This study provides a novel approach to team formation in engineering education, emphasizing a method that significantly enhances the formation of new connections among students. This approach utilizes a spreadsheet and a freely available solver plug-in, making it easy to implement. It ensures that students collaborate with a wide range of peers, thus broadening their academic and social networks. Furthermore, it allows for the accommodation of various constraints, such as pre-assigned students and the balancing of teams, to promote inclusivity and diversity in team compositions. The approach is particularly effective for small class sizes, with some limitations noted for larger classes. The possibility of bias due to inappropriate constraints set by instructors is also acknowledged. Research studies comparing this method with traditional team formation methods in diverse educational settings could provide deeper insights regarding the effectiveness of this approach.

In summary, this novel approach to team formation presents a promising avenue for enhancing teamwork and expanding student networks in engineering education. By fostering more diverse and inclusive team environments, this method not only contributes to improved learning outcomes but also prepares students for the collaborative demands of the professional engineering landscape. The study paves the way for further research and development in the areas of student teamwork and engineering student social network development. Future research on inclusivity and equity in the learning environment can benefit from the novel method of team formation since it takes away the ambiguity of how teams are formed for research projects. In addition, future studies could explore the long-term benefits of putting together diverse teams and how students' learning improves when they expand their social network.

10. References

[1] R. Felder, D. Woods, J. Stice, and A. Rugarcia, "The future of engineering education: Part 2. Teaching methods that work," Chemical Engineering Education, vol. 34, pp. 26-39, 2000.

[2] B.A. Oakley, R.M. Felder, R. Brent, and I. Elhajj, "Turning student groups into effective teams," Journal of Student Centered Learning, vol. 2, pp. 9-34, 2004.

[3] L. Hong and S.E. Page, "Groups of diverse problem solvers can outperform groups of high-ability problem solvers," Proceedings of the National Academy of Sciences, vol. 101, pp. 16385-16389, 2004.

[4] H.H. Friedman, L.W. Friedman, and C. Leverton, "Increase diversity to boost creativity and enhance problem solving," Psychosociological Issues in Human Resource Management, vol. 4, 2016, p. 7.

[5] K. Forslund Frykedal and E. Hammar Chiriac, "Student collaboration in group work: Inclusion as participation," International Journal of Disability, Development and Education, vol. 65, pp. 183-198, 2018.

[6] A. Burke, "Group work: How to use groups effectively," Journal of Effective Teaching, vol. 11, pp. 87-95, 2011.

[7] L. Springer, M.E. Stanne, and S.S. Donovan, "Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis," Review of Educational Research, vol. 69, pp. 21-51, 1999.

[8] ABET, "Criteria for Accrediting Engineering Programs, 2022-2023," [Online]. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2022-2023/.

[9] J. Mott and S. Peuker, "Achieving High Functioning Teams Using Team Based Learning in Flipped Classrooms," Paper presented at the 2015 ASEE Annual Conference & Exposition, Seattle, Washington, 2015, doi: 10.18260/p.23482.

[10] D.R. Bacon, K.A. Stewart, and W.S. Silver, "Lessons from the best and worst student team experiences: How a teacher can make the difference," Journal of Management Education, vol. 23, pp. 467-488, 1999.

[11] K.J. Chapman, M. Meuter, D. Toy, and L. Wright, "Can't we pick our own groups? The influence of group selection method on group dynamics and outcomes," Journal of Management Education, vol. 30, pp. 557-569, 2006.

[12] S.A. Myers, "Students' perceptions of classroom group work as a function of group member selection," Communication Teacher, vol. 26, pp. 50-64, 2012.

[13] S.A. Rusticus and B.J. Justus, "Comparing student- and teacher-formed teams on group dynamics, satisfaction, and performance," Small Group Research, vol. 50, pp. 443-457, 2019.

[14] B. Rienties, P. Alcott, and D. Jindal-Snape, "To let students self-select or not: That is the question for teachers of culturally diverse groups," Journal of Studies in International Education, vol. 18, pp. 64-83, 2014.

[15] S.B. Feichtner and E.A. Davis, "Why some groups fail: a survey of students' experiences with learning groups," Organizational Behavior Teaching Review, vol. 9, pp. 58-73, 1984.

[16] B.A. Oakley, R.M. Felder, R. Brent, and I. Elhajj, "Turning student groups into effective teams," Journal of Student Centered Learning, vol. 2, pp. 9-34, 2004.

[17] R. Layton, M. Loughry, M. Ohland, and G. Ricco, "Design and validation of a web-based system for assigning members to teams using instructor-specified criteria," Advances in Engineering Education. 2. 1-9, 2010.

[18] A. Hill and S. Peuker, "Expanding students' social networks via optimized team assignments," Annals of Operations Research, 332, 1107–1131, 2024.

[19] A. J. Mason, "OpenSolver – An Open Source Add-in to Solve Linear and Integer Programmes in Excel", Operations Research Proceedings, pp. 401–406, 2012.

[20] A. Hill and S. Peuker , "User Guide - A Novel Approach to Purposeful Team Formation", including MS Excel Spreadsheet available upon request from the authors.

[21] N. A. Bowman, "College diversity experiences and cognitive development: A meta-analysis," Review of Educational Research, vol. 80, no. 1, pp. 4–33, 2010.

[22] M. J. Chang, Quality matters: Achieving benefits associated with racial diversity. Kirwin Institute for the Study of Race and Ethnicity, The Ohio State University, 2011.

[23] R. J. Crisp and R. N. Turner, "Cognitive adaptation to the experience of social and cultural diversity," Psychological Bulletin, vol. 137, pp. 242–266, 2011.

[24] N. Bowman, C. Logel, J. Lacosse, E. A. Canning, K. T. U. Emerson, and M. C. Murphy, "The Role of Minoritized Student Representation in Promoting Achievement and Equity Within College STEM Courses," AERA Open, vol. 9, 2023.