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Automating Project Team Formation with Heterogeneous Project Preferences and Skill Mix Constraints

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Session XXXX

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Abstract

Developing teamwork skills has been identified as an essential educational outcome for preparing graduates to enter the professional practice of engineering. At our institution, a two-semester course sequence in Engineering Design is a primary vehicle for both developing and assessing students' teamwork skills. Although these courses share many structural similarities, offering a broad variety of project topics in the second course adds additional layers of complexity to the team formation task. More specifically, differences in skill mix requirements between projects, combined with consideration of students' individual project topic preferences during team formation, pose challenges that are not addressed by the suite of team formation tools that is currently available.

In this paper, we discuss the development and application of a heuristic optimization algorithm that extends the capabilities of available team formation tools. This tool effectively balances team sizes and diversity profiles within teams while also addressing project-specific skill mix constraints and students' individual project preferences. Comparing results of this team formation tool with results of incumbent team formation tools shows that our tool satisfies project-specific skill mix constraints and effectively matches students to preferred project opportunities (placing 92% of students on one of their three most preferred project choices over four semesters of application) while offering comparable performance to off-the-shelf project team formation systems in terms of balancing team sizes and diversity profiles within teams below problem scale thresholds of 12 project teams and approximately 70 students. Post hoc analysis of student performance indicates that forming project teams with this tool fosters project team environments that offer students from underrepresented group equal (if not greater) opportunities to succeed. Our analysis reveals several statistically significant differences in performance by gender where female students outperform male students in specific areas. These effects may be attributable to exogenous factors consistent with previously reported results.

Introduction

Developing teamwork skills has been established as an essential educational outcome for preparing graduates to enter the professional practice of engineering. For accreditation periods prior to 2019-2020, this was reflected in the Student Outcomes of the ABET Criteria for Accrediting Engineering Programs as "an ability to function on multidisciplinary teams."[1] Beginning with the 2019-2020 accreditation period, the definition of teamwork in ABET Student Outcomes has been extended as follows[2]:

> "an ability to function effectively on a team whose members together provide leadership [and] create a collaborative and ***inclusive environment****…*"

This addresses the question of *why* team project experiences are incorporated in engineering curricula and (to some degree) *how* to form the teams. The open question is *where* to include these team project experiences in the engineering curricula. At our institution, a two-semester course sequence in Engineering Design is a primary vehicle for both developing and assessing students' teamwork skills. These courses share many structural similarities; however, there are several key differences in the formats of these courses with substantial ramifications on project team formation methods as discussed below.

Both Engineering Design I and II are required courses for all engineering majors. In the courses, teams are deliberately formed by combining students across both fields of study and demographics, providing a richer student experience and ensuring peer support for students from underrepresented groups[3]. Breakdowns of fields of study and demographics within our School of Engineering are shown in Table 1.

Field of Study	Mechanical Engineering (ME)	61%
	Electrical & Computer Engineering (ECE)	29%
	General Engineering (EGR)	10%
Gender	Male	77%
	Female	23%
Race and Ethnicity	White	64%
	Hispanic or Latino	16%
	Asian	9%
	Black or African American	6%
	Other	5%

Table 1: Student Mix by Major and Demographics

In both courses, teams composed of 5-6 students design devices to satisfy specified sets of objectives and constraints, bringing their projects to conclusion by furnishing evidence that their devices perform as required. Teams communicate design development through a combination of oral presentations, written submittals, and physical demonstrations. Team members also provide feedback to one another through a series of regular peer evaluations over the course of the project.

Specifically for the task of team formation, the key difference between these courses is the distribution of project topics. In Engineering Design I, a new design challenge is developed each semester by the course instructors and each project team in the course addresses this common design challenge. In Engineering Design II, the course coordinator solicits a set of design challenges each semester from a broad cross-section of projects clients consisting of approximately 52% industry-sponsored projects, 23% service-learning projects, 11% student design club projects and 14% projects supporting faculty research and nearly every team addresses a unique design challenge. Traditionally, at our institution students' individual preferences for project topics have been considered during project team formation on the premise that matching students with project topics of personal interest increases student engagement and we seek to maintain this tradition. The common design challenge in Engineering Design I allows for team composition with a common skill mix profile, or more specifically, for even distribution of students from each field of study across all teams. However, the broad spectrum of design challenges addressed each semester in Engineering Design II leads to significant differences in skill mix requirements between projects, usually due to varying needs for electronic and control system design across projects. These differences in skill mix requirements, combined with consideration of students' individual project topic preferences during team formation, add additional layers of complexity to team formation in Engineering Design II.

For our institution, the ideal platform would be a single commercial-off-the-shelf (COTS) tool for project team formation in both Engineering Design I and II that provides the following capabilities:

- Balanced distribution of student demographics within teams (as applied in both Engineering Design I and II)
- Application of either a common skill mix profile (as applied in Engineering Design I) or project-specific skill mix profiles (as applied in Engineering Design II)
- Consideration of students' project topic preferences (as applied in Engineering Design II)

In the next section, the capabilities of several off-the-shelf team formation tools are discussed with emphasis on these capabilities.

Prior Work

A variety of COTS team formation tools are available, each with its own constraints and intended purposes. The tools evaluated in this work may be broadly classified by their primary functionality as Random tools, Student Characteristic tools, and Project Preference tools. A more detailed discussion of available tools within each of these categories follows below.

Random Tools

Tools in this class, such as Group Maker[4] and Random Team Generator[5], randomly assign students to groups. They are typically web-based, delivered either online or as web browser extensions, and allow rapid formation of student teams. These tools offer limited degrees of control over team formation parameters, typically allowing the user to specify either the number of teams or the target team size. A random team formation tool seems best suited to frequent application for brief team-based exercises and not well-suited to forming teams for long-term projects. Tools in this class are considered in this work primarily to provide a basis for comparison of team formation tool performance.

Student Characteristic Tools

A prevent tool in this class is the Comprehensive Assessment for Team-Member Effectiveness (CATME)[6], a web-based system developed at Purdue University and used extensively throughout the academic community. To support its Team-Maker functionality, CATME includes a battery of survey questions for gathering student data including demographics, GPA, leadership preferences, extracurricular activities, schedule availability, and more. Users are provided a series of granular scales for weighting the influence of factors during team formation, ranging from no influence to heavy emphasis. For example, for the gender factor, a user may stipulate that any given team cannot have only one female or that one gender cannot outnumber another.

As a comprehensive team effectiveness solution, CATME also includes a sophisticated Peer-Evaluation functionality[7] in which students provide both written feedback and assessments of each other's performance using a rubric of five dimensions that contribute to the effectiveness of teams:

- Contributing to the Team's Work
- Interacting with Teammates
- Keeping the Team on Track
- Expecting Quality
- Having Relevant Knowledge, Skills, and Abilities

Peer Evaluation reports generated by CATME include both raw data, consisting of performance ratings on five-point scales specifically tailored to each teamwork dimension, and a Performance Adjustment Factor for each student in which teammates' ratings across all five teamwork dimensions are aggregated into a single normalized index. A Performance Adjustment Factor equal to 1 may be interpreted as contribution on par relative to other members of the team, greater than 1 for contribution above par, and less than 1 for contribution below par.

Our institution holds a site license for CATME and its Team-Maker and Peer-Evaluation capabilities are applied in multiple courses within the School of Engineering and beyond. Although the CATME Team-Maker functionality does not support the specific needs of Engineering Design II, specifically in the areas of project-specific skill mix constraints and incorporation of students' individual project preferences, CATME Peer-Evaluation is the preferred peer evaluation tool among the Engineering Design II instructors. For Engineering Design I, both the Team-Maker and Peer-Evaluation functions in CATME are aligned with the structure and objectives of the course and are directly applicable. However, it is noteworthy that off-the-shelf products offering comparable similar functionality are available. Gruepr[8] is available as an alternative for team formation as is Teammates[8] for peer evaluation.

Project Preference Tools

Poll and Match: The Poll and Match[10] tool provides a means to form teams using students' project preferences. However, it does not support consideration of any additional student characteristics, such as demographics, and data input functionality is limited to creating a student survey and inviting students to complete it via e-mail. As such, it neither meets the requirements for team formation in Engineering Design II nor supports parsing input data from previous semesters as required for benchmarking its performance versus other tools.

Each of the team formation tools reviewed in this section come with unique combinations of advantages and limitations. Of note, although many of the COTS tools reviewed in this work support a single function required for team formation in Engineering Design II (such as demographic/gender diversity <u>or</u> project preference), none of them combine all required functions into a single COTS solution (e.g., demographic/gender diversity <u>and</u> project preference). This is our motivation for developing the new tool discussed in the next section.

Approach

In this section, we describe the development and embodiment of our methods for data collection and team formation. Henceforth, we refer to the combined embodiment of our methods as the BES Tool.

<u>Data Collection</u>

Our data collection approach has evolved throughout development of the BES tool. Prior to the Fall 2020 semester, CATME was used to gather the required demographic and skill mix data and seriatim rankings of project preferences were collected through paper ballots completed by students after visiting a project information poster session. The information gathered from students through the CATME survey for potential use during team formation included:

- First and Last Name
- Gender
- Race / Ethnicity
- Student ID
- Self-Reported Major
- Self-Reported GPA

Two drawbacks of this approach became evident after the initial application. First, it incurred a burdensome level of pre-processing as project preferences from paper ballots were transcribed into a spreadsheet and merged with survey data downloaded from CATME. Second, it incurred a substantial level of additional work to reconcile inconsistencies in self-reported majors and GPAs. The most common inconsistencies in self-reported majors were appending or substituting a minor field of study (such as mathematics or business), a concentration within the major field of study (at our institution, these could include biomedical, petroleum, or humanitarian engineering) or even a career interest (such as automotive or aerospace engineering) for the major field of study. Likewise, students frequently reported a GPA within the major field of study in lieu of an overall GPA (typically when the former was higher).

The CATME Team-Maker survey includes many additional questions that we have intentionally omitted from the BES Tool data collection instruments. Our primary motivation is limiting the team formation problem to a tractable scope; as will be discussed later in the paper, we have found it quite challenging to consistently generate feasible solutions with the BES Tool using only the variables outlined above. Thus we have omitted some questions in the CATME Team-Maker survey (particularly those related to scheduling constraints, such as time commitments for other courses, sports, or employment) that hold appeal for improving solution quality. In addition, our observations of inconsistencies in students' self-reported data lead us to question the efficacy of applying students' self-assessments of capabilities (such as hands-on skills, shop skills, leadership styles and abilities, or software proficiency) to address skill set requirements in the team formation process.

In Fall 2020, operation under COVID-19 containment protocols drove substantial changes in format of Engineering Design courses and, in turn, triggered development of a new data collection process to support team formation in Engineering Design II. Social distancing requirements and direction to minimize handling of paper documents precluded the practices of hosting an in-person project information poster session and collecting project preference ballots on paper. Although collecting student characteristic data using CATME remained a viable option, the circumstances offered an attractive opportunity to develop and deploy a single solution for collecting both student characteristic and project preference data.

There are several commercial and freely available survey software solutions available that could be used to collect this data. In this work, we apply Qualtrics[11] to this end simply because our institution holds a site license and encourages its use. Like CATME, Qualtrics offers abilities to invite students to complete surveys via e-mail, enforce opening and closing times for the survey, send reminders for missing or incomplete responses, customize fields for information collection, and export survey data in neutral formats (e.g. comma separated variable) that may be readily parsed into other systems. In addition, Qualtrics offers abilities to automatically send reminder e-mails before the survey closes, customize survey opening and closing times, enforce data validation within survey fields, and provides a graphical interface for collecting seriatim ranking information. Specifically for data validation, Qualtrics offers abilities to require an answer to a question, require an answer in a specific format (e.g. numeric or plain text), or require an answer in pre-defined formats using radio buttons, rating scales, or drop-down menus. The seriatim ranking interface is particularly helpful for collecting students' individual project preferences in rank order. A screenshot of this interface as implemented in the Fall 2020 semester is shown below in Figure 1:

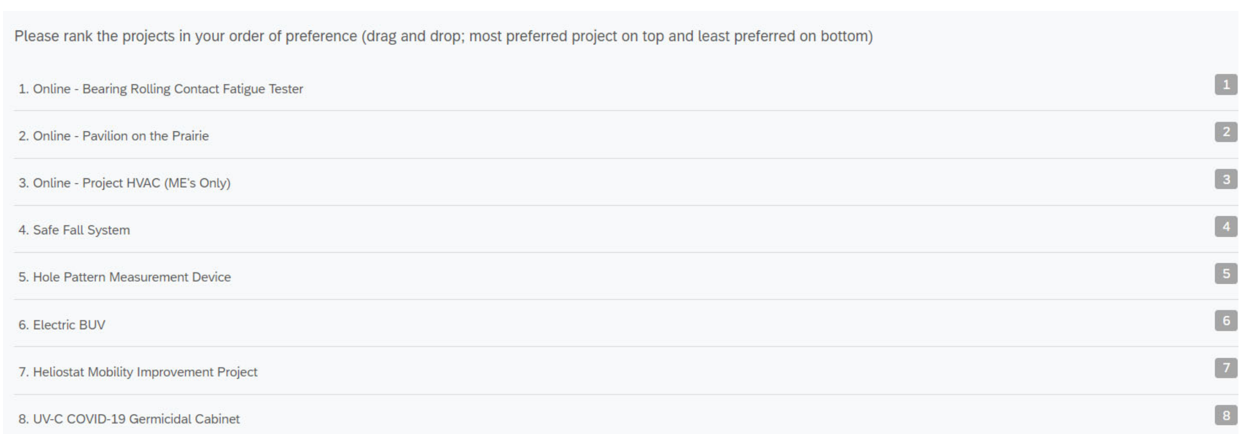

Figure 1: User Interface for Project Preference Ranking

Once the survey is complete, information collected from students is exported in a flat file with rows for each student and columns for each field, including preference orders for each project. At this point, the only additional information fields required are major field of study and overall GPA. At our institution, this data may also be exported from University information Academic records in a flat file. Using the Student ID as a unique identifier in each flat file, the VLOOKUP function in Excel may be used to generate a single flat file for input to the team formation algorithm.

This new approach allows students to submit self-reported demographic information and project preferences in a single operation, eliminates manual recording and transcription of data, and fully complies with institutional COVID-19 directives for maintaining social distance and minimizing handling of paper documents.

Team Formation

In this work, team formation is formulated as an optimization problem. The objective is to minimize the value of a penalty function comprised of the following components:

- **Ordinal Rankings**: In any given solution, this is the sum of students' seriatim rankings of the projects to which they have been assigned minus the number of students. Hence, if all students are assigned to their first-choice project, this component of the penalty function would equal zero.
- **Bounds on Team Size**: Within our program, the default lower and upper bounds on team size are 5 and 6 students respectively; however, the algorithm readily supports customization of upper and lower team size bounds on a project-by-project basis. In any given solution, this component of the penalty function is a count across teams of the number of students by which team sizes either exceed upper bounds or fall short of lower bounds. When the size of each team falls within its respective upper and lower bounds, this component of the penalty function equals zero.
- **Bounds on ECE membership**: Using similar logic to that described above for team size, for each project open to ECE majors, lower and upper bounds are established for the number of ECE majors to be placed on the team. In our program, the default lower and upper bounds for ECE team membership are 2 and 3 students respectively and, again, the algorithm readily supports customization of upper and lower bounds on a project-by-project basis. In any given solution, this component of the penalty function is a count across teams of the number of ECE students by which teams either exceed upper bounds or fall short of lower bounds. When the number of ECE students assigned to each team open to ECE membership falls within its respective upper and lower bounds, this component of the penalty function equals zero.
- **Diversity Rules**: These rules are evaluated simply by evaluating solutions on a team-by-team basis, setting a logical flags for the team if there is only one female member, and setting a separate logical flag if there is only one member from an underrepresented racial or ethnic group. This approach to managing racial and ethnic diversity within teams is not necessarily ideal, but given the demographic mix of students within our program, management of racial and ethnic diversity at finer levels of granularity makes the team formation problem intractable.

Components of the penalty function are then combined as a weighted sum. Weights may be adjusted between iterations as needed to improve solution quality.

The <u>design variables</u> in this problem are a string of integers, one for each student, with allowable values corresponding to available project opportunities. In our program, all projects are typically open to ME and EGR majors and, in this case, for a set of *n* project opportunities, the design variables for ME and EGR majors would be constrained to integer values between 1 and *n*. A helpful (though not strictly necessary) approach for defining allowable values of design variables for ECE majors is to assign a contiguous range of project numbers to projects open to ECE majors; for example, for a set of *n* project opportunities with *m* projects closed to ECE majors, project numbers 1 to (*n*-*m*) could be assigned to projects open to ECE majors and the design variables for ECE students would be constrained to integer values between 1 and (*n*-*m*).

In this work, we strongly prefer to enforce boundaries on the solution by increasing weights within the penalty function rather than applying constraints. This is due largely to our selection of solution engine. The discrete and discontinuous nature of the design space in this problem lends itself naturally to solution with an evolutionary algorithm. As with survey software, many suitable choices are available and the capabilities offered in the MATLAB Optimization Toolbox[12] are attractive. However, for the sake of convenience, the ubiquitous Microsoft Excel[13] was selected as the solution platform for this application. In our experience, when applied as a solution engine in this application, the Evolutionary Algorithm available in Excel Solver is prone to premature convergence when constraints are applied to responses, reinforcing preference to enforce solution boundaries by manipulating weights within the penalty function in lieu of applying constraints on responses.

To illustrate operation of the solution algorithm, we present a hypothetical class of 17 students that will be assigned to three project teams, one of which will be closed shown in Figure 2:

	A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q	R	S
Gender	Male	Male	Male	Male	Male	Female	Female	Male	Male	Male	Male	Male	Male	Female	Male	Female	Male
Ethnicity	Hispanic	Hispanic	Black	White	White	White	White	White	White	Asian	White	White	White	Asian	White	White	Hispanic
Major	ME	ECE	ME	ECE	ME	EGR	ECE	ME	ME	ME	ECE	ECE	ME	ME	ME	ME	EGR

<u>Figure 2: Hypothetical Class for Project Team Formation with BES Tool</u>

To streamline evaluation of the objective function, the matrix of student information is restructured with ECE students grouped in the leftmost columns and student characteristics (gender, ethnicity, and major) represented as Boolean vectors as discussed above. Seriatim project preference ranks for each project are also appended to this matrix. Note that the Acme project, closed to ECE majors, is shown as the third of three projects in the list. The restructured student information matrix is shown in Figure 3:

	B	D	G	L	M	F	S	A	C	E	H	J	K	N	P	Q	R
Gender	Male	Male	Female	Male	Male	Female	Male	Male	Male	Male	Male	Male	Male	Male	Female	Male	Female
Ethnicity	Hispanic	White	White	White	White	White	Hispanic	Hispanic	Black	White	White	White	Asian	White	Asian	White	White
Major	ELC	ELC	ELC	ELC	ELC	EGR	EGR	ME	ME	ME	ME	ME	ME	ME	ME	ME	ME
Gender	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1
Ethnicity	1	0	0	0	0	0	1	1	1	0	0	0	1	0	1	0	0
Major	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Globex	1	1	2	1	2	1	2	3	3	3	1	1	2	1	2	1	3
Initech	2	2	1	2	1	3	3	2	1	2	3	2	1	2	1	2	2
Acme						2	1	1	2	1	2	3	3	3	3	3	1

<u>Figure 3: Student Information Matrix</u>

Again, to streamline evaluation of the objective function, a vector of design variables generated by the solution engine is represented as a Boolean team membership matrix (shown in Figure 4), mapping students to projects. A vector of students' seriatim rankings for the projects to which they are mapped may be generated using the Excel OFFSET function to retrieve the project ranking from the Student Information Matrix in Figure 3. Counts of team members for any project may be determined as the sum of the project's row in the Boolean team membership matrix. Likewise counts of female students, students from underrepresented racial and ethnic groups, and ECE majors may be determined by evaluating the dot product (or, specifically for Excel, using the SUMPRODUCT function) of the project's row in the Boolean team membership matrix and the corresponding Boolean vector in the Student Information Matrix. Once these operations have been performed, the objective function is evaluated as shown in Figure 5.

	B	D	G	L	M	F	S	A	C	E	H	J	K	N	P	Q	R
Team	2	1	2	2	1	2	3	1	2	3	2	2	2	1	3	1	1
Rank	2	1	1	2	2	3	1	3	1	1	3	2	1	1	3	1	3
Globex	0	1	0	0	1	0	0	1	0	0	0	0	0	1	0	1	1
Initech	1	0	1	1	0	1	0	0	1	0	1	1	1	0	0	0	0
Acme	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0

Figure 4: Evaluation Matrix for Solution Vector

	Bounds				Bounds						
Members	Lower	Upper	Penalty	ELC	Lower	Upper	Penalty	Female	Penalty	Under-Rep	Penalty
4	5	6	1	0	2	3	2	0	0	2	0
10	5	6	4	4	2	3	1	3	0	2	0
3	5	6	2	0	0	0	2	1	1	2	0
Sum			7				5		1		0
Weight			1				2		3		1
										Objective	20

Figure 5: Evaluating the Objective Function

In this work, default parameters have been used for convergence and mutation rate. The threshold for time without improvement has been increased to 60 seconds and initial population sizes have been determined as ten times the number of design variables.

Post Processing

Before announcing team assignments to students, Engineering Design II instructors meet to review proposed team assignments and make adjustments as needed to reach consensus. Traditionally, these reviews were conducted by distributing a proposed solution to instructors, either as a spreadsheet or on paper, and attempting to facilitate a discussion. This practice often fostered divergent thinking among the instructors with each one independently exploring alternative scenarios. The need to explore alternative scenarios to build confidence in a final solution seems to be innate; hence our solution has been to manage the exploration process and make it collaborative in nature. Once a baseline solution is complete and ready for discussion, we now conduct our sessions as follows:

1. Generate a profile card detailing each student's characteristics and project preferences
2. Group the profile cards by team, then attach them to whiteboards or poster boards
3. Conduct an introductory briefing with the instructors, reviewing the characteristics of the proposed solution and discussing any known issues such as team sizes, skill mixes, or diversity metrics outside of established bounds
4. Conduct a gallery walk with the instructors to review the proposed placements of students on project teams
5. Collaboratively explore adjustments to team composition by manually moving student profile cards between teams, keeping a laptop with the evaluation spreadsheet nearby to evaluate the impacts of manual adjustments on the penalty function in real time
6. Conclude the session when all instructors have explored adjustments to their satisfaction, then update the team assignment records and distribute them to all instructors

Communication with Students

Complementing development of the BES Tool, we have developed new practices for communicating team assignments to students. Prior to development of the BES Tool, team assignments were communicated to students by e-mail the evening before their first team meeting with no accompanying discussion of results from the team formation process. Under this approach, instructors received multiple requests each semester for changes in team assignments from students who were not placed on their first-choice projects. Under our new approach implemented concurrently with the BES Tool, instructors deliver a presentation to students in class prior to data collection explaining the multiple objectives considered in team formation. After instructors concur on a final solution, they deliver a follow-up presentation in class detailing performance of the BES Tool on each objective with discussions of trade-offs between the objectives. Following this presentation, team assignments are presented in class and students proceed immediately to their first meeting. Although peer pressure may be a factor influencing students' decisions, since implementing this change the Engineering Design II instructors have received no requests for changes to team assignments. We believe the transparency we provide into our team formation process builds trust and improves student acceptance of team assignments even when the solution does not match their personal ideal.

Results

The BES Tool was introduced in the Fall 2018 semester and has subsequently been applied in the Spring 2020, Fall 2020, and Spring 2021 semesters. Class enrollments averaged approximately 32% ECE majors and 68% ME and EGR majors, varying by semester as shown in Figure 6. The high proportion of ME and EGR majors in our program presents a perennial challenge in staffing projects with substantial electronic and control system design content with adequate numbers of ECE students. To alleviate this challenge, in any given semester a proportion of projects in Engineering Design II are deliberately scoped to contain no electronic or control system content and are closed to ECE majors. Over the four semesters in which this algorithm was applied, 70% of projects were open to ECEs with the remaining 30% closed to ECEs, varying by semester as shown in Figure 7.

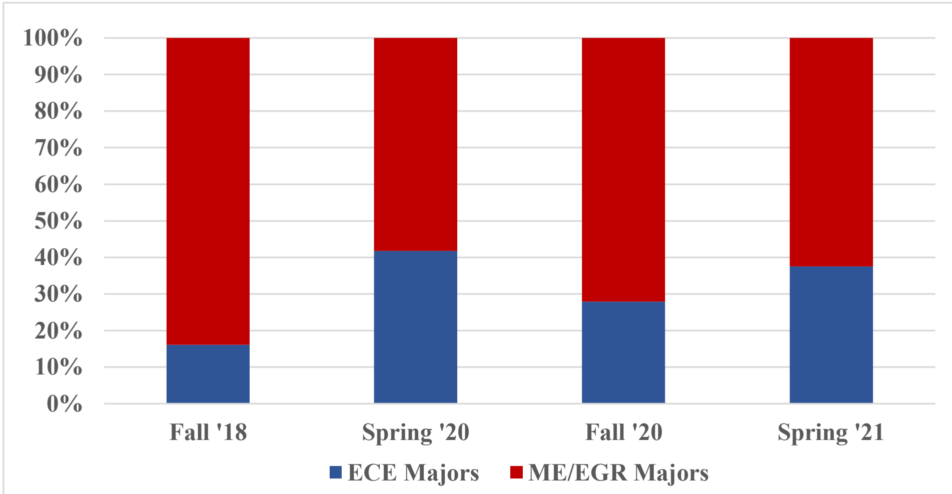

Figure 6: Proportions of ECE Majors by Semester

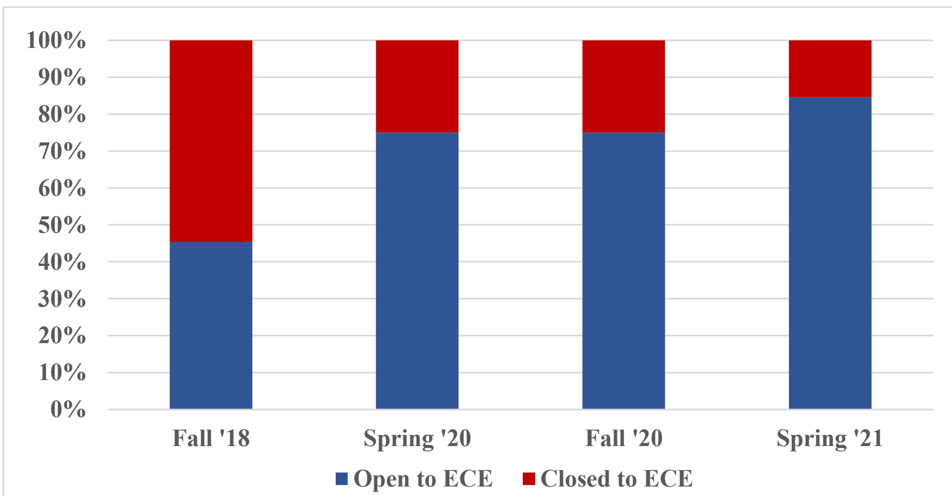

Figure 7: Proportions of Projects Open to ECE Majors by Semester

Over the four semesters in which this algorithm was applied, a total of 31 projects were open to a total of 76 ECE students, yielding an average of slightly less than 2.5 ECE students per project team. This supports the goal of equitably distributing electronic and control system design responsibility by placing at least two ECE students on each team in which electronic or control system content is anticipated to fall within the project scope.

Over the four semesters in which the BES Tool was applied for team formation, 51% of students in Engineering Design II were placed on their first-choice project. 92% of students placed on one of their top three projects and all students were placed on one of their top four projects. These proportions vary substantially between semesters due to varying degrees of dispersion in project preference rankings as well as fluctuating numbers of both students and project opportunities. The BES Tool performance by semester on matching students to projects by students' seriatim project rankings is shown in Figure 8.

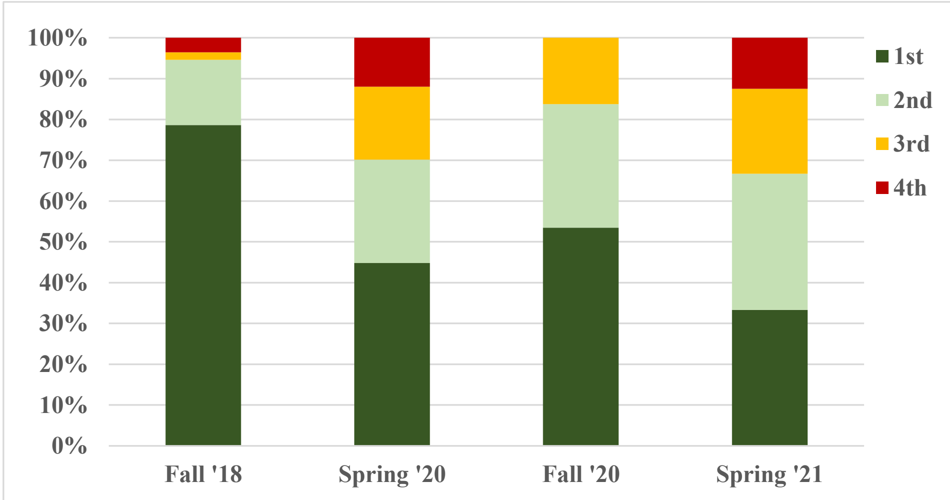

Figure 8: Student Placement by Seriatim Project Preference Ranking by Semester

To evaluate the capability of the BES Tool to satisfy team diversity constraints, hypothetical teams were formed with alternative team generation tools purposely selected to provide extreme bounds of performance. By its nature, Random Team Generator (RTG) would be expected to perform poorly in terms of controlling proportions of demographic characteristics while CATME, by design, would be expected to perform well in this regard. Performance of the BES Tool relative to RTG and CATME specifically for avoiding placement only one female student on a project team is shown in Table 2.

	Number of		Team Formation Tool		
Semester	**Students**	**Teams**	**RTG**	**BES**	**CATME**
Fall 2018	56	11	58%	0%	0%
Spring 2020	67	12	42%	0%	0%
Fall 2020	43	8	50%	0%	0%
Spring 2021	72	13	54%	8%	0%
Total	238	44	51%	2%	0%

Table 2: Comparison of Team Formation Tool Performance on a Diversity Objective

Discussion

In this section, the results BES Tool application are discussed from the perspectives of the tool's performance and its impact on both student success and the student experience.

Tool Performance

The results indicate that the BES Tool performs well within limits. It performs well on smaller scale team formation scenarios, such as the Fall 2018 and Fall 2020 semesters, meeting diversity objectives and placing high proportions of students on highly-ranked projects. However, performance begins to degrade on larger scale scenarios with 12 or more teams and more than 70 students. Applying an evolutionary algorithm more sophisticated than the one available in Excel solver could improve performance; however, evolutionary algorithms are heuristic in nature and do not scale favorably to large problems. The team formation problem is rich in constraints and a constraint-based solver such as the CPLEX Optimization Suite[14] may scale more favorably to larger scenarios. Further investigation is required to determine the most promising direction.

Impact on Student Success

The BES Tool was adopted in Fall 2018 during a comprehensive redesign of Engineering Design II emphasizing improved project execution, increased transparency in assessment procedures, and closer alignment of course grade distributions with students' performance. We believe that intentionally forming diverse teams fosters an environment that positively contributes to students' success and, while the results reported below are consistent with that belief, this analysis is not intended to demonstrate such an effect. Rather, this analysis was performed to create a baseline for future analyses of student performance and as a diagnostic for implicit bias in course assessments.

To explore potential effects of team composition on student success (as measured by the final course grade) we applied a one-way analysis of variance (ANOVA) with results shown in Table 3:

Factor	Treatments	Degrees of Freedom	P-Value
Team Size	4 Members	62	0.4137
	5 Members		
	6 Members		
Race and Ethnicity	White	333	0.8751
	Hispanic or Latino		
	Asian		
	Black or African American		
	Other		
Gender	Male	336	**0.0248**
	Female		

Table 3: Analysis of Team Formation Factors on Student Success

The effects of team size, race and ethnicity are not significant, supporting the encouraging claim that our team formation process fosters an environment in which all students have equal opportunities to succeed. However, the statistically significant effect of gender on student success in Engineering Design II merit a more detailed analysis. Results of a one-way ANOVA to explore the effects of gender on Engineering Design II student performance by assignment group in shown in Table 4. In this course, students prepare a number of written submittals recording the development of their designs, some of which are completed jointly by teams with others completed by individual designers. In this course, students are also assessed on their abilities to constructively apply and receive feedback; this group of assignments is collectively known as the Individual Development Plan. Finally, peer evaluation adjustment factors generated by CATME are applied as a scalar in determining the final course grade to hold students accountable for their respective levels of contribution to the team's overall workload.

Factor	Degrees of Freedom	P-Value	Difference Between Genders
Incoming GPA	336	**0.0060**	Women 0.16 grade points higher
Team Design Submittals	43	0.8826	n/a
Individual Design Submittals	336	0.9325	
Individual Development Plans	336	**0.0061**	Women 3.5% higher
Peer Evaluation Adjustment	789	**0.0001**	Women 2.6% higher

Table 4: Gender Effects in Engr. Des. II Student Performance by Assignment Group

The performance difference between genders could be completely attributable to the exogenous factor that female students enter the course with a GPA, on average, 0.16 grade points higher than their male counterparts. This finding agrees closely with previous findings of Hartman and Hartman[15]. A weak correlation of $r = 0.221$ (with 335 degrees of freedom) was observed between students' GPAs and their average peer evaluation adjustment factors; however, both these may stem from a latent variable that female students who have persisted through the engineering curriculum to senior year are more likely to have high levels of both capability and motivation. Nonetheless, for the continuous improvement of the Engineering Design II course, it may be advisable to develop additional resources for successfully completing Individual Development Plans to support male students. Establishing an intervention process triggered by low peer evaluation scores could also prove effective for addressing underperformance on team contribution; as shown in Figure 9, the population of students underperforming in this area is predominantly male.

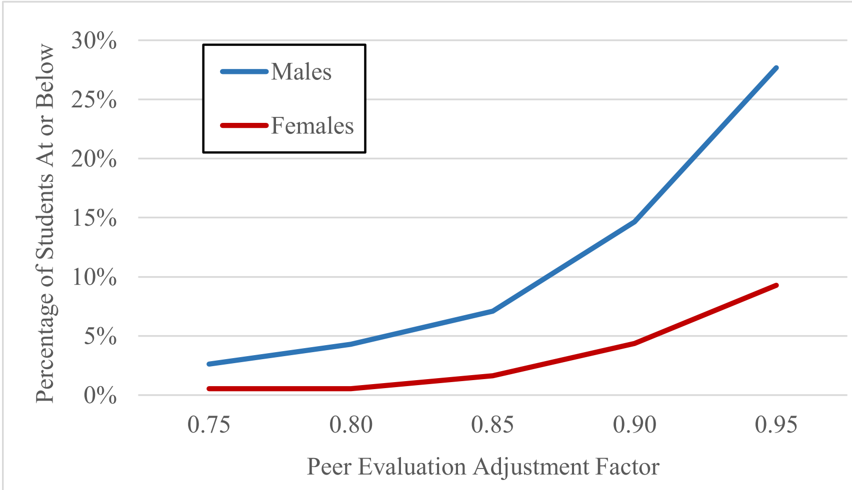

Figure 9: Subpar Peer Evaluation Adjustment Factors by Gender

Student Experience

Student feedback on project team formation with the BES Tool have been largely favorable. In end-of-project reflections from the Fall 2020 semester, several students specifically mentioned positive team dynamics and benefits of diverse perspectives and skill sets within project their project teams:

> *"During this project I have genuinely enjoyed working with my team…I feel we really came together to produce a functional project and…useful data for [the project sponsor]."*

> *"I was blessed with a fantastic team who had so much grace but we all learned together, leaning into each other's strengths."*

> *"I have also learned to work in a collaborative environment much better…with this group, I have really been able to appreciate the extra input each member has had to give. We all have a different way to look at problems and each perspective everyone provides is amazing. It helps us to attack each problem with confidence"*

Others presented specific examples of capitalizing on opportunities for personal growth presented by circumstances they considered less than ideal:

> *"At the beginning of the project, I was upset that I did not get the project I wanted and I was able to be vulnerable and share with everyone how I felt. This set us up to communicate well. As far as skills that I have developed and honed, communication with my team has definitely been one of them. I believe that I have grown in boldness with sharing my thoughts."*

> *"I think I have learned a lot about grit...I believe I learned a big lesson in that whatever you are working on, there are parts you will enjoy and those you do not, but for completeness sake, both parts must be equally valued and finished."*

We consider both of these types of feedback to be indications of desired course outcomes. Naturally we seek to provide enjoyable and fulfilling experiences for our students; however, to be fully prepared for the realities of professional practice (and life in general) we also believe our students must learn to be content and thrive regardless of their situations.

Conclusions and Future Work

The BES Tool has proven effective for consistently placing students on highly preferred projects without compromising team skill mix and diversity objectives. Statistical analysis confirms that forming teams using the BES Tool fosters a team-based learning environment in which all students have equal opportunity to succeed. In addition, we contend that matching students to highly preferred project opportunities fosters strong levels of student engagement.

The performance degradation of the BES Tool on larger scale problems could potentially be addressed by migrating to a more capable solution engine. Evolutionary algorithms tailored more specifically for this problem or constraint-based solvers show promise for improving BES Tool performance on larger-scale problems. Solution quality could then be improved by incorporating additional variables such as students' schedule constraints or validated assessments of specific project-related skills. Performance differences observed between genders in Engineering Design II show no direct connection to team formation methods; however, developing additional resources for successfully completing Individual Development Plans and establishing intervention thresholds based on peer evaluation adjustment factors could improve course success for lower-performing male students.

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