Work in Progress: An optimization model for assigning students to multidisciplinary teams by considering preferences and skills

Dr. Megan Hammond, University of Indianapolis

Megan Hammond received her Ph.D. in Industrial Engineering from Western Michigan University. She is an assistant professor in the R.B. Annis School of Engineering at the University of Indianapolis. Her research interests include cluster analysis, anomaly detection, human centered design, and engineering education.

Dr. Joan Martinez, University of Indianapolis

Joan Martinez is an assistant professor in the R.B. Annis School of Engineering at the University of Indianapolis. He received his Ph.D. in Industrial Engineering from Western Michigan University. His research interest lies in developing data-driven models within the fields of production systems, financial systems, decision sciences, and engineering education.

Dr. Joseph B. Herzog, University of Indianapolis

Joseph B. Herzog is an Assistant professor in the R.B. Annis School of Engineering at the University of Indianapolis. He chose to come to the University of Indianapolis because he is passionate about teaching, is excited about the direction of the new R.B. Annis School of Engineering, is glad to return to his engineering roots, and is happy to be close to his extended family. Previously he was an Assistant Professor in the Department of Physics at the University of Arkansas. He is truly grateful for his time at the University of Arkansas, and enjoyed his department, students, and the campus. While in Fayetteville, he also served as a faculty in the Microelectronics-Photonics Program and the Institute for Nanoscience and Engineering. He received his PhD from the University of Notre Dame working in the Nano-Optics Research Lab with J. Merz and A. Mintairov. After this he was a Welch Postdoctoral Research Associate, researching plasmonic nanostructures at Rice University with Douglas Natelson in the Department of Physics &; Astronomy. In the summer of 2017 he was a Fellow at the U.S. Naval Research Laboratory (NRL) in Washington, DC working with Jake Fontana on tunable subnanometer gap plasmonic metasurfaces as part of the Office of Naval Research Summer Faculty Research Program. At the NRL he worked in the Center for Biomolecular Science and Engineering, which is a division of the Materials Directorate at the NRL. His experience also includes working for Intel Corporation both in Hillsboro, OR and Santa Clara, CA; and he worked at the Berliner Elektronenspeicherring-Gesellschaft für Synchrotronstrahlung m.b.H. (BESSY - Berlin electron storage ring company for synchrotron radiation) in Berlin, Germany, researching ultra thick high-aspect-ratio microfabrication. His research focuses on experimental nano-optics, including plasmonics, nanofabrication, computational modeling, photonic crystals, and engineering education.

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Abstract

Project-based learning has become popular and prevalent across higher education. Additionally, the Accrediting Board for Engineering and Technology also emphasizes the ability to function in multidisciplinary teams. These educational practices have resulted in the implementation of team-based projects throughout engineering curriculums. Team formation, however, is not a trivial process and occasionally can result in conflict or issues when completing project tasks. At University of Indianapolis' R.B. Annis School of Engineering, we noticed that student interest level in a project topic is a significant factor toward commitment and contribution to project completion.

Our institution's senior capstone course requires students to participate in design projects as members of multidisciplinary teams solving open-ended real-world problems. Assigning students to projects can be a complicated process, especially considering student preferences, majors, skills, and the needs/nature of the project. We are a young program continuing to grow and are interested in a systematic approach to assign teams. Currently, a rank-based survey is used to gauge student interest in each individual project for assignment purposes. Faculty leaders consider students' ranking of the projects and the project needs to assign student teams. While we consider our current assignment method effective, it is a manual, time-intensive, and highly iterative process.

This paper presents a work-in-progress of a new assignment method using weight-based integer programming techniques. Some of the considerations for assignment weights and constraints include student preferences, student technical skill sets, and team sizes. A comparative analysis between our proposed optimization model and the current assignment method is shown. Discussions of the similarities and differences between these two assignment methods are also presented.

Introduction of Problem and Need

The benefits of project-based learning have been well established, especially in providing students opportunities to develop their independence, responsibility, and social skills [1]. This, in addition to the push of the Accrediting Board for Engineering and Technology (ABET) to involve students from multiple disciplines in solving complex engineering problems [2], have resulted in the implementation of interdisciplinary team-based projects throughout engineering curricula.

However, team-based project teaching can experience several instructional challenges, particularly when working with a large number of students and projects. Interdisciplinary team formation can also impose difficulties as students vary in technical skills, project management experience, motivation, and engagement; these last two potentially influenced by the type of project a student is assigned to. Lack of motivation and engagement can potentially result in conflict or issues when completing project tasks, jeopardizing the project success.

The R.B. Annis School of Engineering's senior capstone at the University of Indianapolis is the final sequence in the *DesignSpine* curriculum [3]. Students are required to participate in design-focused projects while being part of an interdisciplinary team, with the goal of solving open-ended real-world problems. External entities, primarily local companies, provide a pool of projects for the multi-project-based course [3-5]. Assigning students to projects can be a complicated process, especially considering student preferences, majors, skills, and the needs/nature of the project. Much like others have experienced [6], we have noticed that student interest level in a project topic or application is a significant factor toward commitment and contribution to project completion.

At our institution, a rank-based survey is currently used to gauge student interest in each individual project for assignment purposes. Faculty coordinators then consider students' ranking of the projects and the project needs to assign student teams. While we consider our current assignment method somewhat effective, it is a manual, time-intensive, and highly iterative process. A systematic approach will drastically reduce the time and effort in assigning students to projects, especially with our increasing student population.

While maximizing the likelihood of project success is considered during our allocation efforts, our main objective is to maximize the student satisfaction, engagement, and motivation by providing students some agency in their capstone projects. We believe that giving students a central role in selecting their projects is essential for a positive learning experience. However, we also consider faculty input in assessing necessary skills for a successful project completion.

This paper presents a work-in-progress of a new assignment method using weight-based integer programming techniques. We are developing a model that takes into consideration student preferences, student technical skill sets, team sizes, and faculty input for creating constraints and computing assignment weights. In the next section, we explain our current assignment process, followed by a literature review of related work, and a description of our methodological approach and mathematical model. The paper is finalized with a comparative analysis between our current optimization model and the original assignment method followed by discussions for future improvements.

Current Assignment Process for Team Selection

Prior to the 2022-23 academic year, student-project assignment has landed in the hands of the senior capstone course coordinator. They would collect student information including declared major, grade point average (GPA), prior teammates, and prior leadership experience. With the organized student information, the tedious process of fitting students to projects began.

Projects are proposed to the School of Engineering by external entities, and upon review of faculty are either accepted or rejected as a potential senior capstone project. Of the accepted projects, faculty determine, based on project interview and descriptions, what student majors (i.e. technical skills) would be needed for each project. The combination of student information and project needs contribute to the assignment process.

A group of 3-4 faculty representing various school disciplines manually generate student-project assignments, attempting to optimize the following: interdisciplinary team membership, distribution of GPA, and new team relationships (avoid students working with the same individuals from prior years). After initial team assignments were made by the group of 3-4 faculty, the full engineering faculty review the team assignments for any potential issues, and assign Project Managers and Assistant Project Managers, attempting to ensure student leadership opportunities to those who have not had prior leadership experience on previous projects.

In the 2022-23 academic year faculty agreed upon modifying the senior capstone team assignment process. In particular, the process was updated to accommodate student agency within the team, fostered by student feedback and faculty discussions. To provide this agency, the team assignment process saw two primary changes, (1) remove the assignment of team management from the faculty role and (2) allow the students to provide some indication of preference to proposed projects.

In the Fall of 2022, prior to the beginning of the semester, students were sent a survey that included project titles and brief descriptions. Each student then rated each project on a scale of 5 to 1 (5 = Very Interested, 4 = Interested, 3 = Neutral, 2 = Not Interested, 1 = Not relevant to my major or Highly Uninterested). The survey results were tabulated by the capstone course coordinator and the assignment process, with a group of 3-4 faculty, repeated itself to manually distribute/optimize team membership. Prior team membership was no longer an assignment priority and students were now responsible of selecting team management during the first week of the semester.

The update to the student-project assignment process was in effort to increase student interest level in a project topic. However, this manual and iterative process remains quite time consuming with estimates of 2+ hours of faculty time per faculty member involved in the assignment process, which is typically conducted during the Summer session in preparations for the approaching capstone course (i.e. Fall semester).

Assignment Methods in Literature

There have been many attempts to solve group assignment problems with applications in a broad range of fields. Some research focused on assigning faculty members to different classes while considering class schedules [7] and/or course preferences [8, 9]. Similarly, Iqbal et al. [10] developed a mathematical model to assign faculty members to different committees based on faculty preferences while considering rules and committee requirements. Their model considered the agreement level of a faculty member to serve in a particular committee using a Likert Scale and transformed these into a weight-based measure using an Analytical Hierarchy Process (AHP). These weights were then used in a programming optimization model with the goal of maximizing weighted preferences during committee assignments. A highlight of their model is that it considers the ranking of all available committees, not just top preferences, in their integer programming solution.

Layton et al. [11] developed a web-based software tool that surveys students about criteria that instructors want to use when creating teams. These criteria or considerations can be things such as GPA, schedule-compatibility, and underrepresented members. This input is fed into a max-min heuristic optimization model to determine and suggest team assignments, dramatically decreasing the instructor time required to assign teams and allowing multi-criteria team-based assignments in large classes.

Other assignment models have also been developed, in particular for improving student experience in project-based learning. Previous research has shown that the students' performance tends to increase when they are allowed to develop their own project ideas [12]. However, in courses where projects are pre-defined, the student engagement and motivation can be increased by actively involving them in the process of allocating students to the projects [13].

Lambić et al. [14] used a mathematical optimization model in order to assign students to project groups containing four members each. Holmgren et al. [13] proposed an optimization model for assigning student groups to projects based on a bidding procedure. Similar to other models, they used integer programming for their mathematical optimization of student preferences (total satisfaction level) while also considering the number of students assigned to each project and requirements on particular skills, in a zero to three level, that the assigned students need to have. A new proposed model and application of the student-team assignment problem is presented in the next section. While our proposed model shares some similarities with the model used by Holmgren et al. [13], we would like emphasize that our approach uses different model inputs and a different model solution process.

Proposed Model and Application

In this section, we present the current status of our weight-based integer program for team assignment. Two variables are of primary interest in the development of this model, student preference toward the project and student technical skill sets. At the current time, our team is still exploring how to effectively incorporate student technical skills within the model decisions.

Data Processing: In its generic form, this is an assignment problem where a set of students (I) are being assigned to a set of projects (J). For each student $i \epsilon I$ and for each project $j \epsilon J$, let there be a decision, x_{ij}, such that

$$x_{ij} = \begin{cases} 1 & if\ student\ i\ is\ assigned\ to\ project\ j \\ 0 & if\ not \end{cases} \tag{1}$$

An assignment problem framework exists [15] to maximize the cost (C) associated with the assignment and can be expressed by the program:

$$\text{Maximize} \quad Z = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} x_{ij} \tag{2}$$

$$\text{Subject to} \quad \sum_{j=1}^{n} x_{ij} = 1 \quad \text{for } i = 1, 2, \cdots, n \tag{3}$$

$$\sum_{i=1}^{n} x_{ij} = 1 \quad \text{for } j = 1, 2, \cdots, n \tag{4}$$

$$x_{ij} \geq 0 \text{ and } x_{ij} \in \{0,1\} \quad \forall\, i \in I, j \in J \qquad \text{(5) and (6)}$$

Where c_{ij} is the cost associated with assigning student i to project j.

We have three key components within our model: student preference toward a project, team size, and student technical skill sets. Student preferences will be applied as the cost variables within our objective function, and were sourced from responses to the project preference survey. We did not consider previous team memberships, previous leadership experience, or GPA (former team assignment constraint).

Student Preference Values: To create a set of student preferences (P), we needed to transform the project preference survey responses into individual and comparable values. In the project preference survey, students ranked each project on a scale from 5 to 1, which provided us with a metric of priority per project within student. With 38 students in the course and 8 available projects, we needed a scale to understand the degree of preference of one student compared to another.

We applied the Analytical Hierarchy Process (AHP) to normalize and arrange the project scores in order of importance, following the outline of the AHP explained by Iqbal et. al. [10]. The first element of the AHP is to compare project scores according to importance, often using the values 1, 5, and 9 to measure equal, stronger, and extremely strong importance, respectively, from one project (m) to another (n). Their inverses (1, 1/5, and 1/9) indicate the opposite, weaker importance and extremely weaker importance. With responses from 1 to 5 we needed a definition of strong importance and extremely strong importance comparison. We decided that project importance (q_{mn}) would be calculated as

$$q_{mn} = \begin{cases} 1/9 & -4 \leq d_{mn} \leq -3 \\ 1/5 & -2 \leq d_{mn} \leq -1 \\ 1 & d_{mn} = 0 \\ 5 & 1 \leq d_{mn} \leq 2 \\ 9 & 3 \leq d_{mn} \leq 4 \end{cases} \quad (7)$$

Where d_{mn} is the difference in project ranking between project m and project n and $m, n \in J$.

This created an importance matrix, of project comparisons that was then normalized down the column and averaged across the row, to compute the preference score (p) for each project per student. We calculated the 8 preference scores for all 38 students, creating the set of preference scores, $p \in P$, where p_{ij} is the score for student i and project j. From the survey responses, 7 students did not submit preference scores and were treated as if no project held more importance to them than any other, resulting in equal scores of project preference.

Student Technical Skills: The 8 available projects were proposed by area businesses and external departments of the University. Through relationships and connections within the School of Engineering, projects are proposed throughout the year and faculty are responsible for screening the proposals for feasibility, relevance, and fit for our students. A common question when screening proposals is resource allocation, do we have the student skills (i.e. educational majors) to contribute to the project? Through answering this question, the School has an idea of what majors (not individual students) should be assigned to certain projects.

In our model we define student technical skill as a student's educational major. This variable directly relates to the project screening process that certain projects will need students from a particular major. We offer 7 programs (majors) in our School of Engineering, including: Computer Science (CSCI), Computer Engineering (CMPE), Electrical Engineering (EENG), General Engineering (GENG), Industrial and Systems Engineering (ISEN), Mechanical Engineering (MENG), and Software Engineering (SWEN). The collection of programs is referenced in our model as the set of majors (M). Our team has discussed the major (or student technical skill) requirement as a minimum allocation of students per major identified for the project, but are continuing to investigate how to directly constrain the requirement. At this time in our model development, we include the constraint, but have set all inequalities to be greater than or equal to zero. Therefore, we are not currently imposing technical skill requirements, and will discuss further in our future improvements section.

Mathematical Model: Consider the following sets, parameters, and variables.

Let I be the set of students, where $i = 1, 2, \ldots, 38$
Let J be the set of projects, where $j = 1, 2, \ldots, 8$
Let K be the set of majors, where $k = 1, 2, \ldots, 7$

Let t be the team size for a project, where $t_{min} = 4$ and $t_{max} = 6$
Let m_{jk} be the number of students of major k needed for project j
Let s_{ik} indicate the major of student i, such that

$$s_{ik} = \begin{cases} 1 & if\ student\ i\ is\ majoring\ in\ program\ k \\ 0 & if\ not \end{cases}$$

Let p_{ij} be the normalized project preference score of student i for project j

Let the decision variable x_{ij} be a binary variable such that

$$x_{ij} = \begin{cases} 1 & if\ student\ i\ is\ assigned\ to\ project\ j \\ 0 & if\ not \end{cases}$$

The integer program is given by the following:

$$\text{Maximize} \quad Z = \sum_{i \in I} \sum_{j \in J} p_{ij} x_{ij} \tag{8}$$

$$\text{Subject to} \quad t_{min} \leq \sum_{j \in J} x_{ij} \leq t_{max} \tag{9}$$

$$m_{jk} \leq \sum_{i \in I} \sum_{k \in K} s_{jk} x_{ij} \tag{10}$$

$$\sum_{i=1}^{n} x_{ij} = 1 \quad \text{for } j = 1, 2, \cdots, n \tag{11}$$

$$x_{ij} \geq 0 \text{ and } x_{ij} \in \{0,1\} \quad \forall\, i \in I, j \in J \qquad \text{(12) and (13)}$$

The objective function (8) maximizes student preferences during project assignment, which we believe will positively impact commitment and contribution to project completion. Constraints set (9) provide upper and lower bounds for the team size. Constraints set (10) ensure that technical skills necessary for a project are fulfilled by students that meet those skill sets (i.e. educational major requirement).

Initial Results and Comparative Analysis of the two methods

The Linear Programming (LP) model reassigned 50% of the students compared to the instructor assignment method. The objective function of the original project assignments produced a total preference score of 10.18 and the objective function of the LP model increased the total preference score to 11.71. Observing the individual student preferences, the reassignment produced an average change in student preference rating of +64% (mode = 0% change). Despite half of the students being assigned to different projects, the majority of student assignments increased or maintained project preference (36 out of 38) and the distribution of majors (skills) among teams saw minor changes seen in the team sizes and major reallocations in Figures 1 and 2.

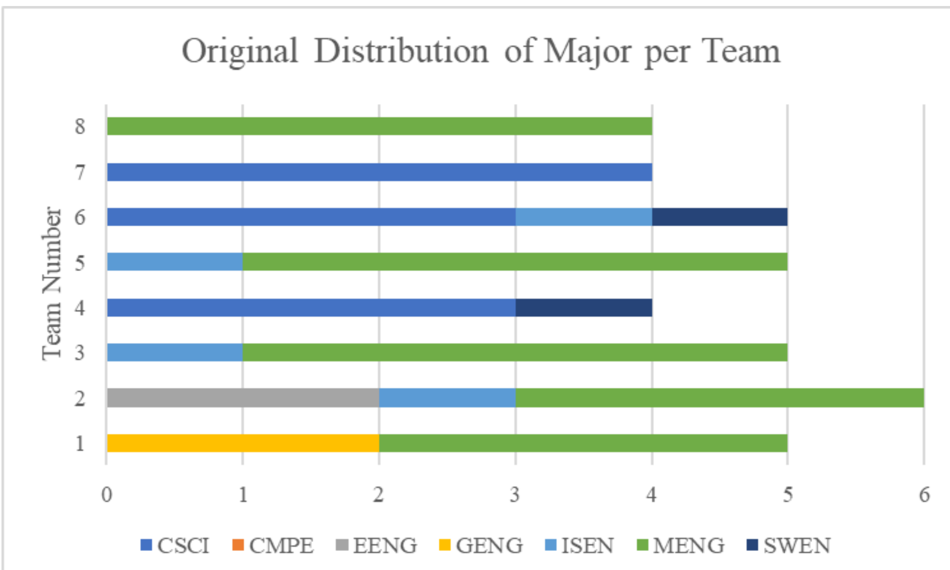

Figure 1. Original distribution of majors per project assignment (team number)

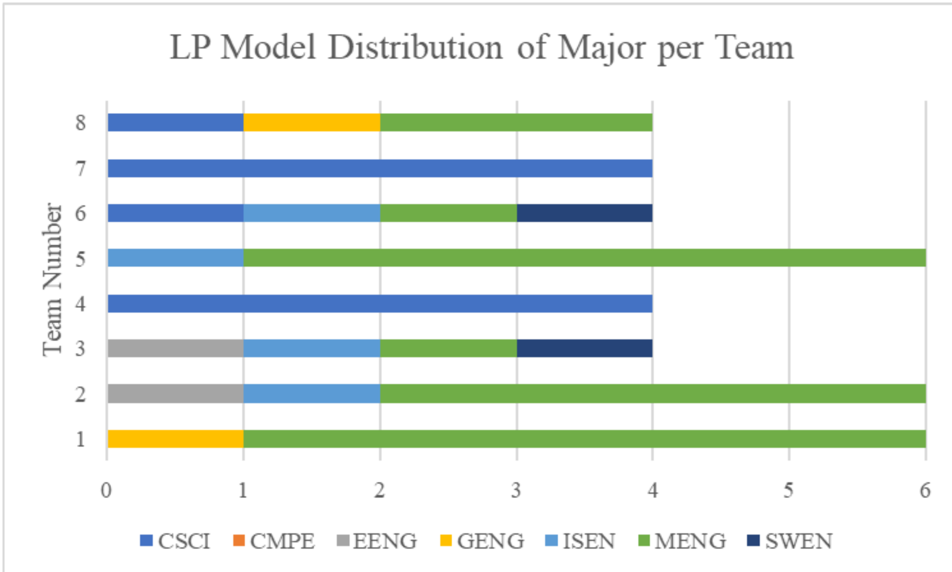

Figure 2. LP model distribution of majors per project assignment (team number)

Figure 3 displays the student preference scores of their assigned team comparing the original assignment to the LP model assignment. It is unsurprising that the overall team preference ratings show improvement, the initial goal of the LP model. We also noticed in many of the reassignments that the range of preference scores shrunk, supporting the effects of the LP model to assign students with common interest in project topics.

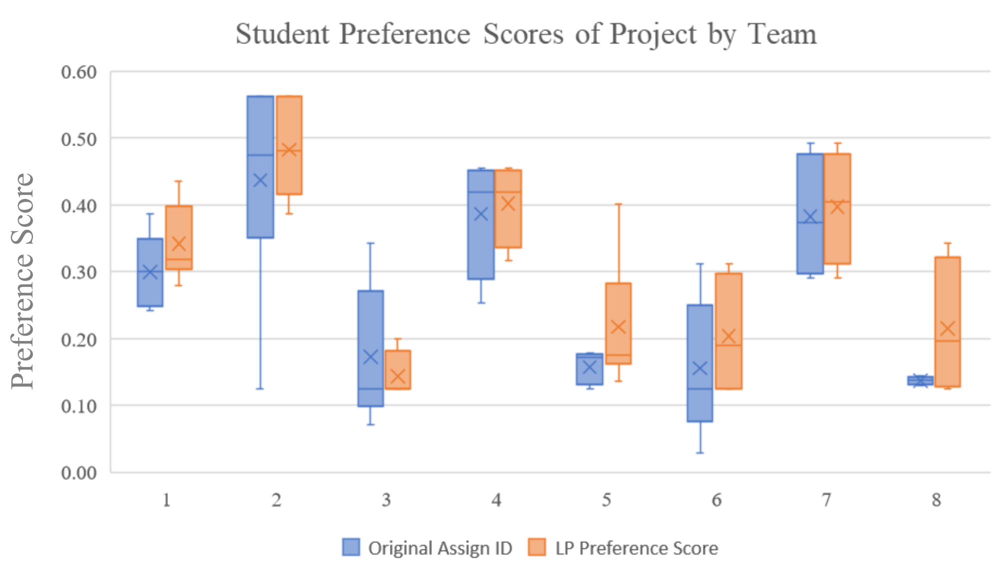

Figure 3. Comparison of student preference scores among team assignment

While we are encouraged by the performance of the model to improve student preference, one of the greatest metrics of this model is the time saved in the student-project assignment process. As explained earlier, the original assignment process consumed the time of the course coordinator and 3-4 representatives of the school's programs. Collectively, it was estimated that the 4-5 individuals devoted nearly 12 hours to the assignment process. We are hopeful, through the development of this model, we can reduce the faculty hours to approximately 4 hours. The course coordinator will still have to collect and organize student information to incorporate into the model (estimated 2 hours of faculty time), but the initial assignment through the LP model takes seconds, and faculty consultation among program representatives can be productive and efficient to review a set of assignments rather than creating assignments from scratch (improved session estimate of 30 minutes).

Future Improvements

Currently, we are not strictly constraining student assignment by technical skills (i.e. educational majors) identified for the project. This development is ongoing, due to our fluctuating class sizes, inconsistent distribution of majors, and varying skill requirements of the projects. The application of this model from year to year will have to adapt to the constraints of the projects acquired each year (roughly 70% of projects are new each academic year) and the available skills of the student body. We have struggled to map student skills to project needs in the past, in such instances students with minors or concentrations have been considered as meeting the "skills" requirements. The consideration of educational minors and concentrations will be investigated within our model development. Additionally, we need to compose a method to identify the appropriate skill constraints while preserving a feasible solution space.

Another factor not currently implemented within our program is faculty input. Faculty are some of the best resources to provide insight on student fit to a particular project. Information pertaining to performance in previous courses or research interests of a student is valuable to create appropriate assignments of students to projects. Our team will be investigating how faculty input could be captured within our linear model.

The assessment of this assignment tool is of interest to our team as well. Currently, our seniors provide exit information at the end of the year regarding the teams and projects (open ended questions and Likert Scale evaluations). In the future, we will also review student team scores on major team assignments from year to year to see if prioritizing student project preference in team assignments can improve overall improvement in team-related course assignments.

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