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Automation of the Capstone Team Formulation Process

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Work in Progress: Automation of the Capstone Team Formulation Process

Abstract

The team formulation process is one of the most time-consuming activities for senior design capstone course instructors. Some of the factors contributing to the complexity of the process include balancing students' project interests, interest in working with specific students, personalities, and instructor/institutional project priority. Instructors have used various techniques and subsequent combinations to guide the capstone team formation process: student self-selection, instructor selection based on student leadership style, academic performance, and student "mingling" based on their project preference. Several attempts to automate the team formation process based on combinations of the aforementioned techniques have also been employed. Our capstone teams are multidisciplinary, with 52% industry-based projects; and the remaining 48% being either competition, entrepreneurial, or research-based projects, and require the placement of 200+ students across four sections of mechanical engineering capstone courses, with each section having an average 14 teams, with 3 to 5 students per team. The team formation process has typically taken four faculty, 80 hours (collectively) to manually construct the teams based on the prioritized criteria: institutional project priority, student preference (rating of their top 10 projects), discipline requirements, student's self-identified personality (leadership) profile to account for a balanced team, and student's self-identified skillset. We present two algorithmic approaches to automate the capstone team formation process based on our prioritized criteria. The Fall 2023 team formation process using the algorithmic approach took 10 hours (collectively) with an average student project preference rating of 2.5. Approximately 47% of students were placed on their top project, while 77% were placed on their top-3 project.

Keywords

capstone, senior design, automation.

Introduction

Capstone Design, usually taken in the fourth year, is a required course for students in all engineering majors at the University of Georgia in the College of Engineering (CENGR). Capstone is a project-based, two-consecutive-semester course that introduces students to a real design problem proposed by an external client, i.e., projects are not proposed by course instructors. For students in Agricultural or Mechanical Engineering, the project clients or sponsors are often local, regional, or global companies with whom the CENGR has developed some partnership but can also be CENGR Faculty (research-based projects), competition-based (sponsored by various national societies), or entrepreneurial. Students are assigned to a project team that is then expected to deliver, over two semesters, a verified and validated solution that solves the design problem proposed by the project client. The two-course track lets students experience the process of engineering design in a systematic and controlled way by following pre-defined project milestones with corresponding project deliverables. Deliverables are disseminated to clients as the design solution.

Historically, project assignments have been completed in a time-consuming process of back-and-forth communication among instructors and in extended group meetings, iterating many cycles to reach final assignments. Earlier in the timeline of the CENGR, the manual process of assignments was completely tenable (course enrollment of ~81 ME students in 2016), but as enrollment has swelled since the College's inception in 2012 and in particular, over the past five years, the manual process has become overly laborious (course enrollment of ~200 ME students in 2023).

In the current iteration of capstone, four instructors co-teach the course, each leading a course section comprising 55 students and roughly 14 projects. During the project assigning process, the Agricultural and Mechanical Engineering instructors work with instructors in Computer Systems, Electrical and Electronics, Biological, Biochemical, Civil, and Environmental Engineering to assign students to projects within disciplines and among disciplines for inter- and multidisciplinary projects.

Student team formation in the capstone course is one of the most important activities undertaken by the course's instructors. Team formation plays a vital role in the overall success of the project (i.e., did the project outcome meet the client's objectives?) and student satisfaction with the capstone experience. Many factors contribute to the project's success and student satisfaction, sometimes in complementary ways, and at other times, in contradictory ways. Some of these factors include: balancing students' project interests, desire to work with specific students, personalities; and instructor/institutional project priority. The net result for instructors to appropriately balance all these inputs is a very time-consuming team formation process.

Instructors have used various techniques and subsequent combinations to guide the capstone team formation process. Based on a 2015 survey [1] of 256 institutions with a capstone course that included various engineering disciplines, the most common approaches to team formulation included student self-selection [2], [3], [4], [5], [6] or instructor selection based on various combinations of student interest [7], [8], [9], [10], skills [8], [9], academic performance [9], [10]and/or personality characteristics [11], [12], [13].

In our case, we sought to maximize team success by weighing several factors including project priority, student preference, major/discipline requirements (defined by project sponsor and instructors) and leadership style when assigning projects to students. By factoring leadership styles into project assignment decisions, the goal is to diversify leadership styles and personality traits to promote effective collaboration and team management and to promote positive intra-group conflict. Yet, two more factors further complicate the formation process: increasing capstone course enrollment (as noted earlier) and the need to form teams as quickly as possible in the Fall semester.

Project bidding is consistently the first step in the team formation process. Our bidding process has been automated since AY 2020-2021 with the use of EduSourced. EduSourced is an experiential learning platform that serves as the depository for all Capstone-related documentation and associated processes for all Capstone courses in the CENGR. Within EduSourced, students are able to view project information, bid on projects, communicate with clients, course instructors, TAs, and each other, log hours, track budgets, share files, and submit project deliverables. For the project bidding function of EduSourced, the CENGR set up a data collection system (bidding database) that allows students to bid on their top ten projects, list their leadership style, expressed as a shape (e.g., square, circle, triangle, or "z" to be discussed later), their engineering major, and their focus areas/interests/skills/previous experience. Once bidding ends, instructors are provided with bidding reports with which to assign students to projects. For AY 2023-2024, the bidding report encompasses a spreadsheet with over 400 rows and 30 columns. The collective effort to manually and thoughtfully assign students is immense – by our estimate over 80 hours total for 4 instructors. Although the adoption of EduSourced has simplified and standardized the Capstone experience for all the various participants, the challenge of matching 200 students to 51 projects (for AY 2023-2024) remains monumental in the absence of further automation of the team formation process.

Several attempts to automate the team formation process based on combinations of the aforementioned techniques have previously been employed. Like our current situation, the primary motivation for automating the process stemmed from year-over-year enrollment growth, which rendered ever increasing time burdens on course instructors to manually formulate student groups. Mohan et al [7] developed a web-based application to assign students to project groups using a genetic algorithm (GA) that considers student preferences, team size and academic performance. The algorithm was used to assign 100 students to twenty-four, 3-5 student teams and reduced the team staffing time by about three hours compared to the manual process. A GA was also used by Schmidt et al [10] to formulate capstone teams with algorithmic weights placed on project priority, student's GPAs, and student preference. A Blackboard based algorithm is used by Freiheit et al [6] to staff capstone projects based on maximizing the chance that a student is assigned to their preferred project.

Both Michaelis et al [3] and DuPont et al [13] used mixed-integer linear programming to formulate their respective capstone teams. Michaelis' et al approach formed 40 project teams using 230 students based on desired team size and average student "happiness" defined as "how close students get to their first choice", but it did not account for how well the formulated team would work together (e.g., team personality/leadership style composition). The results of their approach yielded 74% of students getting their first choice project and 94% getting one of their top 3 project choices. Additionally, the team staffing process took 1 hour instead of 2 days using a manual staffing process. DuPont et al's automation approach is one of the few that considered student personality types via the Myers-Briggs Type Indicator (MBTI) to staff teams (in addition to student preferences). The authors focused their algorithm to specifically emphasize the diversity of MBTI personality types as well as leadership traits derived from the MBTI personality types for team formulation. They defined an "optimal" team as having one MBTI defined leader or leader pair with nonhomogeneous MBTI types for the overall makeup of the team (e.g., teams containing personality types).

Like DuPont, we have also emphasized the value of leadership in the staffing of our capstone teams. All capstone students complete several leadership modules [14] as part of the capstone course. The first module examines leadership styles by teaching students to 1) identify different leadership styles, 2) recognize ways to work across leadership styles, and 3) create leadership goals. In completing this leadership module, students learn what social/leadership style, either square, circle, triangle, or "z", best mirrors their own style. The shapes and subsequent characteristics are illustrated in Figure 1 in four quadrants defined along a horizontal Dominance axis and a vertical Responsiveness axis.

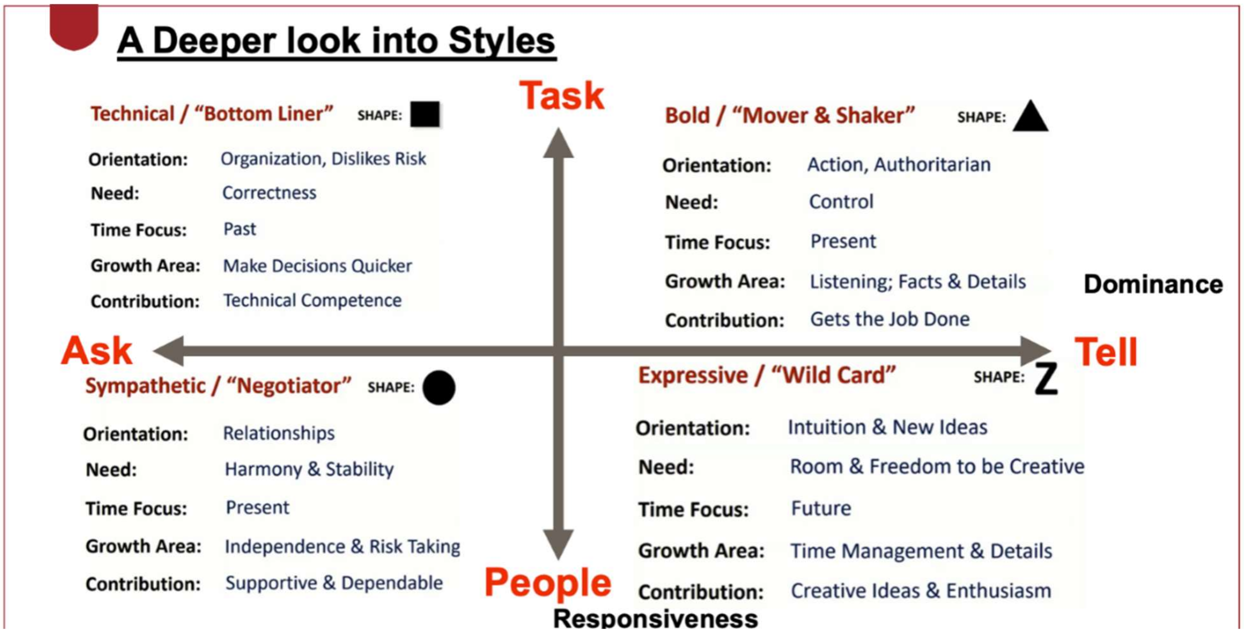

Figure 1. Leadership style/shape characteristics [14].

A core belief underlying our process of project assignment is that projects staffed with students representing each of the leadership style shapes will be most effective and successful. We contend that a group of individuals with distinctly different leadership styles is most likely to find success given the breadth of skills including building effective relationships among project participants (Circle), innovating and keeping the big picture in focus ("Z"), organizing and getting things done (Square), and striving to reach goals (Triangle). A successful project needs people with all these skills. It is worth noting that no one completely falls into one shape category, but if all leadership shapes are represented among participants, a project team likely has the skills to ensure success.

In subsequent studies, we hope to test the theory that using leadership style shapes as a tool to diversify project staffing results in more productive and successful teams. For this study, however, we'll show how we automated the team formation process to account for leadership style and other factors while reducing the time commitments of instructors, delivering project assignments in less time, and simultaneously assigning students to top choice projects. In what follows, we will present our approach to the automation of team formation, the results we witnessed, and our concluding remarks.

Algorithm Methodology

To automate the team assignment process, decision priority was assigned to both the projects and the student bidding information. The projects were prioritized based on the following factors in order of importance:

P1. Sponsor relationship with the CENGR
P2. Instructor rating of project merit
P3. Date of project submission

P1 covered the relationship of the project sponsor with the CENGR and includes both established and new sponsor relationships. P2 consisted of capstone instructor rating from 0 to 3 of each project (0=unacceptable project, up to 3=highly desirable project). P3 gave higher priority to sponsors that submitted projects earlier in the project solicitation phase. The list of 138 projects was then arranged by priority from 1 to 138 using these factors.

The student bidding information from EduSourced was prioritized based on three factors:

- S1. Student project bid value
- S2. Student major
- S3. Student leadership style

where S1 is the student's ranking of their top 10 project choices (1=top choice, 2=second preferred choice, and so on). S2 is the declared major of the student (recall that some projects are multidisciplinary). S3 is the leadership style (shape) of the student as determined in the leadership style module discussed earlier.

Two algorithms (Algorithm E and Algorithm P) were developed for the team formation process. Algorithm E was a semi-automated process based on Excel. Algorithm P was a fully automated process using Python scripting language. Each algorithm will now be described in more detail.

Algorithm E

To begin the semi-automation process, the columns from the bidding database, were rearranged to align the institutional priority by using the vlookup tool in Excel. Projects were originally arranged in alphabetical order from left to right to transform the order based on its priority number. Starting by the far left, the highest priority project (1) column students were reordered by the filter tool to show the numbered bids on top starting by the top 1 priority followed by the integer numbers up to 10, which was followed by the blank cells accounting for students that did not bid on that project. The initial list of students was then arranged by alphabetical order based on the student name column (set up as "last name:major: first name"), thus when rearranged based on their project priorities from those having the same bid number to those that have a last name closer to A would appear higher up on the list.

Teams got assigned to a project by noting its name in the team column and noting the number of bids that the student had for that project in the picked bid column. From the list of students bidding on the project, the first two places on the team were selected based on the students having a major (disciple) that matched the required discipline of the project, and with unique leadership styles. The remaining two places on the team were assigned to any other eligible disciplines that would result in the result in the team having all representation from all four leadership styles. The leadership style criteria were relaxed if there were insufficient students available with the missing leadership styles. Instead, students were assigned based on their bidding place and discipline. This process was followed for one pass to complete as many teams as possible with teams of 4, and 3 when not enough students were available. Projects were declined when no more than 3 students were available for the project. A second pass was done, just considering the bidding place and discipline, adding a fifth member to those teams that had the option for additional members.

Algorithm E semi-automated process took less than 45 minutes to complete and provided an initial team formulation for further instructor consideration. Some limitations of Algorithm E: The self-identified skillset (strengths and weaknesses) was not used and for the Fall 2023 semester trail, 2% of the students were not assigned to teams. These students were manually placed in teams. The instructors met for 2.5 hours (10 hours collectively) to finalize all teams (including the unassigned students).

Algorithm P

The second sorting method (Algorithm P) sought to sort students to projects by quantifying the best-fit between the student's bidding score and the requirements of the project. Algorithm P generated a summed score for each student based on their bid for each project using the following parameters and weights (Table 1):

Table 1. Algorithm P Variable and weights	
Variable Parameter	Weight
Project Priority (p)	+100-p
Bidding Value (b)	+200-b
Major aligned (m_a)/misaligned (m_m)	m_a = +45; m_m = -200
Leadership Style Available (l_a)/unavailable (l_u)	l_a = +20; l_u = +0

where the major alignment/misalignment is based on requested majors for project and the stated major of the student, and the leadership style availability is based on what leadership style shapes have been assigned to the project, with the goal of creating teams for projects that meet all the major-based staffing requirements, while ideally having at least one of each leadership style.

Where for a total score calculated through:

$$fit_{student} = (100 - p) + (200 - b) + m_a + m_m + l_a + l_u$$

Algorithm P then begins assigning students one by one to projects, starting at the top of the project priority list, and recalculating the $fit_{student}$ for the remaining students each time a student is assigned to adjust for majors and leadership styles already placed into the project. Project teams were bounded by a minimum of 3 students and a maximum of 4 students.

Two key limitations of Algorithm P are that it assigns students to teams that they did not bid on and provides different results each time it is run.

Results and Discussion

Table 2 provides a comparison of the various team formation approaches from the Fall 2022 and 2023 semesters. The bid picked for each student was averaged with the ones from their team mates to originate the averaged project preference per team, and subsequently per class, discipline. The Fall '23 (post-algorithm E) column represents the follow-up instructor meeting noted earlier in the Algorithm E Methodology discussion. While Algorithm P had the lowest instructor time, it did not perform as well in terms of average student project preference and %

students obtaining their 1st or top 3 project choice. Algorithm E was ultimately used for Fall 2023 team formation based on the results from Table 3. Overall, comparing the algorithmic approaches to the Fall '22 manual approach, there are clear reductions in cumulative instructor time, but with trade-offs in the average student project preference. This is expected given our previously mentioned criteria for project team formation: CENGR/instructor project priority, balancing of leadership styles on the teams, and project discipline requirements.

Table 2. Comparison of team formation approaches

	Fall '22 (Manual)	Fall '23 (Algorithm E)	Fall '23 (post-algorithm E)	Fall '23 (Algorithm P)
Teams formed (MCHE)	53	51	51	43
Instructors time (cumulative hours)	80	1	10	1 sec
Average student project preference	2.055	2.495	2.5	3.82
%students with top 1 choice	42	48	47	32
% students with top 3 choice	75	77	77	51

Focusing on Algorithm E, Table 3 details the decreased number of days required to form the project teams in the Fall semester from 2020 to 2023. This was another desirable outcome of our automation efforts. Compared to Fall 2022, project teams in Fall 2023 had 6 more days to begin work on the project and possibly more importantly, getting to know each other.

The leadership style of each team was analyzed once teams were formed using Algorithm E. Recalling Figure 1, which shows the leadership style/shapes mapped in four quadrants with a Dominance horizontal axis and Responsiveness vertical axis, Figure 2 shows the results of the normalized balance of leadership shapes on each team mapped along the x (dominance) and y

Table 3. Number of Fall semester days for team formation based on approach

Semester	Team Formation Approach	Business Days elapsed
Fall 2023	Algorithm E	12
Fall 2022	Manual	18
Fall 2021	Manual	19
Fall 2020	Manual	20

(responsiveness) axis. The numerical values assigned for each team in Figure 2 are derived from Table 4. The value for both axes were summed for all team members to determine a single Dominance (x axis) and Responsiveness (y-axis) value for each team. This result was then normalized by the team size, resulting in a +1/-1 range of values along both axes. This value was plotted for each team in Figure 2. The quadrant with an ideal team on leadership style diversity was defined when -0.5 < x <0.5 and -0.5 < x <0.5. Nine quadrants were defined as illustrated in Figure 2.

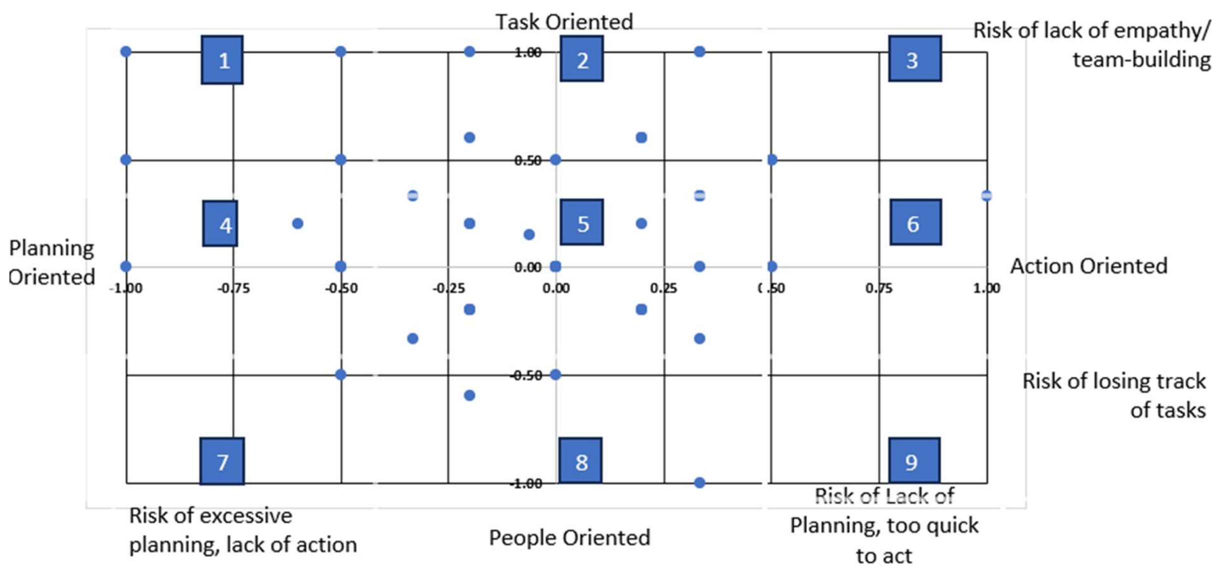

Figure 2. Mapping of normalized leadership styles for each team

Table 4. Leadership style/shape values used for mapping leadership shape distribution for project teams.

Leadership Shape	**X axis**	**Y axis**
Square	-1	+1
Triangle	+1	+1
Circle	-1	-1
Z	+1	-1

The results from Figure 2 were further examined by counting the number of teams in each quadrant as shown in Table 5. Forty-nine percent of teams are in the balance quadrant, where 10% had a single member from each leadership style. The remaining 51% fall in the boundary conditions, having specific team imbalances. Specifically, there is 8% of teams with increased risk for lack of planning (3+6+9), 22% have an increased risk of lack of action (1,4,7), 29% are task-oriented, and 8% are people-oriented. As previously noted, we plan to explore how these distributions of leadership in the design teams manifest in team performance throughout the semester. For example, do we observe teams in the 3, 6 or 9 quadrants struggle to plan their project activities? Do we observe teams in the 1, 4 or 7 quadrants being hesitant to move from the project planning to action stages?

Table 5. Number of teams in each of the 9 quadrants (defined in Figure 2)

Quadrant	**Count of Teams**	**%Teams**
1	5	9.80%
2	8	15.69%
3	2	3.92%
4	5	9.80%
5	25	49.02%
6	2	3.92%
7	1	1.96%
8	3	5.88%
Grand Total	**51**	**100.00%**

Conclusion

Capstone team formulation is a daunting task given the ever-growing enrollment and subsequent increase in the number of teams, and the desire to form the teams as quickly as possible. Prior to this current automation effort, we collectively spent 80 hours formulating our teams, taking up to 20 days during the Fall semester to form and notify students of their teams. We have developed and implemented two algorithmic approaches to forming our capstone teams for the Fall 2023 semester. Using Algorithm E, the team formation time was reduced to 10 hours of collective instructor time and reduced the number of semester days to notify students of their teams by 6 days, which gave them more time to work on their projects. Work will be continued to improve both algorithms for use in subsequent team formation efforts.

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