Team formation in the ECE Capstone course and studying impact

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Abstract
This paper describes an instructor-assigned team formation technique used for an electrical and computer engineering (ECE) capstone design class which is devised to take technical and non-technical skills, individualized personality profiles, student team preferences, and other intangible details about each student into consideration for team assignment. The paper explains each of these parameters in detail and their impact on the team formation process. Three main goals achieved by this team formation process are optimizing team assignments across the entire class, teaching students' team effectiveness, and making it easier to assign teams across large class sizes (140 students, 35 projects). The method results in a marked improvement in the team's final assessments, project success and feedback collected over the dataset. The purpose of this paper is to share the technique and nuances that has made this instructor-assigned team assignment successful and feasible for large classes. Finally, this paper shares methods to add depth to the teamwork learning outcomes.

Keywords: Team formation techniques, team establishment, team success, teamwork assessment

Introduction, purpose, and goals

Teamwork is one of the essential learning outcomes of a capstone design course. As no two teams are the same; each will go through fundamentally different experiences throughout the various phases of their projects. The most successful teams may have a balance of technical and non-technical competencies, complementary personalities, and other intangible properties – such as trust and security[3]. It is also observed that synergistic teamwork leads to more diverse and effective designs and more robust project implementations by a team[3-12]. The team formation process, which tries to take all of this into consideration, can have an enormous impact (and can be a stepping stone) on a team's successful journey through their design project. At the same time, upfront team assessment and feedback from the team have a strong impact on improving the team formation techniques and teamwork progression – thus closing the decision loop[10,11,13].

Over the first 3 years (2015-2017, ~400 students) of the observation period, authors collected data using student feedback and surveys to learn the following: (i) The project desirability is very unbalanced across the entire suite of projects in every class. On average, 30% of the available projects are extremely popular & together they end up on the top 2 choices of more than 50% of the class. Given the unbalanced student project choices, no procedure achieve both the matching of all students to their most preferred project and building an ideal team for a project. In this limited resource matching optimization problem, a fixed number of students with certain skills are to be matched to a fixed number of projects requiring certain skills. Therefore more data than simply students' technical backgrounds, skills, and project choices is required to form impactful and suitable teams across the board. (ii) Many students have team member preferences which are more important to them than project preferences. On the other hand, there are students who care more about being on a certain project irrespective of who else is on the team. (iii) Though all students have a list of preferable projects, several students have compelling reasons or are passionate about a certain project due to their background, surroundings, or experiences. Such students are much more likely to drive success for that project, and (iv) Different students find enjoyment in different aspects of the applied engineering process. In ECE capstone class, the following three engineering personalities were consistently observed through multiple student surveys. (1) ***Coder***: Sit and code for hours, ***(2) Builder***: build things in the workshop or lab, (3) ***Designer***: draw/sketch / conceptualize.

During the observation period, a more involved team assignment method was devised to fulfill three main goals. (1) Optimizing across the whole class and all projects: While we may be able to build a dream team for a project, we may greatly weaken another. The optimal goal is to build the *best set of teams* to ensure the success of the largest number of capstone projects. (2) Teaching team formation effectiveness: This is an opportunity to teach students about important aspects of team effectiveness, team imbalance & how may they overcome challenges during various stages. (3) Ease of assignment: The assignment procedure should be relatively easy, logical & straightforward for the instructors for a student-instructor ratio of 70 or more.

The ECE capstone program mentioned here is two semester long where students are provided a new set of projects (sponsored by internal and external entities) in the beginning of the class. In addition, students are welcome to submit project ideas of their own. Some example projects can be found in the Appendix. This method has been adopted and used for class sizes ranging from a minimum of 30 (~7/8 teams) to a maximum of 140 students (35/36 teams) with the average team size being 4 to 5 students[8]. The process has been in practice for the past 3 years (2018-2020, execution period.) The process is described here:

Pre-assigned data collection from students

Before project assignments are completed, the following data is gathered from each student using automated tools such as Google Forms, SurveyMonkey or Qualtrics and is automatically formatted for the ease of assignment. The complete process is kept transparent to the students before they provide the needed information. Students are presented with teamwork theory and are provided an explanation of how the teams are going to be formed using each input beforehand. This encourages students to provide complete and detailed information about their choices and preferences.

(1) Shared Capstone Resume

Students create a "capstone resume." There are three main sections to this one-page resume which is automatically created from the following data submitted by each student. The resumes are then shared amongst the entire class prior to project selection.

(a) Technical skills: Each student rates themselves on a number of critical competencies: core ECE skills and special skills needed for the projects' that year.
(b) Student profile: There are two aspects to the student profile.

Personality Profile of 5 top strengths: Numerous assessment models exist to evaluate students' personalities. Here, the CliftonStrengths assessment model [1] was leveraged. Each student takes the Strengths assessment test which identifies their top 5 strengths. In a team setting, the ideal approach then is to create teams of members with complementary strengths where possible[9,11].

Engineering inclination: Students are asked to categorize themselves in one or more of the following engineering inclinations: ***Coder***, ***Builder***, and/or ***Designer***. Students may pick what they enjoy the most or feel is their forte. This helps to match the students quickly with certain projects based on their high-level requirements.

Interesting facts: Students are asked to include interesting facts about themselves. This may include their hobbies, extracurricular activities, a project they worked on or something other than their engineering resume. This element helps with getting to know each other better and connect with each other (the first step towards building trust and security). Sharing such information via a written survey rather than in-person in a team meeting or in-class activity has many advantages. Students get time to think about what they would like to share about themselves. Introverted students do not get put on the spot. This also has helped instructors find a better project match in some difficult cases.

(2) Project choices and preferences

Instead of giving a list of top 3/5 project choices, every student is asked to rate each available project in one of the 5 categories: (a) Most Desirable (b) Very desirable (c) Desirable (d) Least desirable (e) Undesirable. Each student is expected to select at least 25% of the projects in the categories (a) and (b).

(3) Team member preferences and project choice reasons

As part of this, two main things are collected from students, their team member preference (who they prefer to and not to work with), and compelling reasons/passions if any for a certain project. Students are also encouraged to state which is more important to them between project choices and team member preferences in case their project choices do not match with the other students with whom they desire to team. Project or team member preferences are only shared with the instructional staff.

Observations during execution period: Data collected over the past 3 years of execution period (391 students, 96 teams), states: (i) only 40% of the students on average have stronger team member preferences than project preferences. And only 15 to 20% of the students actually form complete teams (3 or 4) beforehand and report that as a choice. That means most of them have only one person they would like to work with or are completely open to form a new team to get a desirable project. (ii) On average, 40% of the students report a very sensible compelling reason to be on a certain project which proves to be very useful for that project.

Team and project assignment algorithm

Technical skills are always matched to the best possible ability to the project requirements. Students will develop some missing skills in senior design beyond their present capabilities if the motivation and team security factors are strong; but, it is beneficial to evaluate and sensitize to that skill gap.

Student's team and project preferences are given the highest priority. Only mutually agreeable team preferences are considered above their technical match to the project. More often than not, if a student has a reasonable and sensible compelling reason which matches with a project need then that student is assigned to that project. This may not happen if the student states that their team member preferences are more important than their project choice. Some of the examples of sensible & useful compelling reasons from our case studies are, a student wanting to be on a horse rehabilitation monitoring shoe project because they have spent half their life on a horse farm & know a lot about horses, a student wanting to be on a soccer training app because they are a university soccer player and also a soccer coach to little league, a student wanting to be on company A's project because they were their intern & have worked with the tool & the technology closely related to the project.

Student's personality profiles are used beyond their team/project preferences. Frequently it is seen that students propose teams of "like" individuals - e.g., highly technical or highly hand-on students tend to "cluster." Personality profiles present an opportunity to teach students the effectiveness of team balance and need for various intangible skills for a successful team.

Engineering inclinations are used in conjunction with project needs. Some of this is explained through examples. As an illustrative example of the tradeoffs considered when balancing and assigning teams, please consider the following.

In our case study, *three students have shared compelling reasons for why they want to be assigned to a project for developing biosensors for diagnosing a training dog. One has parents who are Veterinarians, one student plans to apply to Veterinary school after obtaining their BS, and the third has a pet dog with the "disease" for which these biosensors are to be developed. Further, each of these students have primarily software skills and an inclination of a "coder" and the project requires some hardware development as well as software. Further, when evaluating personality traits, we find that these three students all have strong "Executing" type strengths, but none have "Strategic Thinking", "Relationship Building", or "Influencing" traits. In this scenario, when applying the overall assessment, we may see that this potential team would lack key technical skills and would have a poorly balanced personality mix. We look for* *opportunities to address the identified gaps. For example, one option might be to identify one or two students with circuit hardware skills who also have a complementary personality type (such as "Strategic Thinking", "Influencing") and have selected this project as one of their desirables. Another option would be to evaluate second and third choice projects for these students. We may find that one of the students was very active in high school robotics and another is on the college soccer team. We might discuss with these students other projects, such as one involving mechatronics and another involving a biomedical sensor for knee injuries. Part of the assignment process then will be to discuss why they have been considered for their particular projects (including team balance considerations). Third option is to modify the scope of the assigned project. In this case, there may be an established hardware platform well suited to extension through purely software development. But this would be the last resort because it would not fulfil the personality balance needed for the team.*

Results, analysis, and impact

The following results are from **391 students and 96 teams** over the **three years** of execution period. The impact of the process is evaluated in two stages. *First stage: An initial assessment of the assignment process* looks at initial student satisfaction with their project assignment and team balance of appropriate technical skills, team member inclinations, and complementary personality types. Data is gathered using a short survey as soon as team formations are announced. Initial student satisfaction is reported to be **<u>98.72%</u> (Extremely satisfied or very satisfied)** We looked at Tuckman's stages of team formation (forming, storming, norming, performing, and adjourning)[2] and observed that the fourth aspect of this method "performing" can be greatly facilitated through an effective "Forming" stage for the team. This team-creating approach is found to be a catalyst for a successful forming stage. After the initial assessment, during the first meeting with the teams, the team composition is reviewed with team members to emphasize the team balance, but also to sens itize the team to any potential deficiencies caused due to imperfect optimization. This is to make the team members aware of potential blind spots to compensate for. The time reported to complete the team assignments using this manual process is 15 min or less per team per instructor.

Second stage: Assessment of the team's overall success is defined by mainly two parameters: (1) ***Team Deviation is the score*** which represents how badly does a team deviate from ideal teamwork. A lower score represents better teamwork through all team stages. See Table 1. This is calculated via team surveys, team assessment score by instructors, team members, mentors and sponsors throughout the project span. (2) How successful was the project outcome: represented by the average scores for quality of design, project demos, design documents by each team.

Team Deviation	***Teamwork***	***What it means***
0-1	Excellent	No issues or able to resolve issues without help, and their project progress reports and assessments match with each other throughout the project.
1-2	Good	Fewer issues resolving quickly, Progress assessment matches to > 90%
2-4	Poor	Several issues, need external help, progress assessment match <70%
>4	Bad	Very bad issues, No team motivation, team is not able to find common ground

Table 1: Definition of Team Deviation Score and respective teamwork effectiveness

Please note that the following support methods are available to improve teamwork throughout the semester: (1) Team workshops and activities to help the team bond, (2) Lectures to teach team accountability and management, (3) Meetings with instructors to evaluate team dynamics/performance and to help resolve issues. And observations during these activities are taken into considerations in the **Team Deviation** score.

Data analysis

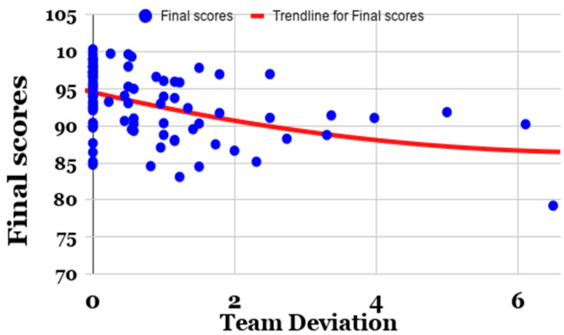

Figure 1: Graph assessing project outcome quality w.r.t. Team Deviation score (See Table 1)

From the data represented in Figure 1, the following observations were made. After putting the explained team assignment into practice ~90% teams demonstrated good (16%) to excellent (74%) teamwork. The average project quality score of these teams is 93.6% opposed to 89.4% reported by teams with Team Deviation > 2, the average score of all the teams being 93.1%. On average this gap represents 2 sub-letter grade. Based on the pre-assignment and post-project execution survey only 55% of students are able to rate their various technical skills with more than 60% accuracy out of a defined list of technical competencies, but more than 90 % of students are able to correctly identify their engineering inclination which proved to be very useful in matching.

In successful teams, team members assume complementary roles. And at the same time, they have each other's back. This trait is observed strongly in 90% of the teams that partially comprise students with team member preferences and the instructor added other students to closely balance personality profiles, required engineering inclination & at least 60 to 70% matching technical skills. More than 50% of the teams that are solely formed by students just using team member preferences without the consideration of team balance and technical skill matching struggle through team dynamics. These teams seek help more often through various team stages.

Conclusion

The instructor based student-driven team formation technique explained in this paper achieves the following goals: (a) It enables class-wide balanced team formation over the entire list of projects. This includes satisfying the majority of students with their project assignments, achieving desired team preferences as well as a reasonable match of skills with project needs, (b) The method enables instructors to efficiently assign balanced teams for large class sizes. This is especially important in large classes because an individual student may know a very small percentage of other students in the class to form a well-balanced team by themselves. (c) The explanation of the process and the inclusion of intangible aspects such as engineering inclination, fun fact, personality profile, compelling reasons, and passion about the project enables teams during forming & storming stages – accelerating progression through the stages of team formation. Thus, this method helps in building team security & initial bond through the shared resume and team initial assessment.

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Dr. Rachana A Gupta is currently a Associate Teaching professor and the Director of the ECE Senior Design Program at North Carolina State University. She teaches and mentors several senior design students on industry-sponsored projects (On average 20 / semester) to the successful completion of an end product. She also manages interdisciplinary senior design projects in collaboration with other engineering. Shas also created and teaches undergraduate as well as graduate-level classes in ECE (Python and scripting, Practical Engineering Prototyping (PrEP). Dr. Gupta earned her Bachelors of Engineering in Electronics and Telecommunication Engineering from University of Pune, India and received her MS and PhD in Electrical and Computer Engineering from North Carolina State University (2010). Her PhD was to design computer vision algorithms for autonomous navigation for cars. She has worked on several product development projects such as automated air suspension system for vehicles, active suspension system for heavy duty off-road vehicles, etc. She joined NCState as Teaching Assistant Professor in 2012. Dr. Gupta's current research projects focus on sensor systems and engineering design education. Dr. Gupta likes to tinker with new technology and work on small hobby projects in her basement lab. Her other hobbies include reading, classical dancing, and traveling.

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Appendix:

Project examples in the ECE Capstone class include all aspects of System Engineering: concept design, product design and design trade-offs, prototyping, and testing (circuit design, PCB, mechanical fabrication, algorithm development). These projects have included Robotics Platforms, Planning, Monitoring and Control algorithms, Sensor Interface, User Interfaces, Wireless communication, Signal Processing, etc.

A few project examples are described here:

Project 1: Student idea, Title: Smart-Kart

Go-karts have been a recreational and professional racing activity for generations and continues to be an activity that friends and families partake in. While the draw to go-karting for many people is the low cost of entry and being a relatively inexpensive racing hobby, there are those who desire more than a simple engine and chassis. Even simple features such as a speedometer or tachometer are rare to find even in high end go-karts. Go-karts are a prime candidate to incorporate smart technologies that provide data collection, ease of use, and safety features into their design.

Creating a smart go-kart will require the use of one or more micro controllers with various sensors attached to the go-kart. The system will provide data and feedback similar to a modern car with information like speed, mpg, and various ease of use features like cruise control. All the data collected will be available to the driver via a display on the vehicle as well as locally on a microcontroller or remotely with a wireless connection to the microcontroller.

Project 2: Funded by Industry, software project. Title: Smart Canine Bite Sleeve

Working dogs play an integral role in the day to day operations of both military soldiers and law enforcement officers worldwide. All canine handlers and trainers use protective bite sleeves for engagement and apprehension training. However, the canine bite sleeves on the market today fail to measure the bite force of the working dog. The result is that trainers must rely on years of training experience to subjectively evaluate their canines which may result in ineffective training, canine/handler injury or unsafe environments during operations. The objective of the project is to re-design, analyze, test a commercial bite sleeve by incorporating electronic (or other) pressure sensors within the sleeve that accurately measures, records, and displays bite force data in real time. Canine bite profile includes overall bite pressure, mapping the bite print and duration of a bite.

Project 3: Funded by internal research center, Title: Nautiloid based robot

The idea is a device (robot) that you can throw over the side of a boat, and as it falls it collects data about the water that it is passing through, when it passes a certain depth it changes its bouncy and returns to the surface. The “Nautiloid “is an example of an ocean creature that can travel between about 800 meters and the near surface by controlling its buoyancy, the robot can be simpler, but investigating ways the robot can stay at a certain depth before returning to the surface is also of interest.

Expectations in final product: Integrated design of case with electronics ~ 3inch diameter, 10 inches long that can be negatively buoyant until a programmed depth, then release weight or pump out water to float back to surface, sensor suite to measure water temp, pressure, optical measurement to assess water quality and turbidity, and wireless connectivity to sensor suit so data can be offloaded without breaching water tight boundaries.