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How Did We End up Together? Evaluating Success Levels of Student-formed vs. Instructor-formed Capstone Teams

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How Did We End up Together?
Evaluating Capstone Project Success as a Function of Team and Project Formation Methods and Other Contributing Factors

Joining together is a beginning, keeping together is progress, working together is success.

~Henry Ford on teamwork

Abstract

Effective team functioning is one of the key ABET criteria and is also essential for successful capstone design work. Existing teamwork enhancement practices focus on key factors such as contributions of team members, balancing skills and personality types, fostering a constructive team climate, and response to conflict; however, the best method for forming successful teams is still the subject of debate. In the Senior Capstone Design course at Northeastern University, no explicit instruction in team functioning is provided at present. Teams are typically student-formed when possible; however, the course coordinator needs to ensure that team formation outcomes align with the course constraints –such as of number of projects, number of faculty advisors, and team size of 4-5 students– and must form teams when students are unable to. In terms of project assignments, students rank possible projects, and although an attempt is made to give them one of their top choices, this is not always possible. In this work, the two types of teams, student-formed and instructor-formed, are examined to see if there are any differences in terms of design quality, project completeness/implementation, and final prototype grade. Assessment tools include the validated prototype scoring system previously developed by one of the authors. Teams were categorized based on how the teams were formed –instructor versus student, topic preference –students initial ranking of their assigned project, what percentage of the team members were actively chosen by other team members, and whether they were chosen based on skill or work style, and/or because of friendship, and the degree to which their assigned advisor was among their top choice. The team's passion and commitment to their project was also assessed, using an operational definition of this engagement factor. Results show that teams who select team members themselves with an eye to the skills and work style of their team members have high final scores and also a high level of commitment to and passion for the project. Additionally, it seems that neither the actual topic of the project nor the team advisor necessarily affects the outcomes of the project. Findings will inform guidelines for capstone team formation and future coaching of the students in general and in capstone teams once formed. Results will help determine what type of team-formation protocol is recommended and the coaching intervention may improve the performance of potentially low-functioning teams.

Introduction and Overview of Previous Work

Capstone design teams have been studied by a number of authors. Dutson *et al*. in their review of capstone design courses noted that a majority of capstone courses use teams, as the ability to work in teams is seen as an essential skill for engineers.[1] They observed that team formation schemes vary across programs from students being randomly assigned to groups, to students selecting their own team members, to instructor-formed teams. Instructors who assign students to teams may do so simply on the basis of interest in project topics, or may strive to consider skills, personalities, academic strengths, nationality, and gender among other characteristics.

There have been a number of efforts to assign students to teams based on various student characteristics. Brickell *et al.* compared groups that were formed based on GPA and project interest to groups that were self-selected by the students.[2] Both Brickell and other authors[3] have observed that self-selected teams often perform *worse* than intentionally formed teams that take into account specific skills and academic ability. Other researchers have found that there was no one good way to form teams, and that having teams carefully crafted by the instructor was no guarantee of team success.[4]

The Meyers-Briggs personality test has also been used in various institutions to attempt to form groups that would potentially function more smoothly, although the link between personality and team performance is not always clear.[5] Tools such as the CATME web based system for team formation[6] and other institutionally developed tools[7] have been used to allow instructors to match students to their most desired projects while controlling the mixture of skills and abilities in the team members. Some of these tools have specifically been used to develop high performance teams, with a reasonable rate of success in terms of the final result.[8] However, in this case, the high performance teams that resulted were not formed by the instructor, but rather by students using the web-based tool. It is clear from an overview of previous research into capstone team formation that there is no one preferred and foolproof method for forming teams.

Regardless of how teams are formed, there is some consensus about what characteristics make an effective team. Teams that are successful need to have individual responsibility and effective work habits. The team needs to have a mixture of abilities and skills among the team members and they need to have a clear goal with clear metrics and individual tasks and goals for each team to accomplish.[9] High performance teams have similar characteristics, but with strong commitment to the project as well as to each other.[10] The current work will show that carefully considered student-formed groups can foster a mixture of complementary skills and the deep commitment to the project necessary for success as well or better than instructor formed groups.

Capstone Design at Northeastern University

Team Formation and Project Assignment. In the Mechanical and Industrial Engineering Department at Northeastern University, the Capstone Design course is a required two-semester sequence for senior students. Projects can be proposed by industry sponsors, faculty members, or by the students themselves, subject to approval by the capstone administration. All approved projects are presented to the students in the first week of class. After the projects are presented, students are asked to submit a form ranking all the projects in terms of their preferences. Students may submit these ranking forms as a team of 4-5 students if they know who they want to work with. Students can also submit the forms as individuals, or groups of 2 or 3, with the understanding that the instructor will place the students into teams. The instructor makes every attempt to give each team their highest-ranked project. Individuals and small groups are combined based on common interests. Each project has an assigned advisor, with each advisor working with 1-3 teams. Generally, teams work within their discipline (industrial or mechanical engineering) but there are typically 1-3 projects per term that are interdisciplinary.

The goal at the end of the capstone design sequence is to produce a working prototype –or process– that has been tested and validated. For the mechanical engineering students, this typically a physical prototype of their solution, such as a consumer product or a piece of lab equipment. This is then tested experimentally to determine whether specifications were met. For the industrial engineering students, their prototype may be a database, a facilities layout, or a new organizational scheme. These are validated by simulation in some cases or by data collection or observation in others, ideally with implementation.

Prototype Score. At a point three weeks prior to the end of the course, teams must produce an Executive Summary that is sent out to the alumni jury that judges the final presentations. It is understood that the projects are not necessarily going to be completed at this point. Therefore, assessing the prototypes for completeness and extent of testing completed at this point has been found to be a good predictor of team effectiveness.[11] The prototypes are assigned a score of 1-5 for completeness, where 5 indicates a completed prototype and 1 indicates that no prototype is likely by the end of the course. Testing was also rated on a 1-5 scale, where 5 indicates that prototype verification testing is complete and 1 indicates that testing was not planned or discussed. This validated rubric is presented in Table 1. In addition to scoring the executive summary, grades are determined based on oral and written reports and whether the final projects met the specifications laid out by the team and their advisor at the beginning of Capstone.

Table 1: Capstone Executive Summary Scoring Rubric, also called the Prototype Score.

Solution Score	Verification score
5 = Fully developed solution	**5** = Fully verified and validated
4 = Solution partially developed	**4** = Verification substantially done
3 = In progress, solution expected by course end	**3** = Verification planned and in progress
2 = Solution in progress, unlikely to meet all specifications by end of course	**2** = Verification planned, unlikely to be complete by end of course or not started
1 = Working solution unlikely by course end	**1** = Verification not discussed or planned

Methodology

This work follows a model of sociological-based quantitative methods[12]; as such, it is understood to be based on individual and aggregate attested assessments, which is typical for this type of research. While it is challenging to validate all aspects of the inquiry, it helps us ask new questions and investigate old questions in new ways.

Initial Input. As described above, at the beginning of the initial Capstone Design course, the practice has been to allow students to submit *requests* for some of their capstone conditions. For example, they identify who they would like as teammates and rank each of the projects that have been presented/developed by faculty according to their preference. All this information is *tabulated* to form teams and assign projects. There are no guarantees that requests will be granted. However, since students are instructed to give their highest preferences a value of 1 and follow suit with larger ranking values for lower preferences, a heat map and minimizing algorithm is applied that aims to yield the lowest aggregate score across all individuals. This means that –exceptions notwithstanding– the "best" potential combination of student engineers and projects is established. A complementary practice follows the same project ranking scale and assignment, but students are asked to *form their own teams if possible*. Only in unusual circumstances will the Capstone Design coordinator step in to make an adjustment to balance the teams. Presumably this yields the most highly preferred set of project combinations across the board. But are they the most successful?

Coding System. Nearly 50 past Capstone teams and their projects in mechanical and industrial engineering were reviewed for the data for this project. These Capstone teams and projects were categorized based on a number of initial and final criteria, which were scored by faculty and/or students to provide "levels" by which to create a situational profile of each team at the outset of capstone and again in the final assessment at the end of the Capstone experience. Depending on the question, the response data could be metric, ordinal, or binary and the statistical evaluation of each accounted for the scale of data in each case. The factors are outlined in Table 2 below.

Table 2: Evaluation Factors for Capstone Projects. Factors designated as 'overall' were assessed for the team as a whole. Factors designated as 'individual' were assessed for each member of the team.

FACTOR	Lowest Score Depiction	Intermediate value	Highest Score Depiction
1. **TF**: Team Formation Method *Overall*	0 = coordinator assigned team	0.5 = hybrid team formation. Students from each major chose one another, but not the counterparts from other major	1 = students created teams
2. **DEV**: Source/ Method of Development of the Project *Individual*	0 = no input whatsoever	0.1-0.9 = Intervening decimals indicate the degree to which each individual was responsible for and contributed the project development in terms of topic and scope.	1 = entire team worked to develop the project
3. **SEL**: Member Selection *Overall, for student-requested teams only*	0 = no one on the team chose this person	0.1-0.9 = algorithm represents proportion of team requesting	1 = everyone on the team chose this person
4. **CON**: Teammate assess. by perceived capability to contribute: skill set, work ethic *Individual*	0 = not a given reason for selection	0.1-0.9 = level to which contribution potential was a considered factor (as opposed to schedule, living proximity)	1 = the primary reason that person was requested
5. **PAL**: Friendship Level and outside connection *Individual*	0 = were not friends outside of class	0.1-0.9 = degree to which students spend social time together outside class on nights, weekends, and for nonacademic reasons and events, and are pals	1 = hang out together 'nearly all the time' outside class
6. **TOP**: Project topic ranking *Individual*	1 = very top choice project	2- (number of projects minus 1) = corresponding ranking value for each project available for selection and assignment	highest number in ranking = least desired project
7. **ADV**: Preference level for advisor –for skill or demeanor *Individual*	0= low desire to work with given advisor, prefer not to	0.1-0.9 = degree to which the advisor was targeted as a desirable mentor*; ex))* "does not matter" = 0.5; was equally preferred among 2-3 others =0.7	1 = high desire to work w/ advisor, considered best, sought out
8. **PAS**: Level of personal commitment at outset, engagement sustained through to project end; Passion *Individual*	0 = negative, disinterested, skeptical, low energy level for project	0.1-0.9 = represents attitude and personal commitment at outset and level to which it was maintained through project	1 = committed, on board, high-energy directed toward project

Classifications were based on observations of teams that the raters/advisors and authors had worked with closely as well as student attestations, course records and historical tables of initial preferences of team formation and project bids. Because some of the observations were subjective in nature, the study was limited to teams that the authors and raters/advisors had either advised or co-advised. Results were then statistically analyzed to determine what if any trends, patterns or correlations existed within. These results were evaluated in light of the previously validated prototype scores as described above.

Results

Team Formation Method and Prototype Score

Figure 1 below shows the relationship between primary team formation (TF) method and the resulting prototype score out of 10 points as seen above in Table 1. T-tests between completely instructor-formed and completely student-formed groups and prototype score resulted in a TF-Instructor average 6.4 and TF-Student average of 9.1, with prototype scores found to be significantly higher for student-formed teams $p<0.01$. Overall, this suggests that the method of team formation has a significant effect on general performance and success. However, there are instances of instructor-formed teams who earned full prototype scores, so not creating your own team does not imply a certain disadvantage. There are also additional factors that factor into the creation of student-formed teams that can have an influence on the final outcome. Those additional factors will be discussed in this paper.

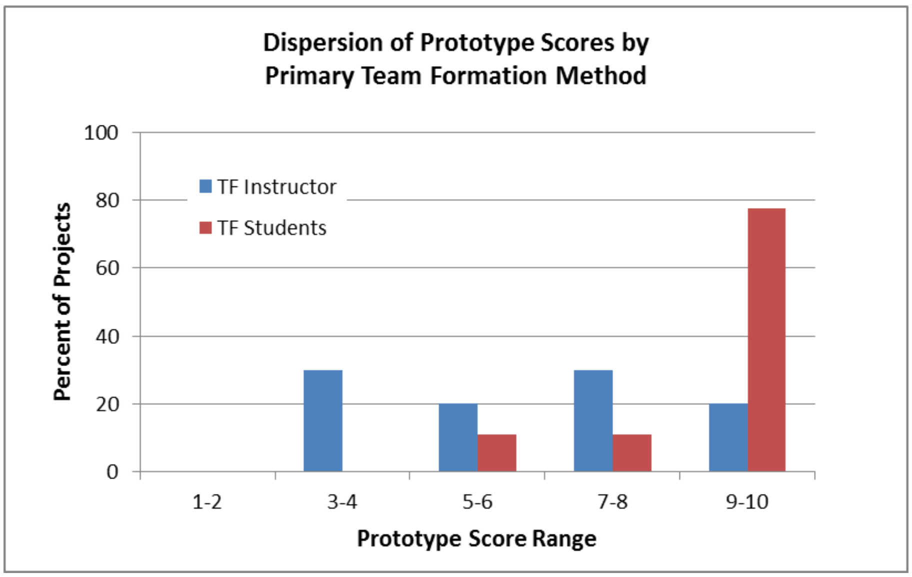

Figure 1: Results of comparison of prototype scores to primary team formation method.

Involvement in Proposing and Developing Project

None, Some, or Full: As discussed previously, projects can be proposed by industry, by faculty, or by the students themselves. Faculty-sourced projects typically have no student involvement (0), student-generated projects may be developed by a group of students who have previously formed a team, or by a smaller cadre of individuals who have team members added by the coordinator. This category has an average development score of ~.44, meaning that proposal involvement across these teams averages a little less than 45%. A fully student-developed project would earn a 1 for this category. Given the category values, Figure 2 shows the notable relationship between the final prototype score and the amount of team member involvement in development of the project topic by the 3 primary categories above. Pearson's product moment correlation results show a strong shared variance (R^2 = 0.92) between the source of projects and final work grade when all prototype scores were compared.

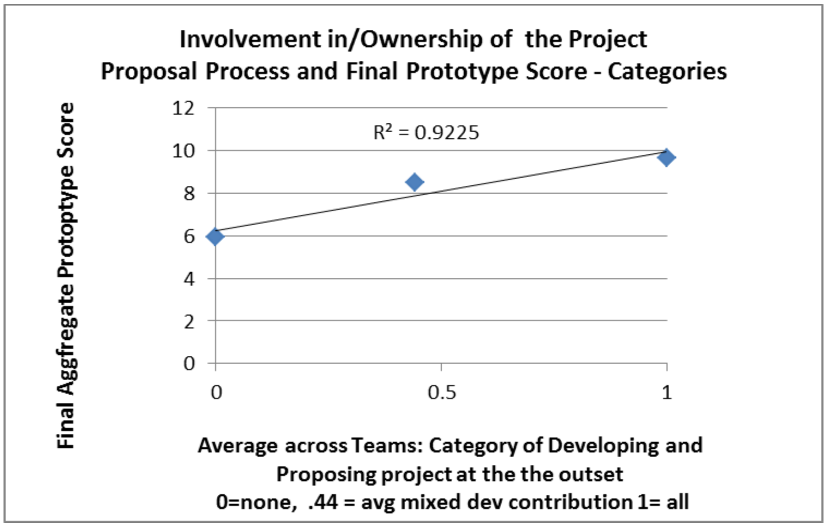

Figure 2: Results showing relationship between student-proposed projects and final prototype score

For the teams who had some level of involvement in creating a project, a more detailed correlation assesment was conducted by each team's decimal level of involvement from 0<level<1. This represents the middle category above, *the mixed development contribution*. With that correlation measure, there was a moderately strong shared variance (R^2 = .40) between the measured level (not just category) of proposing one's own project and the final prototype score. This means that even if only one member of the group had actually proposed the project, there still could be a positive effect on the final score. It seems that the sense of obligation and the personal downsides of failure were more likely to lead to efforts yielding success regardless of how many members had proposed the project. It did not seem to matter if the team members had come on board later in the process; student developed projects showed a significant amount of buy-in from all team members.

Passion for Project/Personal Engagement

The results shown in Table 3 below indicate a complex series of interactions that contribute to whether students are "passionate about their project". The operational definition of the passion factor was "the level to which an individual felt personally dedicated to and enthusiastic about the project and managed to maintain this level of engagement (in general) throughout the Capstone experience". Experience tells us –and we will soon see statistically– that passion and commitment to the project as defined can be strong indicators of success. Thus, it is beneficial to determine what leads to that passion and commitment.

A multivariate multiple regression analysis was run on several of the factors listed in Table 2: These factors included level of proposal development (DEV), the percentage of teammates that were selected by others (SEL), the level to which teammates were selected on their perceived capability to contribute (CON), the degree to which teammates were friends outside of class (PAL), preference level for their advisor (ADV) and the topic ranking value (TOP).

Results of the regression for "predictors" of project passion were found to be highly significant $p<0.001$ (*df:* 6, 119). Factor analyses indicate that the following factors (Table 3) are associated with the level of personal engagement an individual reportedly demonstrates for a Capstone project, with their significance levels.

Table 3. Regression Statistics for Factors Present versus Passion/Level of Personal Commitment for Capstone project.

Multiple R = 0.795	R^2 = 0.632
FACTOR	***Significance?***
CON – Contribution	p<.0001*
ADV – Project Advisor	p=.072
SEL – Team Selection	p=.337
DEV – Development	p=.446
PAL – Friend Level	p=.524
TOP – Topic Ranking	p=.819

The selection of teammates actively chosen because of their perceived ability to contribute (CON) to the project appears to be a strong predictor of passion ($p<0.001$). However, the reason for choosing a given teammate varies, and some methods of choosing are stronger indicators of a high level of commitment. Choosing teammates because of specific skills and work styles seems to lead to a higher level of commitment to the project. In contrast, choosing teammates because of pre-existing friendship (PAL) does not correlate as strongly with commitment and passion. It is recognized that choosing friends versus choosing teammates based on skill and style are not necessarily independent. It is possible that people are friends in part because of one another's dependable characteristics but this is not always the case. The team advisor (ADV) can make a slight difference; this is nearly significant at $p=0.072$, but does not make or break the project. Teams can be passionate about a project without being particularly enthused by the advisor assigned. Similarly, the topic of the project does not necessarily contribute to the passion (TOP). Groups can be or become passionate about a topic and project that was not a top choice for them and/or if did they not propose or develop it.

Factors for Project Success

While there are varied measures of project success in capstone, this work focuses on the final deliverable. Table 4 below shows factors at the outset of Capstone that appear to influence project success as measured by the prototype scores. The regression was significant at $p<0.0001$ with an R^2 value of ~0.66. Participating in the development of a project showed a significant impact on the final prototype score (DEV). An even more significant influence was that of the team member skill set and work style factor (CON). Choosing teammates with the work styles and technical skills to successfully contribute to and complete the project suggests a potentially higher prospect for successful projects with well-developed prototypes. Another contribution factored in is that of the passion/commitment factor (PAS). Students with a strong level of passion for and commitment to the project, as defined above, appear to produce high-scoring prototypes, which will be evaluated below. The remaining factors appeared to have little effect.

Table 4. Regression Statistics for Factors Present versus Final Prototype Score (level of success) for Capstone project.

Multiple R = 0.812	R^2 = 0.659
FACTOR	***Significance?***
CON – Contribution	p<.0001*
DEV – Development	p<.002*
PAS – Passion Level	p<.007*
SEL – Team Selection	p=.477
TOP – Topic Ranking	p=.414
PAL – Friend Level	p=.256
ADV – Project Advisor	p=.184

Other factors which did not appear to have a significant influence on the prototype score are nevertheless instructive to examine. The percentage of team members chosen, as opposed to being imposed on the team by the instructor, did not have a significant effect (SEL). This is particularly interesting since some students seem to be highly concerned when they have no idea who they will work with at the beginning of term. A related concept is the fact that working with friends (PAL) does not contribute to the final prototype score in a significant way. In fact, there is a slight overall negative effect of working with friends, if those friends were not chosen for their technical skills. There was also no significant effect with relation to the topic (TOP) or the advisor (ADV). Students who get a topic that was not a highly ranked choice or who are working with an advisor they were unenthusiastic or unsure about were still able to achieve high scores through a constellation of other factors. On the other hand, getting the 'perfect' topic and advisor combination was no guarantee of success.

Contribution of Separate Passion Metric to Success

Parsing out the single factor of passion/commitment/engagement level from the multiple regression analysis above, a standard linear regression was conducted to relate the potential contribution of passion/commitment to the subsequent prototype score for individuals on each team. This regression yielded an R^2 value of 0.73, which is highly significant at the $p<0.001$ level. This shows a strong relationship between individual strong passion values and high scores.

Figure 3 below illustrates the passion level averages for each prototype score level. This aggregate correlation is very strong, $R^2=0.81$, and highly significant at $p<0.0003$. It is recognized that this correlation is likely made up of several other intermediate factors. However, it is clear that having passion and commitment to the project and remaining personally engaged is associated with higher final scores. This is in addition to having –and being– skilled and prepared teammates, which was shown earlier to be associated with success as well.

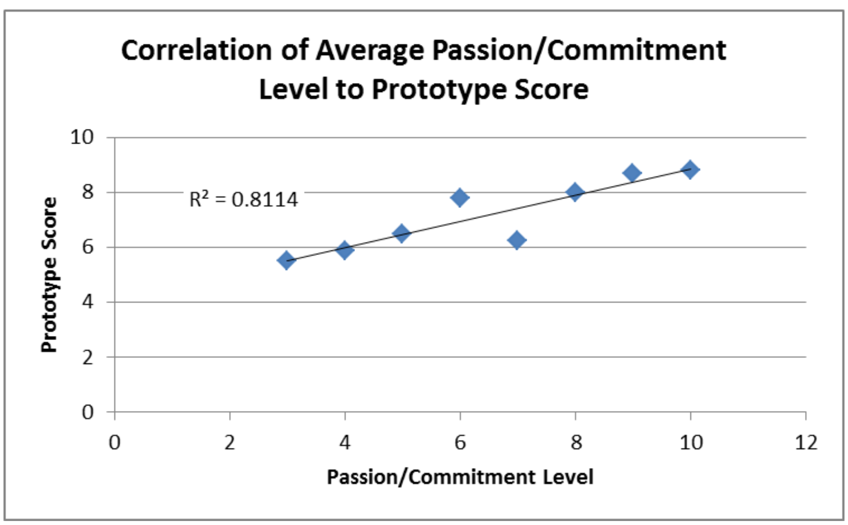

Figure 3. Correlation plot and R^2 value mapping average Passion/Commitment level to the end-of-project Prototype score.

To summarize, the contributors to the elements of "success" are outlined more qualitatively in Figure 4. The notation is given in the caption for reference. In addition to all the work that needs to happen *during* the Capstone journey, this will help us as educators guide our Capstone Design students at the *outset* of the project experience.

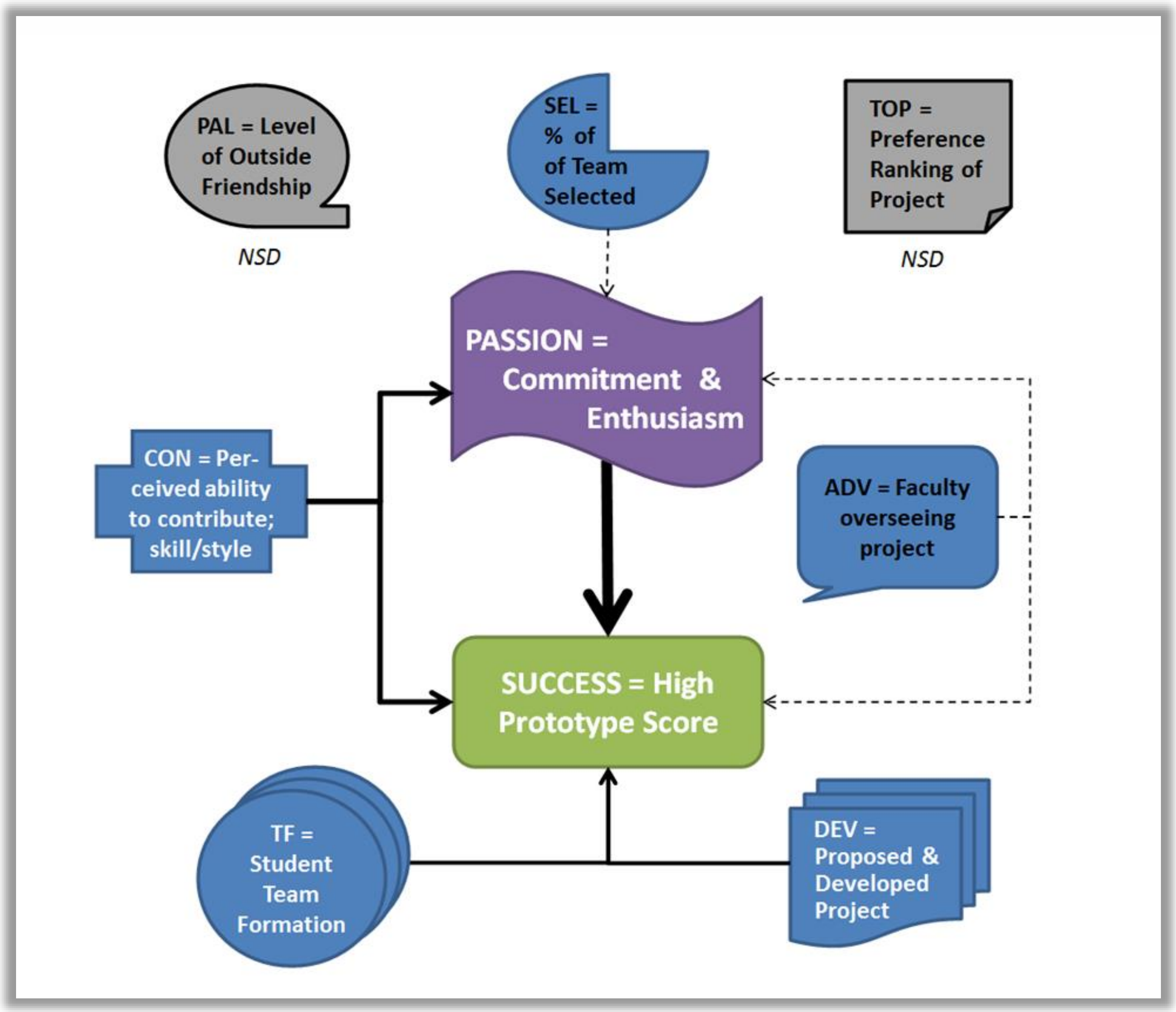

Figure 4. Strength of relationships among factors present at the outset of Capstone and subsequent components of success. Solid line = statistically significant relationship, thicker = more significant connection; black lettering = no statistical difference; dotted line = showing a bearing trend, but not a statistically significant factor; unconnected factors = no significant connection or trend found at all.

Discussion

As discussed above, we have found that in the analysis of Senior Capstone Design factors at the outset of the capstone experience, the exact topic has very little effect and the advisor may have a nominal-to-moderate effect on either the score or the level of commitment to the project. Groups can succeed even if they have a topic they did not rate highly or an advisor they did not know well or choose. In fact, some groups actively did not want their advisor or their project, but were successful ultimately because they were able to commit to the project. Anecdotally, some of these group members seemed to realize that with graduation in the balance, they needed to form a coalition and find something meaningful to engage themselves in with regard to the project if they wanted to pass the course and have a result worth presenting. Other groups who had received a project they had ranked as undesirable were either able to apply themselves to it because of their collective work skills and styles, or because they were eventually convinced of the value of the project.

Interestingly, whether or not students were working with friends did not seem to contribute either their score or their passion and commitment to the project. In fact both of these factors appeared to be bimodal, with the friend-factor being either a drawback or a benefit and not much found in between. As has been seen elsewhere in the literature, sometimes working with friends can be detrimental to the outcomes, because friends who are good to hang out with are not necessarily the ones with the strongest work ethic. However, on the other end, some of the higher performing teams are composed of members who are friends *because* they admire each other's technical skills and work habits. It is the ability to perform the necessary work for the project and the recognition of the value of those abilities that leads to a committed and successful team.

In short, the final prototype score, which is. a measure of Capstone success, is highly correlated with passion, commitment, and personal engagement with the project. In turn, this passion measure is related somewhat to whether or not the students got to choose their own team members. There is also a strong correlation to both the commitment and the score based on whether skill and work style of team members was considered in the team composition. Another strong correlation with the final prototype score is whether or not students developed and proposed the project. Student-proposed projects mean that the team has a lot of personal ownership, and thus the students want to see the project succeed. The personal embarrassment that would result if a student proposed a project and had it fail seems to be a strong motivator in student-proposed project groups.

Recommendations for Future Work

In the future, students should be surveyed to ask them to rate their own enthusiasm for the project more explicitly. Additional ratings from the individual team advisors would provide a means to establish inter-rater reliability.

Conclusion

Based on these results it seems clear that students should be encouraged to develop their own projects whenever possible. This may involve a change in the way this particular capstone course is administered. Since projects must be vetted and approved prior to the first day of class, a system will need to be put in place to elicit proposals from students prior to capstone in order to facilitate project selection and rapid team formation. Students who develop their own projects and join team members who have the skills to complete these projects tend to have a high level of commitment to them. This passion and commitment translate to high scoring projects.

This does not mean that projects which are not student-selected, or teams that are formed by the instructor are doomed to failure. The authors have noticed numerous instances of success in instructor-formed teams being assigned to projects which the students had no say in developing. The key factor seems to be the team's ability to generate a high level of passion for, engagement in, and commitment to the project. Passion and commitment seem to be related to the amount of control a student has in choosing their team members, and in particular choosing team members for their relevant abilities and work ethic. Students who are unable to come up with viable project ideas should nevertheless be encouraged to preselect team members who have desirable skills and work styles. Students should also be cautioned that working with friends solely on the basis of friendship may not be the wisest course of action. The mode word, characteristic, and factor in Capstone success is *commitment*.

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