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Examining the Effect of Design Stimuli on Perception of Peer Contribution in Design Teams

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Examining the Effect of Design Volatility on Perception of Peer Contribution in Design Teams

Abstract

Universities are incorporating more team-based learning (TBL) opportunities throughout their curricula to prepare students for the engineering profession, as observed with courses such as cornerstone and capstone design. Prior research has indicated the importance of design courses in engineering curriculum as it provides students with critical thinking skills in a conceptual setting alongside other students. However, the engineering profession is not as seamless as academic design experiences would suggest, as there are constantly changing requirements, resources, and budgets – what we coin "design volatility". Students do not typically experience design volatility, as most of their courses are well organized with a fixed syllabus. This paper examines the impact of design volatility on perception of individual and peer contribution to a semester-long, sophomore level design project. We investigate design volatility occurrences through the lens of team and peer contribution to determine how students can function on a team during design changes, as we hypothesize design volatility will impact student perception of team contribution toward a project.

To investigate this phenomenon, students were asked to complete two web-based Comprehensive Assessment of Team Member Effectiveness (CATME) Peer Evaluation surveys to assess themselves and their teammate with respect to their contribution to the project and their satisfaction with the team interaction. The initial CATME survey was administered approximately 60% of the way through the semester, when the student teams had finalized their project designs and near project completion. The students were informed shortly thereafter of a design change: the primary requirement of the project had changed, requiring the teams to reassess existing designs. At the end of the project, students were administered a second CATME survey to determine if the design volatility had an impact on the team dynamics. The results of both surveys were statistically compared for significant differences.

The results of the study suggest that student perception of their peer's contribution was unchanged following the design change. However, the students' perception of their individual contribution changed, specifically regarding their contribution to the teamwork and their expectation of quality in the final product.

Introduction

Engineering design has been referred to as a team sport. Multiple disciplines are often required for different aspects of a product, with integration of mechanical, electrical, and computer disciplines commonplace. These systems are further broken down into specialized subgroups to divide tasks equally and ensure tasks are completed by those most qualified for them, such as materials selection. Due to the structure of engineering design teams, it is important to maintain proper communication between the various groups, as alterations in one group's designs could affect other groups' designs.

To better prepare students and meet industry needs, new innovative teaching approaches have been developed, such as Project-Based Learning (PjBL). This method of teaching seeks to encourage students to learn during a project (Uziak, 2016). The closer a project reflects reality, the more a student will learn by utilizing the theoretical knowledge gathered through their coursework (Kanigolla et al., 2014). Beyond theoretical knowledge, PjBL encourages the development of soft skills, such as professional skills. Students often lack professional skills such as communication, creativity, and teamwork; however, following involvement in a project, these skills were notably improved amongst participants (Zhou, 2012). Despite the significant number of benefits that have been proven with the PjBL approach, there are notable shortfalls in this teaching style's current implementation and structure.

PjBL has seen limited application throughout all year of higher education, let alone at lower levels of education (De Los Rios et al., 2015). Rather than a gradual introduction to crucial aspects of projects and project management, it often results in a jarring experience for the student. This detracts from the full development of skills sought in industry. Further, not all students find the most benefit from a PjBL approach. Students that are highly creative often enjoy and benefit from this approach more, as it encourages their creativity. Contrastingly, those with lower creativity often suffer due to the lack of rigid structure (or dependent learning), and they are sometimes unable to participate fully, as those with higher creativity tend to take on more tasks than required (Wu & Wu, 2020). Further, these differences were correlated to other personality traits of these individuals. With creative students, exhibiting more willingness to take risks and often held a high self-image and ability to project themselves. Opposingly, those with lower grades sought to maintain their public image, taking less risks, and worrying far more about grades.

Further improvements and frameworks for PjBL have been attempted to provide accessibility and consistency between institutions. One such approach is the evolution into practice-based education (PBE), which seeks to replicate industry practices better (Mann et al., 2021). One key point of this framework is to replicate an authentic engineering practice. One gap that was noticed by the authors regarding these various frameworks is the inclusion of engineering change (EC). Engineering change (EC) is the process of modifying the functionality and/or properties of a product or the components of a product (Hamraz et al., 2013). Changes in the design of a product are guaranteed to happen throughout the design process, to match market demand or incorporate discoveries made during design or testing (Leng et al., 2016). The impact of the EC greatly impacts many aspects of the product during the product's life cycle. Some of these impacts include the lead time on product delivery, the cost of the product, and the amount of work required from the designers to formulate the changes (Hein et al., 2021). Infamously, the effect of EC can be seen in the U.S military Joint Strike Fighter Program, which delivered the first plane nearly two decades after the awarding of the contract at the cost of $1.5 trillion in 2015 currency (Jon Ludwigson, 2023). Such examples serve as a reminder of the impact that EC can have on a project at all levels of a project.

Though ideal engineering practice would not include room for changes outside of those that occur during testing, changes are inevitable. To fully prepare students for practicing engineering in industry, developing the ability to improvise and change the tasks at hand is imperative. Yet, this aspect of designing has not been studied through project-/practice-based learning framework, nor has the effects on the students of realistic engineering changes been observed. This pilot study seeks to examine the impact of engineering design changes on student teams, using the CATME Peer Evaluation Surveys.

Background

ECs often have far-reaching effects across a project. Effects immediately seen by members of the project are primary changes, however, effects will spread to other aspects of the project initially unforeseen, which are called latent changes. This phenomenon is referred to as design volatility or engineering change propagation. In the *Engineering Change* workshop held by the Cambridge-MIT institute, multinational corporations expressed the need to effectively manage ECs (Koh et al., 2012). The need for this is apparent as ECs contribute an estimated 30% of the work in a project and contribute to upwards of 80% of the cost of a product (Langer et al., 2012; Fei et al., 2011).

Current research focuses on the impact that ECs have on the product design cycle. Through the development of models/networks. An example is the function-behavior-structure (FBS) linkage model, which aims to relate the structural, functional, and behavioral elements of a component with other components in a system (Hamraz et al., 2012). Tools such as these seek to offer an ability for designers to avoid and prevent unforeseen EC propagation. However, these models largely account for the non-human factors in the design process, only factoring the impact between components with an EC. While highly impactful in mitigating an EC's risk and further costs, this excludes the impact on the designers that will implement these EC.

Changes in a project often disturb the abilities of those assigned to work on a project. Those abilities are affected by six factors: schedule and work changes, management and project characteristics, morale, and location (Ibbs et al., 2007). Beyond quantifiable impacts, such as increased worktime or cost, these factors impact qualitative metrics, such personal motivation and team interaction. These metrics prove challenging to track, as data regarding these metrics are not included in regular audits. One such method of gathering this data is the Comprehensive Assessment of Team Member Effectiveness (CATME).

CATME is a tool developed to assess the perceived contribution to a project of oneself, and other project members (Ohland et al., 2012). This tool measures the perception of a team member effectiveness in five areas critical to team problem-solving: contribution, interaction, keeping on track, expectation, and relevant knowledge. These areas are important to employers, who seek students who have developed these skills, which would efficiently transfer into a real-world industrial environment (Pung & Farris, 2011). This information can be vital to an individual, allowing a person to identify an area in which they are deficient, allowing for an avenue of self-improvement (O'Neill et al., 2015). This tool has been utilized at the university level to identify problematic teams during Capstone projects, allowing for intervention by project mentors (Beigpourian et al., 2019). CATME is an effective tool utilized in post-secondary education to evaluate team cohesion and effectiveness, utilizing key characteristics sought by industry. Thus, this study seeks to correlate the impact on these factors measured when an EC is introduced to a design team in a university setting.

Research Method / Research Setting

The data collected for the study was obtained from a sophomore-level cornerstone design course, in which students are required to complete a semester project in teams of two or three. This is the second semester of the students' cornerstone experience; the first semester cornerstone experience requires students to complete a constrained, reverse engineering design project in groups of three. The students are presented with an open-ended forward engineering design project in the second semester. This project requires students to design, build, and test a catapult. The students were provided with basic requirements for the projects: the catapult must fit within a 12" cube, the catapult must be fabricated and assembled using only basic hand tools, the projectile will be a small cork ball, and the throwing arm of the catapult *must* be 3D printed. However, the students are afforded a large amount of design freedom: the groups must indicate how far the catapult will fire the projectile, the students can choose what materials to construct the catapult out of, and the teams will propose their source of potential energy – counterweights, rubber bands, springs, etc.

The students worked throughout the semester to complete their designs, calculations, and construct their catapults. Three weeks before the catapults were to be tested, one of the primary requirements for the project was changed: the students now could *not* 3D print their catapult arms, they were to determine a different material and manufacturing method. By this point, the students had finalized all designs, calculations, and begun constructing their catapults. Directly before the requirement for the project was changed, the students were given the CATME survey to assess team members' effectiveness thus far in the project.

The students were then given another CATME survey at the end of the project, once all final deliverables were turned in, but before the catapults were tested in class. While this is a short time frame, it allows for more specifically viewing the impact of the design change, as most other factors were held constant between the two surveys.

The course was comprised of 52 students, grouped into teams of two for their catapult projects. Of the 52 students, a total of 27 opted-in and filled out the two CATME surveys, and the accompanying qualitative feedback. The study examines only the 27 students that completed all the items. The study is approved by the IRB committee at the university.

The quantitative data is analyzed using t-tests to compare subjects. Paired t-tests are performed between the student's first and second CATME surveys to determine whether there was a significant difference in the students' perception of themselves or their peers. Significance is considered to exist at an $\alpha < 0.05$, however $\alpha < 0.10$ is maintained for discussion purposes. Qualitative data is also included as additional insight into the results obtained quantitatively.

Results

The authors measured the students' team effectiveness using the CATME survey directly before the project requirement was changed, and at the end of the project but before the projects were tested and grades were assigned. The CATME survey measures the students' perceptions of themselves and their team members with respect to five different categories: contributing to the team's work, interacting with teammates, keeping the team on track, expecting quality, and having relevant KSAs (knowledge, skills, and abilities). In addition, the CATME survey requires students to answer the following questions with respect to the individual:

1. I would gladly work with this individual in the future.
2. If I were selecting members for a future work team, I would pick this person.
3. I would avoid working with this person in the future [scale reversed].
4. I like this person as an individual.
5. I consider this person to be a friend.
6. I enjoy spending time with this person.

The survey requires students to answer the following questions with respect to the team:

1. I am satisfied with my present teammates.
2. I am pleased with the way my teammates and I work together.
3. I am very satisfied with working in this team.

CATME also asks the student for qualitative feedback regarding the team effectiveness to supplement the quantitative results. While this was not analyzed statistically, some feedback is mentioned in this section for supplemental consideration.

Student Perception of Themselves and their Team Members

As outlined in the background, team member characteristics are one of the largest struggles for students working on design teams. Additionally, tension within design teams tends to increase as the project deadline approaches. Therefore, the authors hypothesized that the change in a design requirement so far along in the project would cause additional anxiety and further desperate team members. However, there were no significant changes in student perception of their teammates with respect to contributing to the team's work, interacting with teammates, keeping the team on track, expecting quality, and having relevant KSAs (knowledge, skills, and abilities). There were also no statistically significant differences between the ratings for any of the nine questions regarding the individual or the team outlined in the above section. Therefore, student satisfaction did not change with respect to their teammates within the last few weeks of the project, regardless of the design requirement change, which added significant work to the project.

Interestingly, the only significant differences in the data collected were with respect to the students' perception of *themselves*. The student's perception of their contribution to the team's work increased ($p<0.05$) and their expectation of quality increased ($p<0.10$). This is shown in Table 1 and Table 2, below.

Table 1: Contributing to the Team's Work Paired T-Test Results

Contribution	***Survey 1***	***Survey 2***
Mean	4.05	4.30
Standard Deviation	0.865	0.843
Pearson Correlation	0.734	
t Stat	-1.75	
p-value	0.048	
t Critical	1.729	

Table 2: Expecting Quality Paired T-Test Results

Expectation	***Survey 1***	***Survey 2***
Mean	4.00	4.25
Standard Deviation	0.792	0.888
Pearson Correlation	0.545	
t Stat	-1.42	
p-value	0.085	
t Critical	1.729	

Discussion

The results showed that students' perceptions of their teammate's contribution did not change significantly after the design change was introduced for the final few weeks of the project, however the students' perceptions of their personal contribution did change with respect to their contribution to the team's work (significantly) and their expectation of quality increased (maintained for discussion). This was not what the researchers expected to see, as it was hypothesized that this design volatility could cause unrest within the team structure, especially with an increased workload due to the need to redo parts of the design project.

To further examine the results, the qualitative feedback of the students was viewed between the first survey instance (before the design change was introduced) and the end of the project (after the design change was introduced). A few excerpts are included below.

The following excerpts are taken from the two students on the same team, from the two surveys:

> Student A, survey 1: *I had a fun experience working with [Student B] and I hope [they] feel the same about our experience together on this project.*
>
> Student A, survey 2: *I really enjoyed working with [Student B] on this project together, and I am looking forward to participating in group work with [them].*
>
> Student B, survey 1: *There have been a few instances where I have done most or all the work for an assignment, but it was always because there was a time crunch, and I would rather do it myself than spend the time and effort trying to coordinate and split up the work. ([Student A] always completed the work I asked [them] to do, but sometimes I underestimated the workload.) There have also been times where [Student A] has demonstrated a lack of knowledge about certain things… However, [Student A] has stepped up … [They] show up to every meeting, actively participates, and fully completes all the tasks assigned to [them] to the best of [their] ability.*

> Student B, survey 2: *…it is apparent that I did most of the work for this project, but I did this to myself. [Student A] should have put forth more effort and checked on things independently, but I also could have stepped up and informed [them] of what needed to be done and assign [them] more tasks. That would mean that I would have to stay on top of [them] for everything, but [they] would have the opportunity to contribute more. I chose to do most of it by myself because I felt it would be easier than trying to divide the work, especially if I might have to redo the work myself in the end.*

Student A expressed satisfaction in the team dynamics, while Student B expressed a great dissatisfaction working with the other team member. Further this student began to blame themselves, reflecting on ways they could have cooperated better with their teammate. This reflects a person with low and high creativity, respectively. A person with lower creativity tends to be kind and agreeable, while a person with higher creativity tends to be more asocial and hostile (Kaspi-Baruch, 2019). Utilizing the CATME tool and collecting qualitative data such as the feedback provided would allow project managers to address team members' concerns, while also improving project efficiency.

There were also a few instances in which the first set of feedback was positive, but the second survey had different results. Some comments from the second survey include:

> *I would have liked to complete this project by myself, but I understand why I could not. However, it was very difficult to work with [teammate]. [They] rarely answer my communications in a timely manner, and any time [they] say [they] will complete a certain part of the project [they] either waits to last minute to tell [they] did not do it or sends it to me after the deadline.*
>
> *[We] worked well together towards the start of the project, meeting frequently and completing checkpoints days in advance, but once we got to the building phase our pace dropped significantly. Communication became more difficult, resulting in me having to build the catapult, complete the slides, and write the report almost entirely myself. [They] put lots of time into the SolidWorks drawing package, however, and it was very well done. I believe the slowing of our pace was due to the stress… and I'm partially to blame for not requesting progress checks more often. In the future, I will make sure that I am more up front with scheduling meetings and progress checks to ensure our team is productive throughout the entire project process.*

However, rather than significantly dropping their teammate's scores for the CATME survey, the students focused on their increased contributions to the team and expecting higher quality from themselves. This could be because they could not rely on their teammates to get work done, and with increasing project pressure and additional design measures required, they opted to do the work themselves. Observations from the authors noted that those who followed this trend often exhibited introvert personality tendencies. Introversion indicates increased creative capacity for tasks that require an introspective approach and application of knowledge in information critical fields (Kaspi-Baruch, 2019). As noted previously, those with increased creativity tend to increase contributions to a project, while those with less will decrease contributions, as the increased risks introduced further their personality type (Wu & Wu, 2020). This warrants further exploration.

From the personal perspective of one of the authors, who participated in the same project as a student, this trend was consistent amongst teams. Teams often consisted of one highly creative member, and one with lower creativity, with a select few teams containing only highly/lower creativity members. Those teams with a mixture of creativity often resulted in the highly creative member contributing much of the work, while those with only one level of creativity put forth the most or least amount of effort into the project respectively. The level of creativity was reflected in the project's outcome, ranging from highly inventive designs and approaches to simple methodology to achieve the project's goal.

Conclusions and Future Work

This investigation sought to find the impact of the EC on the self-perception of a student's contributions and that of their peers in a cornerstone-level design project. Utilizing CATME, it was found that the student's self-perception increased following the EC as their contribution to the project increased, while remaining neutral of their peers. The authors plan to implement this methodological approach into a Capstone design course to measure observable change as a student would have further experience with design projects, offering a longitudinal comparison. Additionally, the authors can view other factors impacting team dynamics, such as student demographics, motivation, and attitudes toward project-based learning. Finally, there is a possibility for expanding these efforts to predict the impact of EC on human factors that also impact a design project.

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