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Design Team Processes that Contribute to Innovative Outcomes: A Mixed Methods Approach*

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It is critical to focus on the foundations of innovative design in preparing today's engineers. An understanding of the relationship of design team processes to product innovativeness can be used to mentor teams in producing innovative designs. Our objective was to measure process-level differences between engineering teams that produced innovative versus non-innovative designs by examining the behaviors and characteristics of team members from problem definition to working prototype. To do this, a mixed methods analysis was conducted on reflections made by design students. Reflective journal entries were coded using a framework tool developed in a grounded fashion from the student data. Hypotheses about the prominent themes that emerged from the content analysis were then evaluated using statistical testing to determine if process-level differences existed between teams with innovative versus non-innovative artifacts. We found that innovative teams solved problems significantly more than non-innovative teams and were proactive, reworking items early and believing in working hard initially. Innovative teams also critically assessed their skillsets and sought expertise when necessary significantly more. Many of the characteristics that innovative teams exhibited significantly more are characteristics of high performing teams as well as the entrepreneurial mindset currently advocated within engineering education. This type of design process data can be used by engineering educators to mentor teams in developing innovative outcomes. Having demonstrated that process-level behavioral characteristics of design teams can be measured, our framework tool can be used by other educators to further assess process-level data and continue to establish additional connections to innovative designs.

Keywords: innovation; engineering team design; reflection; qualitative framework

1. Introduction

Engineering innovation and the development of progressive technologies are essential to solving pressing global problems, for enhancing the quality of life, and for maintaining U.S. competitiveness in the global marketplace [1]. Currently, however, most practices in engineering education focus on aspects of "good" technical design, and innovation and entrepreneurship have *not* been fully integrated into engineering curriculums [1]. Given our competitive global environment, therefore, engineering faculty must also educate and mentor students in practices that lead to more innovative products and services. In a recent publication by the National Academy of Engineering, it was stated, "It is the responsibility of engineering educators to teach their students to be more innovative and entrepreneurial" [1]. The Obama administration has proposed a national strategy that invests in the building blocks of innovation for the next-generation STEM workforce [2]. Their premise is that engineers must be educated to be innovative for economic growth.

The present research paper focuses on these building blocks of innovative engineering design and is based on an in-depth funded research project and doctoral dissertation [3]. Specifically, to explore the foundations of innovative design, it is necessary to study the processes that occur as teams develop their products. Many different activities, contexts, challenges, and behaviors comprise the "process" that is involved in creating a senior capstone design project, including team dynamics and morale, technical design and research, problem solving and knowledge acquisition, planning and scheduling, customer communications, mentoring and support, roadblocks to progress, and revision and iteration. Since design is a complex process, teams versus individuals tend to engage in this engineering activity [4, 5].

Given this complexity, rich information and understandings can be obtained from design teams as they actively work on their projects over the course of a semester or more. A qualitative approach can be used to gather and analyze this rich, complex, process-level data, enabling and empowering students to "tell their stories" of the creation of their design projects [6]. A qualitative analysis can be extended by incorporating quantitative aspects, allowing one method to build upon the other and create depth as well as breadth of knowledge [7]. Our research takes a mixed methods approach by combining qualitative and quantitative techniques to understand the foundational

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processes involved in innovative team design projects.

In studying these building blocks of innovative designs, we are able to provide engineering educators with information to better support and mentor their students as they progress through design projects towards an innovative outcome. To this end, our research question is as follows:

> *What process-level behaviors, characteristics, and attitudes exhibited by design teams between the problem definition and working prototype stages are related to the innovativeness of the final product?*

Process-level behaviors and characteristics associated with innovative designs are likely to be characteristics of *entrepreneurial* engineers. Entrepreneurial engineers view their work through the lens of innovation. They view problems as opportunities for innovation, and they aim to design products and services that will create demand through innovation [8]. Based on a recent National Academy of Engineering publication by leading innovation and entrepreneurship researchers, engineers will need to be entrepreneurial in order to navigate in an environment of competitive pressures and bring opportunities to life in this type of environment [1].

In the following sections, we first present a review of the related literature, including studies of student design processes and reflective journaling during design as well as teamwork. We then discuss our methods for the reflective data collection, outcomes measurement, qualitative framework development and content analysis of the reflective data, and statistical testing involving the frequent themes identified during the content analysis. In the next section, we present the statistical test results comparing innovative and non-innovative teams in terms of the themes identified by project phase. Finally, we discuss the implications of the test results and evaluate our initial hypotheses about innovative versus non-innovative teams based upon the themes identified.

2. Literature review

2.1 Cognitive processes in engineering design

Among the eleven outcomes specified by the Accreditation Board for Engineering and Technology (ABET), design is one of the most complex. The design criterion states that . . . "*graduating engineers should have acquired an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability*" [9]. Further, in its 2010 annual report, ABET proposed that commitment to innovation is an important component of continuous improvement. Although not specifically called out in the eleven outcomes, innovation lies at the heart of good design [10]. Designing a complex product requires a combination of science, mathematics, and domain-specific knowledge as well as the ability to work within constraints, assess trade-offs, and meet the needs of the customer. Given these challenging requirements, engineering design education has drawn considerable attention [4, 11], and it has been proposed that engineering educators need to focus not only on teaching the technical fundamentals but also on developing behavioral and professional skills such as teamwork, communication, leadership, and multidisciplinary-based skills [12].

To this end, a previous study explored the relationship of several professional behaviors to cognitive processes and ultimately to the generation of new business ideas [13]. These researchers theorized that one's behaviors trigger cognitive processes to produce innovative new ideas. They developed and tested a theory that innovative entrepreneurs exhibit differentiating information-seeking behaviors involving questioning, observation, experimentation, and idea networking with others. They found that the ability to generate new ideas is indeed a function of these behaviors, with observation and experimentation being the most robust predictors. Questioning and idea networking were significant upon interaction with each other or the other behaviors. Our research also examines the relationship between various behaviors and elements related to the engineering design process and the outcomes of this process.

A real-world design project is complex and requires a significant time investment. Unlike the present research, most design studies in engineering education have been limited to the analysis of projects of a relatively short timeframe (i.e., a few hours or days). For example, Atman et al. compared freshman and senior engineering design processes for projects of approximately three hours in length [11, 14–16]. Although our research does not compare designers of different experience levels, experts have been found to be more organized and able to conduct concurrent processes when designing compared to novices [17].

Another differentiating aspect of our research is the focus on team-based design. Design is notably a collective endeavor given its complex nature; however, the literature for the most part has focused on studying individuals. For example, Atman et al.'s comparison of freshman and senior design processes was exclusive to individuals [14]. Another study involving engineering design processes investigated the cognitive process of iteration and characterized iterative behavior versus level of experience and performance [18]. Our research also considered elements of iteration in engineering design, such as review and modification, and their impact on design outcomes. Thus, the existing literature has taken a process-level view of design, and our research adds to this literature by examining student processes during team-based projects of considerable length (i.e., approximately six months).

2.2 High performing teams

As stated earlier, design is often a collective activity. Roberts and colleagues investigated design and problem solving and in particular how students problem solve in active and collaborative team-based contexts [19]. High performing teams have been studied in terms of their characteristics. Members of high performing teams take individual responsibility and are supportive, self-directed, and focused [20]. High performing teams also complete their projects 10–15% under budget as well as on or ahead of schedule, and typically have diverse functional backgrounds [21]. Seven characteristics of high performing teams have been identified as follows: purpose and values, empowerment, relationships and communication, flexibility, optimal productivity, recognition and appreciation, and morale [22]. Our research explicitly considered the impact of team dynamics on design outcomes and identified associations between these outcomes and critical team-level variables including interpersonal relationships and awareness of productivity.

2.3 Student reflections on the design process

Reflective journaling, which is commonly used in engineering design research, has been demonstrated to be an effective tool for students, and in particular engineering students [23, 24]. Our research uses online reflective journaling to capture the design teams' process-level data, which was subsequently analyzed via a content analysis using a coding framework developed in a grounded fashion from the data [25]. Similarly, Atman and Adams have used student design reflections to characterize the engineering design processes of freshmen versus seniors [11, 26], and Genco et al. used design reflections to compare innovative behaviors in freshmen versus seniors by examining their concept generation exercises [27]. Furthermore, student design reflections have been analyzed to understand the relationship between engineering design and the quality of the outcome, as we did in this study [28]. Many researchers have investigated the use of both individual reflection tools (e.g., sketching, journaling, and Smart Pens) as well as team-based tools (e.g., wikis and weblogs) and have found that such tools can improve ideation and conceptual design [29]. According to Adams et al., the reflective designer "moves" toward a solution and reflects on the outcomes of these moves [26].

3. Methods

3.1 Data collection

Our research takes a "process-level" mixed methods approach in studying the design work of undergraduate engineers working in teams. Our goal was to understand the underlying team processes that facilitated innovative design outcomes. This process-level data were collected as part of bioengineering senior capstone projects during the 2007–2008 and 2008–2009 academic years at two U.S. institutions. Examples of such projects included design of a new vertebral hook, development of an incubator for a third world hospital, and design of a bone screw system. Additional details of the capstone design courses can be found in the first author's dissertation in Appendix A, including additional project examples and the course requirements and curriculum [3]. Twenty-six teams participated, with 18 teams from an engineering school in the Mid-Atlantic region and eight from an engineering school in the Midwest. The number of students per team varied from three to five, and the students were paid for their participation in the study.

Each individual student was surveyed twice a week (Tuesday and Friday) through a secure online system. Both the Tuesday and Friday surveys prompted students for the activities they had utilized since the prior survey. In addition, the Friday survey included the following two open-ended questions on which our mixed methods analysis was based:

1. As you reflect over the past week, please provide a description of how you think your team is progressing on your senior project. Specifically, comment on any issues related to: team dynamics, technical design aspects, strategic considerations about the project, and customer and competitor aspects related to product development.
2. Describe an 'ah-ha' moment of the week, if any. (An 'ah-ha' moment is an instance when new or difficult concepts/issues become understandable, often suddenly or with great clarity.)

The students from the Mid-Atlantic institution completed the survey over the course of two semesters (i.e., 24 weeks), and the students at the Midwest institution completed it over three quarters (i.e., 22 weeks). Collecting qualitative data over a sustained period has been shown to provide a robust data set [30]. In total, 101 students participated in the research over a 23 week period on average. Given that a capstone is typically a four-credit course, it was assumed that each student spent approximately 12 hours per week on the project. Hence, the total study population likely spent over 1,200 hours on the design per week. Thus, our reflection data encompassed approximately 27,800 hours of student experiences with engineering design.

In this study, we assumed that students were honest in answering the open-ended questions; and it is our belief that students were honest in providing data. First, during the initial training session, students were informed that their answers would not be shared by the instructors and would not impact their grades. Second, students had the option to select "did not work," which was chosen a total of 129 times. Third, upon reviewing the data, students appeared to be selecting logical activities and writing detailed reflections; and their responses did not appear cursory in any manner.

3.2 Measuring design outcomes

The instructors at each institution rated the projects using a common scale consisting of five criteria. The rating scale was derived from a scale used for the BMEidea Competition sponsored by VentureWell, formerly known as the National Collegiate Inventors and Innovators Alliance (NCIIA) [31]. Using this as a starting point, the research team and instructors iteratively revised the rating scale to arrive at an agreed upon set of defined attributes and criteria. The rating scale contained the criteria of technical performance and standards, documentation, innovation, working prototype, and overall impact on the market or to the client. In this work, we utilized the innovation criterion to assess project outcomes. Four sub-criteria based on Schumpeter's landmark definition of innovation comprised the innovation criterion. Specifically, instructors were asked to assess product innovativeness as it related to (1) new applications of existing technology to solve problems, (2) innovative use of materials or components, (3) introduction of new manufacturing processes, and (4) design changes that reduced manufacturing costs [32].

The scale values ranged from 1 (poor) to 5 (excellent). Projects having a score of 4 or 5 on the innovation criteria were considered innovative, while projects having scores of 1 or 2 were considered non-innovative. From the instructors' ratings of the 26 capstone projects, there were eight innovative and eight non-innovative team projects. Ten projects received scores of 3 and were considered neither innovative nor non-innovative and thus not used in this portion of the analysis.

3.3 Qualitative content analysis

The reflections were instrumental in understanding team-member attitudes, behaviors, and processes as they progressed through the design projects. A grounded, emergent qualitative analysis was first done using all student reflections to identify themes, categories, and patterns present in the process data [25, 33]. Specifically, the students' complete set of weekly reflections from the start of the design project to the working prototype (i.e., approximately 23 weeks) were read by the primary analyst, and the key themes and categories were identified. Based on this initial analysis, an overarching frame-

Table 1. Categories of the Qualitative Analysis Framework

Category	Definition	Examples
Timing	Related to schedule or time.	Keeping track of the schedule, taking time issues into account, etc.
Team Dynamics	Related to team functioning, relationships, or behavior.	Ability to work as a group, complaining about other members, etc.
Skill	Related to ability or skills needed for the project.	Students' strengths, abilities, etc.
Progress	Related to tasks, activities, or qualities of the design process or project.	Testing, revising, reviewing, simplifying, ordering materials, slow, waiting, etc.
Problem	Related to problems or issues encountered.	Identifying a problem, solving a problem, potential issues, etc.
Plan	Related to project planning.	Developing a project plan, preparing a GANTT chart, dividing work, etc.
Knowledge	Related to learning or gaining project-related knowledge or experience.	Learning a concept, figuring out how to use equipment, coming to a realization, etc.
Getting Help From	Related to requesting help from particular people, such as experts, instructors, or customers.	Getting help from experts, instructors, clinicians, mentors, etc.
Getting Help In	Related to the details or experience of requesting help, such as methods, topics, obstacles, or feedback.	Financial, received feedback and suggestions, unavailability of a mentor, had a meeting with an expert, etc.
Emotional Assessment	Related to a student's feelings and emotions.	Positive, optimistic, non-confident, worry, etc.
Extra	Related to issues not categorized above.	Considering source limitations, finding a mentor, etc.

work of eleven categories was developed, as shown in Table 1. More than one category in Table 1 could apply to a given student reflection. Moreover, the categories in Table 1 contain subcategories, as shown in Table 11 in the Appendix. More than one subcategory within a given category could also apply to a given reflection.

The complete framework tool containing all of the categories and subcategories is presented in Table 11 in the Appendix. This tool, which can be used by other engineering education researchers to code design team process-level reflection data, includes a definition and example quotation for each subcategory. Following the development of this framework, a full content analysis of the student reflections was conducted by the primary analyst using the software NVivo [25, 34].

To ensure consistency during the content analysis, a detailed handbook of the codes and categories was developed and used. The framework and handbook were analyzed by a second analyst knowledgeable in engineering design and team processes to mitigate potential coder bias. Given resource limitations, the reflections were coded by the primary analyst. However, if an issue or question related to the coding occurred, the appropriate code was determined after discussion with the secondary analyst. To further ensure reliability, the entire dataset was re-coded six months later by the primary analyst, and an overall agreement of 87% was found between the two coding events. Across the various categories, the agreement was in the range of 80% to 100%, with the lowest agreement associated with the Progress category, in part due to the number of subcategories. Creswell has used the percentage of agreement among coders to ensure reliability in qualitative research, with 80% as a target level [6]. The analysts had no knowledge as to whether the reflections were from an innovative or non-innovative team.

3.4 Hypotheses about innovative versus non-innovative teams

In implementing our mixed methods approach, the prominent themes or categories that emerged from the qualitative content analysis were used to statistically test various process-level hypotheses or claims of interest about innovative versus non-innovative teams. These were the themes that occurred most frequently during the content analysis and for which we could feasibly perform statistical testing. Note that an "innovative team" refers to a team having an innovative final product, with a "non-innovative team" having a non-innovative final product. We investigated the following hypotheses, shown in Table 2, which directly align with our research question.

Table 2. Hypotheses about Team Processes

	Compared to non-innovative teams, do innovative teams . . .
1	Act like problem solvers to a greater extent?
2	Revise their designs early to a greater extent?
3	Strategize their time and progress more?
4	Recognize when they do or do not have sufficient understanding and know where to go for assistance to a greater extent?
5	Discuss their progress, albeit positive or negative, more?
6	Communicate with their customers from the beginning of the project more?
7	Work together as a group more?

To test these hypotheses for significant differences between innovative and non-innovative teams, we used the non-parametric Mann-Whitney test for independent samples given our small sample sizes. The Mann-Whitney test is based on a ranking of the data and can be used when there are concerns about meeting the assumptions of the t test, such as normality [35]. We used an alpha, or significance, level of 0.10 given the relatively small n. Since our data contained ties, we used the p-values from the Mann-Whitney tests that were adjusted for ties. To further ensure the robustness of the results given the small n, a method motivated by "leave-one-out" cross validation was employed [36]. Specifically, all possible combinations were tested using the Mann-Whitney test, with each test excluding a different innovative and non-innovative team each time. The resulting robustness percentage corresponded to the proportion of "leave-one-out" combinations that were also significant.

In addition to the open-ended question about team progress that drove the development of the coding framework in Table 1, the students were also asked to comment on any "ah-ha" or innovative moments they had over the past week. These purported "ah-ha" moments, which occurred approximately 15% of the time, were categorized as being either "substantive" or "non-substantive." A substantive "ah-ha" was associated with actual and specific progress by the team (e.g., a breakthrough on technology, a creative problem solution, etc.). Conversely, there were some reflections in which the students believed that innovation had occurred; however, nothing specific was discussed. In addition, students occasionally discussed their impressions in a non-serious or jovial manner, and these moments were also categorized as non-substantive. Table 3 shows several examples of students' ah-ha reflections. The Mann-Whitney test was also used to investigate differences in the number of substantive or non-substantive ah-ha moments reported by innovative versus non-innovative teams.

Table 3 Examples of Substantive vs. Non-Substantive Ah-Ha Moments

Ah-ha Category	Example Text
Substantive	*"One of the members had a great idea for keeping the tubing submerged. It involves putting weights in the bottom of the pool and somehow attaching these to the tubing. The attachments would have lengths that allow the tubing to be at a constant depth."*
Non-Substantive	*"Not really ah-ha, but finally meeting with our mentor and playing around with an Otoscope was really helpful."*
Non-Substantive	*"We've finally realized that the parts aren't going to magically appear and assemble themselves."*

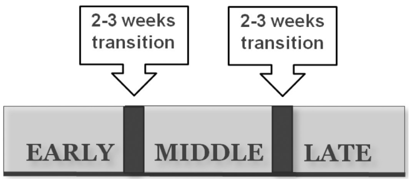

Fig. 1. Timeline of the Design Process.

To achieve more granular results, the design process timeline was taken into account when conducting the various hypothesis tests, with three separate project phases of equal duration investigated—early, middle, and late phases. This was necessary because we conjectured that student processes, behaviors, and activities likely differed according to elapsed time and student experience with the project, particularly since these projects lasted about 24 weeks, and this proved to be the case. A similar conjecture was recently put forth by a team studying innovation in engineering education. They planned to investigate how the characteristics of innovativeness "differ in the stages of innovation" [37]. A transition period was included between consecutive phases to prevent rigid borders, as shown in Figure 1. For reflections made during the transition periods, the codes were counted twice. Thus, the codes that appeared in the first transition period were counted for both the early and middle phases, and codes that appeared in the second transition period were counted for the middle and late phases.

4. Results

This section provides the results of statistically testing for differences in innovative versus non-innovative teams based on the various subcategories in the coding framework, using $\alpha = 0.10$ given the relatively small n. In this section, we present the significant findings for each project phase to provide the granular and detailed view of the process characteristics. In section 5, we will discuss the significant findings for all phases with respect to our hypotheses in Table 2. In addition, the differences in the occurrences of the "ah-ha" moments for innovative versus non-innovative teams are presented in this section.

4.1 Early phase

In the early phase, the most significant difference between innovative and non-innovative teams was in technical problem solving. Table 4 summarizes the statistical results and provides definitions and examples of the significant categories. Innovative teams solved their problems significantly more than did non-innovative teams (p = 0.01). Innovative teams also expressed their "need to work" significantly more than non-innovative teams did. In addition, in analyzing categorical data also collected as part of our overall journaling study [38], we found that innovative teams utilized significantly more management activities in the early phase, including creating a product schedule, developing a work breakdown structure, creating a communication plan for team members, and defining the statement of work. This seems to corroborate their "need to work" early in the design process. Innovative teams also discussed re-doing or starting over on some of their activities in the early phase to a larger degree than the non-innovative teams did.

Interestingly, non-innovative teams ordered needed materials for the project in the early phase to a greater extent than did innovative teams. We believe this procurement of materials so quickly may be indicative of prematurely "jumping forward" with the preliminary or detailed design versus thoroughly conducting problem definition and conceptual design, as prescribed in Dym and Little's engineering design process framework [39]. The four significant categories in Table 4 had different levels of robustness when the leave-one-out procedure was applied. However, when different α (i.e., significance) levels were used, we were able to achieve a 100% robustness percentage for all of the categories at no larger than $\alpha = 0.23$. Thus, we are able to show our significant results to also be robust at $\alpha < 0.25$, despite the small sample sizes. Since the Mann-Whitney test is based upon the ranks, removing one of the data points can change the average rank significantly, given the small sample size.

4.2 Middle phase

In the middle phase, innovative teams still solved their technical problems significantly more than non-innovative teams did (p < 0.0005), as shown in Table 5. Innovative teams evaluated or assessed their progress significantly more than non-innovative teams and indicated to a greater degree that team-member skills and abilities were considered before dividing the work. In contrast, non-innova-

Table 4. Definitions of Significant Sub Categories in the Early Phase

Category	Sub Category	*p*	Higher for Group	Definition	Example of Student Reflections
Problem	Solve	0.01	I	The students solved a technical problem encountered during the design process.	"To solve this problem and to allow for it to hit with multiple magnitudes of force we made two pivot joints on the arm, one for angle variation and another for force variation." *(innovative team)*
Progress	Order	0.08	NI	The students ordered needed materials for the project.	"We are beginning to order raw materials for our first prototype." *(non-innovative team)*
Team Dynamics	Need to Work	0.09	I	The student(s) indicated needing to be more productive with or achieve greater progress on the design.	"We SERIOUSLY need to get to work." *(innovative team)*
Progress	Re-do	0.10	I	The students started over or re-did certain portions of the project.	"We re-designed one of our sub-systems for our simulation device." *(innovative team)*

Table 5. Definitions of Significant Categories in the Middle Phase

Category	Sub Category	*p*	Higher for Group	Definition	Example of Student Reflections
Problem	Solve	<0.0005	I	The students solved a technical problem encountered during the design process.	"We bought the plastic washers to create our own bobbin." (This action solves the problem) *(innovative team)*
Progress	Review	0.04	NI	The students reviewed items related to the project or engaged in activities related to the design review.	"We have been reviewing everything we have done and been getting consumer input and advice about how to make our product." *(non-innovative team)*
Progress	Evaluation	0.06	I	The students evaluated, assessed, or interpreted their progress.	"Deciding to just adapt the power source to an LED otoscope will save a considerable amount of money and time." *(innovative team)*
Progress	No Work	0.06	NI	The student(s) had not worked on the project since their previous journal entry prompt, or they did not provide a response.	"We haven't worked on the project since last Friday." *(non-innovative team)*
Getting Help From	Instructor	0.10	NI	The student(s) received help, input, guidance, or information from the design instructor.	"Getting positive feedback on our design from our instructor was encouraging. It helps to know that we are on the right track." *(non-innovative team)*
Skill	Consider	0.10	I	The student(s) assessed, considered, or accounted for their skills when taking action on the project.	" . . . we are gaining more and more information to determine which projects complement our team's skill sets and which will provide us with the greatest design team-customer relationship." *(innovative team)*

tive teams mentioned significantly more progress reviews in the middle phase ($p = 0.04$) and therefore reviewed and verified what they had done to date. Non-innovative teams also began to seek help from their instructors significantly more. Not surprisingly, non-innovative teams indicated significantly more that work on the project had *not* occurred since their last journal entry. The robustness testing results were similar to those in the early phase. When different a levels were used, we were able to achieve a 100% robustness percentage for all of the categories in the middle phase at no larger than $\alpha = 0.23$.

4.3 Late phase

In the late phase, innovative teams received expert help in technical or specialized topics significantly more than non-innovative teams ($p = 0.02$), as shown in Table 6. Innovative teams also simplified their design activities, documented their progress, and believed they had the necessary skills to progress on their designs significantly more than their non-innovative counterparts, with *p*-values ranging from 0.09 to 0.10 for these categories. However, in the late phase, the non-innovative teams indicated that their instructors, mentors, and experts were not available to meet (i.e., "availability negative") significantly

Table 6. Definitions of Significant Categories in the Late Phase

Category	Sub Category	*p*	Higher for Group	Definition	Example of Student Reflections
Getting Help In	Expertise	0.02	I	The student(s) received technical or specialized help from their mentors, instructors, customers, etc.	"We met with Dr. X, who helped us find a pelvic trainer for testing and he showed us the trainer and we practiced and threw around ideas of the most effective way of testing our prototype compared to the current plastic models." *(innovative team)*
Getting Help In	Availability Negative	0.08	NI	The student(s) were not able to contact or reach their mentors, instructors, etc. for assistance or a meeting.	"Our meetings were canceled by our mentors so we were unable to work on this project again this week." *(non-innovative team)*
Progress	Documentation	0.09	I	The student(s) indicated that documentation related to the project was occurring, including papers, presentations, etc.	"Wrote first draft of design brief." *(innovative team)*
Progress	Simplify	0.10	I	The students simplified their design activities or process.	"He gave us a much simpler route than what we were going to do with our plates." *(innovative team)*
Skill	Positive	0.10	I	The student indicated that the team possessed the skills required to complete the project.	"We realized that although we have many things to accomplish, one of us is an expert in almost each one of them" *(innovative team)*
Team Dynamics	Refresh	0.10	NI	The student(s) refreshed, changed, or repaired team dynamics.	"Our team dynamic seems to be almost fully repaired, with our problem member being very enthusiastic about making up for lost time." *(non-innovative team)*

Table 7. Statistical Results of "ah-ha" Moments by Phase

Type of ah-ha	Early	Middle	Late
Substantive	ns	ns	$p = 0.06$ (Innovative higher)
Non-substantive	ns	ns	ns
Total	ns	$p = 0.10$ (Innovative higher)	ns

more. Interestingly, during the late phase of the project, non-innovative teams announced the need to "refresh," or repair, their team dynamics significantly more than innovative teams. The robustness testing results in the late phase were the same as those determined in the early and middle phases.

4.4 Analysis of "ah-ha" moments

Table 7 displays the Mann-Whitney test results for each type of "ah-ha" moment across the three phases. In the late phase, as may be anticipated, innovative teams had significantly more substantive "ah-ha" moments than non-innovative teams. Also, in the middle phase, innovative teams had significantly more total "ah-ha" moments. Interestingly, innovative teams did not realize "ah-ha" moments until the middle and late portions of the design process.

5. Discussion

Based on the prevalent themes that emerged from the content analysis of the students' weekly reflections, we statistically investigated several hypotheses about process-level differences between innovative and non-innovative teams. This provided rich insight into differences in the teams' attitudes, characteristics, and behaviors throughout the approximate 24-week design process. Many of the activities that were utilized significantly more by innovative teams were also characteristics of high-performing teams as well as attributes of the entrepreneurial-minded engineer, as identified by KEEN, the Kern Entrepreneurship Education Network [8]. This serves to corroborate as well as highlight our results. These entrepreneurial mindset skills go beyond the traditional technical and analytical skills that engineers must possess. They enable engineers to be members of a workforce that can maintain America's global competitiveness through ongoing innovation [1].

The hypotheses that we tested provide direct evidence for our overarching research question—*What process-level behaviors, characteristics, and attitudes exhibited by design teams between the problem definition and working prototype stages are* *related to the innovativeness of the final product?* The evidence uncovered for each of our specific hypotheses is discussed below. Capitalizing on similarities among the hypotheses, we grouped them according to the following categories for richer, more in-depth discussion: problem solving and revision, planning and reflection, and communications and teamwork.

5.1 Problem solving and revision hypotheses

Our research hypotheses related to problem solving and revision were as follows:

Hypothesis 1*:* Do innovative teams act like problem solvers to a greater extent?
Hypothesis 2: Do innovative teams revise their designs early to a greater extent?

As shown in Table 8, there is strong evidence that innovative teams solved their problems significantly more than non-innovative teams did, with significant results occurring in the early and middle phases. Anecdotally, we noticed that members of the non-innovative teams tended to spend their time "realizing what the problem was" rather than solving it. Innovative teams also re-worked portions of the project or even started over in the early phase and simplified aspects of their projects in the late phase. Since revision activities were not significantly higher for non-innovative teams, it may be possible that they "jumped forward" and focused on just one design during their project work.

In aligning our findings with previous literature, solving ambiguous and complex problems as well as the ability to learn from failures and persist have been identified as attributes of the entrepreneurial mindset [1, 8]. In addition, Ferguson and Ohland indicate that "Creatively Solving Design Problems Supports Engineering Innovativeness" [40]. In their concept map of the innovation space, problem solving skills are related to innovation skills which are in turn related to entrepreneurial skills [40]. Likewise, an entrepreneurship research team identified "creativity and innovation in problem solving" as an entrepreneurial characteristic after surveying faculty and students on their definitions of entrepreneurship [41].

5.2 Planning and reflection hypotheses

Our hypotheses related to planning and reflection were as follows:

Hypothesis 3*:* Do innovative teams strategize their time and progress more?
Hypothesis 4: Do innovative teams recognize when they do or do not have sufficient understanding and know where to go for assistance to a greater extent?

In evaluating hypothesis 3, innovative teams understood the need to work hard early in the project, as shown in Table 9. Hence, they were proactive and managed their time from the start. As stated by a member of an innovative team in the early phase, *"We SERIOUSLY need to get to work."* In the middle phase, innovative teams strategically evaluated their progress, allowing sufficient time for revision if necessary. It's possible that innovative teams did not have to be concerned with strategizing their time and progress in the late phase given their time management and proactivity in the first two phases. In a recent large-scale interview study of engineering innovators, longer-term vision and caring for the future was identified as one of the critical characteristics of an engineering innovator [37, 42].

In evaluating hypothesis 4, innovative teams assessed and considered their skills in the middle phase significantly more than non-innovative teams did. When necessary, they obtained specialized assistance by seeking help from experts and mentors in the late phase. As stated by a member of an innovative team, *"We met with Dr. X, who helped us find a pelvic trainer for testing . . . and we practiced*

Table 8. Support for Hypotheses Regarding Problem Solving and Revision

Higher for Group	Category	Sub Category	*p*	Design Phase	Hypothesis
I	Problem	Solve	0.01	Early	1
I	Problem	Solve	<0.0005	Middle	1
I	Progress	Re-do	0.10	Early	2
I	Progress	Simplify	0.10	Late	2

Table 9. Support for Hypotheses Regarding Planning and Reflection

Higher for Group	Category	Sub Category	*p*	Design Phase	Hypothesis
I	Team Dynamics	Need to Work	0.09	Early	3
I	Progress	Evaluation	0.06	Middle	3
I	Skill	Consider	0.10	Middle	4
I	Getting Help In	Expertise	0.02	Late	4
I	Skill	Positive	0.10	Late	4

and threw around ideas of the most effective way of testing our prototype compared to the current plastic models." In certain other cases, innovative teams assessed their skills and knowledge as sufficient to accomplish the project in the late phase. As a member of an innovative team noted, *"We realized that although we have many things to accomplish, one of us is an expert in almost each one of them."* The entrepreneurship research team (discussed previously) identified the ability to find, manage, and utilize resources as an entrepreneurial characteristic, in particular based upon the input of the faculty participants in their survey [41]. More generally, critical thought and reflection regarding the sufficiency of their skillsets likely contributed to the success of the innovative teams, as critical thinking is an attribute of the entrepreneurial mindset, as is the planning-centric quality of fulfillment of commitments in a timely manner [8, 43]. The tendency to frequently ask critical questions coupled with other behaviors was previously found to significantly impact innovative idea generation [13]. In his book *Consider: Harnessing the Power of Reflective Thinking in your Organization*, entrepreneur and strategist Dan Forrester states that, "Organizations that embed think time and reflection into processes and routines are more likely to generate new ideas, products, services, and solutions" [44].

In a related fashion as shown in Table 5, non-innovative teams sought help from the instructor significantly more in the middle phase, possibly after reviewing their progress significantly more. Unfortunately, in the late phase, non-innovative teams were not able to reach their mentors or instructors for assistance when needed, possibly due to the late timeframe.

5.3 Communications and teamwork hypotheses

Our three hypotheses related to communications and teamwork were as follows:

Hypothesis 5*:* Do innovative teams discuss their progress, albeit positive or negative, more?

Hypothesis 6: Do innovative teams communicate with their customers from the beginning of the project more?

Hypothesis 7: Do innovative team members work together as a group more?

As shown in Table 10, there is evidence that innovative teams discussed and evaluated their progress more than non-innovative teams. However, this is supported only in the middle phase. From the evidence in the reflections, there were no significant indications that innovative teams communicated with their customers to a greater degree at the beginning of the project. Innovative teams did document their work significantly more in the late phase, thus displaying a tendency to communicate their project in writing to the stakeholders more.

We propose that when the innovative teams considered their skills in the middle phase, they created the foundation for the team members to work together in a complementary fashion, thereby enabling the team to succeed through each member's contribution. Interestingly, in the late phase, non-innovative teams indicated the need to refresh, or repair, their team dynamics significantly more than did innovative teams ($p = 0.10$). Thus, non-innovative teams likely had problematic team dynamics and attempted to resolve them in the late phase.

Relative to the existing literature, solid communication skills, including listening, proactive and upfront customer communications, and customer needs awareness and empathy, have been called out as attributes of the entrepreneurial mindset, as has the highly-related ability to effectively collaborate [8]. Also, communication skills and effective collaboration have been identified as "21st century" skills that students need to master for work in this century [45]. In the large-scale interview study with engineering innovators, being a team manager or leader and discovering that working with other people is enjoyable and beneficial was identified as a critical characteristic of an innovator [37]. This characteristic also entails creating a shared direction in which people work together to accomplish a task [42]. In this study, being "communications-skilled" and a "team player" were also stated as characteristics of an engineering innovator [42].

In addition to displaying many of the characteristics of the entrepreneurial mindset, the teams that produced innovative designs also demonstrated many of the characteristics of high performing teams as identified in the literature to a significantly greater degree. Specifically, the innovative teams acted like problem solvers, managed and strategized their time and progress, and were mindful of the need to be proactive by working harder and re-doing certain tasks early in the project. Also,

Table 10. Support for Hypotheses Regarding Communications and Teamwork

Higher for Group	Category	Sub Category	*p*	Design Phase	Hypothesis
I	Progress	Evaluation	0.06	Middle	5
I	Progress	Documentation	0.09	Late	5
I	Skill	Consider	0.10	Middle	7

innovative teams were aware of what they knew or did not know and where to go for expert support when needed. Members of innovative teams considered their teammates' abilities and skills when taking action. These traits are all critical characteristics of high performing teams [20–22]. Thus, engineering educators should encourage and mentor their design students in these behaviors and activities and be knowledgeable of what their students are aware of, as these characteristics are associated with innovative designs.

6. Conclusions

In this research, we investigated the behaviors, characteristics, and attitudes of design team members to understand the "process" variables that corresponded to both innovative and non-innovative engineering design outcomes. The teams consisted of bioengineering students completing their senior capstone design projects during the 2007–2008 and 2008–2009 academic years. Twenty-six teams at two institutions were investigated through the use of weekly reflective journaling of their design team experiences. Using a framework tool developed from the reflective data in a grounded fashion, a content analysis of the journals was conducted. This was followed by non-parametric hypothesis testing to determine if process-level differences existed between innovative and non-innovative teams.

Using a mixed methods approach, we were able to determine that innovative teams engaged in the following activities and behaviors to a greater extent from a statistical standpoint: problem solving in several design phases, early proactive rework of designs, diligent yet strategic efforts early in the project, critical analysis and consideration of team-member skillsets, and procurement of expertise when necessary. These attributes have previously been called out in the innovation, entrepreneurship, and 21st century skills literature and are important as today's engineers prepare to enter the workforce and contribute to maintaining America's global competitiveness. Thus, it is important for engineering design educators to know that successful teams will need to act as proactive, conscientious, and critically-thinking problem solvers, being aware of their own strengths as well as their deficits and how to overcome them. In general, using this type of process-level data collected through student metacognitive exercises such as journaling, engineering faculty can formatively assess and mentor their design students during the design process, with the ultimate goal of producing more innovative products.

Thus, our study demonstrated that it is possible to measure team member, process-level behavioral characteristics and statistically relate them to the innovativeness of a capstone design product. Using the framework tool we developed after some initial training, other engineering educators or capstone project coordinators can continue to formatively assess team processes and possibly find additional connections to innovative design outcomes. Our small sample sizes were unfortunately a limitation of this study. Therefore, continued research is needed to strengthen and add to our findings and ultimately better mentor our design students for innovative outcomes. This type of research should also be pursued through additional types of qualitative methods to gather and triangulate the findings, including student interviews and focus groups. In our small sample, many of the sub-categories in our framework tool did not emerge as prevalent enough for us to conduct meaningful statistical testing. However, future and hopefully larger studies of this type will likely uncover these same themes (i.e., sub-categories), leading to the possibility of investigating additional hypotheses within the larger research question of determining those design process elements that lead to innovative design outcomes.

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Appendix

Table 11. Qualitative Analysis Framework Tool

Category	Sub Category	Definition	Example Quotation
Timing	Behind-worry	The student expressed concern about being behind schedule or not being able to complete the project on time.	"We are seriously behind on all aspects of the design process."
	Conscious	The student was aware of time constraints and deadlines relative to the project.	"We are all dedicating time to getting the requirements in on time."
	Positive	The student expressed positive or confident feelings about being on schedule or completing the project on time.	"I feel we have enough time to complete the ideas set forth at the beginning of the project."
	Urgency	The student expressed a need to work on, accomplish, or finish an aspect of the project soon.	"We should hopefully have our project finalized ASAP!"
Team Dynamics	Communication Bad	The student indicated that communications were poor, difficult, or non-existent among or between team members.	"No communication between group members."
	Complain	The student expressed annoyance with team members or team functioning.	"No one wants to take charge and put forth any ideas. We went to a meeting with our group members and three group members did not contribute anything. They didn't say a single word beyond hello. It really irritated me."
	Difficulty to meet	The student indicated that it was difficult for the team members to meet as a group or for certain members to attend meetings as often as desired.	"Our schedules have been such that we have not met as a whole group in weeks."
	Unmotivated	The student indicated that there was a lack of motivation or interest for the project by one or more members of the team (including the student himself).	"Sometimes my partner is unmotivated to do work and that puts more stress on me."
	Managerial	The student indicated that the management of team-related activities was occurring, such as setting meeting times, maintaining communications, or distributing work.	"We email back and forth to keep everyone updated with the design process."
	Motivated	The student indicated that there was good motivation or interest for working on the project by one or more members of the team (including the student himself).	"Our team dynamic is strong and our group members are all willingly contributing to the design process."
	Need to work	The student(s) indicated needing to be more productive with or achieve greater progress on the design.	"We need to start working harder, faster, smarter."
	Negative	The student indicated that problems existed with the relationships, behaviors, and functioning within the team.	"Also, another big thing is responsibility. If a team member says that they will do something, they should."
	Neutral	The student indicated no particular problems or advances, highlights, or changes with the relationships, behaviors, or functioning within the team.	"We still haven't had any issues with team dynamics or really gotten into the technical design."

Category	Sub Category	Definition	Example Quotation
Team Dynamics (*cont.*)	Positive	The student indicated particular strengths or desirable qualities in the relationships, behaviors, and functioning within the team.	"I feel we have established great team dynamics." "Everyone is contributing equally." "Our communication is good."
	Refresh	The student(s) refreshed, changed, or repaired team dynamics.	"Our team dynamic seems to be almost fully repaired, with our problem member being very enthusiastic about making up for lost time."
	Separately	The student indicated that individual or independent work was being done on the project.	"Our work was more individual this week."
	Working well	The student indicated that the team was performing work together well.	"So far our team has been working really well."
Skill	Consider	The student(s) assessed, considered, or accounted for their skills when taking action on the project.	"We currently have 3 different proposal ideas, all of which may be beyond our ability for design."
	Negative	The student indicated a gap in particular skills required to complete the project.	"However, we do not necessarily have all of the programming and electrical skills necessary to work towards the simulation projects and might be getting in too deep."
	Positive	The student indicated that the team possessed the skills required to complete the project.	"We all have strengths that others don't. Some members are more organized and delegate better while others are more technical and create designs better."
Progress	Almost done	The student(s) indicated that work on a particular aspect of the project or a project milestone was nearly complete.	"We're almost done; everything is coming together."
	Brainstorming	The student indicated that group members met for brainstorming and discussion, resulting in ideas.	"So far, our team has been brainstorming potential project ideas."
	Decide	The student(s) indicated that a decision or choice had been made related to any aspect of the project.	"Making important decisions. . ."
	Documentation	The student(s) indicated that documentation related to the project was occurring, including papers, presentations, etc.	"Wrote first draft of design brief."
	Done with the design-prototype	The student(s) indicated that the design or the prototype was complete.	"We've finally developed a working prototype of our design."
	Done with the project	The student indicated that work on the project (as a whole) was complete.	"We finished our project."
	Evaluation	The students evaluated, assessed, or interpreted their progress.	"I think one of my biggest concerns is that we choose a project that's going to be feasible within our experience and knowledge base. I don't want to take on something we can't handle, so right now my main focus is gaining more information about our potential projects to better be able to choose which one will suit us best."
	Feasibility	The student(s) considered the feasibility of the design or final product.	"We are also considering the technical feasibility again of the WISER center project."
	Idea	The student(s) indicated that an idea or alternative was generated by an individual or a group.	". . . finding alternatives."
	Make changes	The student(s) made larger changes within the project, such as a design change, or switched projects completely. This excludes changes to project documentation.	"However, we are running into many technical problems as we begin to assemble the completed pieces and have had to make several design changes along the way."
	Meet	The student discussed the occurrence of a team meeting.	"We meet on Tuesday night to look at the assignment and then split up the work from there."
	Modification-Revise	The student indicated that small adjustments were made to the design or the project.	"In this stage we refined our design to only include a fraction of the system we had originally thought of."

Category	Sub Category	Definition	Example Quotation
Progress (*cont.*)	Moving ahead	The student indicated that the team was making progress on the project, or that the project was progressing forward.	"Our project is moving along very well."
	Need to do	The student indicated that particular tasks or objectives had to be completed or accomplished, or that certain actions related to the project were necessary.	"Our group needs to do significant research before we all meet together and decide how we're going to tackle the assignments."
	Neutral	The student indicated that work had occurred on the project; however, there was nothing particularly positive or negative mentioned.	"We worked on the draft."
	No physical	The student(s) indicated that the team had not begun, or had made negligible progress, in the physical design since their previous journal entry prompt.	"We do not have any physical design."
	No progress	The student(s) perceived there to be no progress, despite having worked on the design or project.	"There has been no progress."
	No work	The student(s) had not worked on the project since their previous journal entry prompt, or they did not provide a response.	"I have been on vacation since Thursday of last week, and have not worked on the project.
	Order	The student(s) ordered needed materials for the project.	"We are beginning to order raw materials for our first prototype."
	Positive	The student(s) indicated that forward progress was occurring on the project, possibly due to a positive contributing factor.	"We have accomplished the items we have set out to do and we are moving right along with the process."
	Presentation	The student mentioned activity related to a project presentation.	"We worked on our presentation."
	Re-do	The students started over or re-did certain portions of the project.	"We redesigned one of our subsystems for our simulation device."
	Research	The student(s) conducted research or sought unknown information related to the project, such as patent searches.	"This week we considered several designs and did more research on current designs available in the field."
	Review	The students reviewed items related to the project or engaged in activities related to the design review.	"We are reviewing multiple prototypes."
	Revise Documentation	The student(s) made changes to their documentation for the design or project.	"Modified previous documentation (really productive)."
	Simplify	The students simplified their design activities or process.	"During our client meeting, I realized the project was not as complex as I had thought; we are simplifying some aspects."
	Slow	The student(s) indicated that progress on the design or project was slow, or that faster progress was necessary.	"We're coming along slowly."
	Strategy	The students applied a particular method or approach to solve a problem or accomplish a task.	"We have decided on our final design concept and have broken it into subsystems."
	Testing	The student(s) planned for or performed testing or engaged in activities related to testing of the design.	"We tested our materials and neoprene was the best choice."
	Waiting	The student(s) mentioned they were waiting for something related to the project work.	"We are currently waiting for our mentor's advice on how to proceed."
	Well	The student(s) indicated that progress on the design or project was good, or that the project was doing well or running smoothly.	"Our team is progressing well."
	Work hard	The student(s) indicated that hard work, good effort, or significant time was being invested on the project.	"We are putting in some late stressful nights."
	Quickly	The student(s) indicated that progress on the design or project was particularly fast.	"We are progressing very rapidly in building our model."

Category	Sub Category	Definition	Example Quotation
Problem	Could not solve	The students have not been able to solve a technical problem(s) encountered during the design process.	"We have made multiple modifications to our solenoid, but none has produced enough voltage to successfully power our otoscope."
	Did not apply the solution	The students were not able to implement a particular solution within the design, possibly given certain constraints such as time or money.	"Ideally, we would remake another prototype with professional stitching and retest it, but we don't have the time to do so before the end of the semester."
	General	The student(s) encountered a physical, concrete problem with their design or within the project.	"When we tested our product, the material that we were using for the skin wasn't as conductive as we had hoped."
	Generate solutions	The student(s) indicated that possible solution ideas had been generated for a technical issue.	"Met with our adviser and came up with some good solutions to problems in our design."
	Identify	The student(s) identified, pinpointed, or discovered a technical problem within the design, or identified reasons or explanations for a problem.	"After a meeting with the design professors, we believe that the excess air in the tubing may be causing a great amount of extra stress on the motor."
	Issue	The student(s) encountered intangible problems or issues related to the project, such as struggling or disagreement.	"We have some ideas, but are still struggling with how everything will fit together."
	Potential Issues	The student(s) indicated a current condition or situation that could become an issue of concern in the future.	"We still have not picked a project."
	Solve	The students solved a technical problem encountered during the design process.	"We wound a new solenoid this week and are now achieving enough voltage to power the LED in the otoscope."
Plan	Divide work	The students assigned and divided work responsibilities among the team members.	"We split up the documentation that needs to be completed and set a schedule."
	Progress	The student(s) developed a plan for the project or design, or indicated activities that are planned to occur for the project.	". . . made a more detailed plan for our design."
	Schedule	The student(s) created or updated a schedule or timeline for project activities, or scheduled time for a certain task.	"We order supplies this week and were able to get a clear schedule of what needs to be completed at certain times."
	Short term	The student(s) made plans to work on certain tasks in the short term (i.e., within the next week).	". . . drawing up the final design in the next week."
Knowledge	Experience	The student(s) gained knowledge or understanding through observing, experiencing, or using a process, event, or object/device.	"We went to UPMC to learn how the current device works and to get our hands on what we need to accomplish in adding to the device."
	Learn	The student(s) learned project-related concepts or topics, or gained knowledge for the project through items such as tutorials or other training.	"We learned to put a counterbore into a square piece of poly that we had in order to sink the screw inside."
	Realization-Figuring out	The student(s) came to a realization or discovery, figured out a problem or challenge, or gained clarity (sometimes suddenly) related to a certain aspect of the project.	"We came to the realization that a crank dynamo would provide a more reliable power source, but sacrifice ease of use."
Getting Help in	Availability Negative	The student(s) were not able to contact or reach their mentors, instructors, etc. for assistance or a meeting.	"We had a hard time getting hold of our mentor so that slowed us down."
	Expertise	The student(s) received technical or specialized help from their mentors, instructors, customers, etc.	"This week we have met with two experts. Dr. X who showed us a vascular injection on the Blue Phantom simulator and Y who does all of the machine work in Benedum."
	Financial	The student(s) received funding or other financial help or assistance.	"Our mentor has stated that money is not an issue and he will work with us as much as possible."
	Meeting	The student(s) had a meeting or a conference to speak to or get assistance from a mentor, instructor, expert, customer, etc.	"We have met with outside expertise, such as clinicians, nurses, etc."

Category	Sub Category	Definition	Example Quotation
Getting Help in (*cont.*)	Motivation	The student(s) were motivated, encouraged, or excited by positive or good feedback received on the design.	"After talking to X, we got a lot of encouragement and positive feedback on our design so far."
	Review	The student(s) received feedback or suggestions on, or had a review of, the design.	"We also received feedback from a doctor who works with health care in developing countries, the proposed market for our device."
Getting Help from	Clinician	The student(s) received help, input, guidance, or information from a clinician, such a doctor, nurse, or pharmacist.	"I met with the doctor and viewed a couple of colonoscopies to discuss the trouble doctors have with endoscopes."
	Customer	The student(s) received help, input, guidance, or information from the customer, client, or end user.	"We have spoken to our mentors and the customer about the project, but have not yet begun the actual design."
	Experts	The student(s) received help, input, guidance, or information from an expert, specialist, or other person skilled, knowledgeable, or having authority in a particular area (excluding the design instructor, mentor, customer, or a clinician).	"We have already spoken to an OT and an engineer about the feasibility and usefulness of the project."
	Instructor	The student(s) received help, input, guidance, or information from the design instructor.	"The documents have come together pretty well and have had positive initial reviews from our instructor."
	Mentor	The student(s) received help, input, guidance, or information from the design mentor or advisor (excluding the design instructor).	"We also met with our mentor to brainstorm project ideas and decided on the specific project we want to do."
	Negative	The student(s) indicated problems, concerns, or gaps related to receiving help, input, guidance, or information on the design.	"However, as I have mentioned in the past, the lack of support from our professor and his lack of understanding our project along with how advanced we are, hinders our self-esteem as a group greatly."
Emotional assessment	Positive-Optimistic	The student(s) indicated that he/she or other team members felt good, happy, positive, optimistic, or confident about the design or an aspect of the project.	"In general it is easy for us to stay on task and efficiently complete work at our weekly meetings."
	Negative	The student(s) indicated that he/she or other team members felt disheartened, unhappy, negative, overwhelmed, non-confident, or non-hopeful about the design or an aspect of the project.	"This will be extremely difficult."
	Worry	The student(s) indicated that he/she or other team members felt scared, worried, anxious, or concerned about the design or an aspect of the project, excluding concerns about being behind schedule or not being able to complete the project on time.	"His concern about the feasibility of our device scares me."
Extra	Communicating with the customers in "Problem definition" phase	The student(s) met with or communicated with the customer to gather or discuss requirements, or considered or sought the customer's needs or requirements.	"So, this week we sat down with the customer to try and better define the objectives and design specifications of the two other projects."
	Considering source limitations	The student(s) considered or indicated an awareness of physical resources and/or limitations related to the project, including money, machinery, and software.	"Since our budget is small, we cannot spend frivolously, but we must spend some money so that we can get moving."
	Have a mentor	The student(s) chose or found a mentor for the project.	"This week we found a mentor."
	Hope	The student(s) expressed a hope or desire related to some aspect of the project.	"Hopefully this weekend something will break for us".