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Promoting Individuals' Teamsmanship and Goal Achievement while Working on Team Design Projects

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Introduction

In accredited mechanical engineering undergraduate programs, there is often a gap in the structure and educational outcomes between Freshman/Sophomore-year design projects and Senior/Capstone design projects. In the former category, projects are usually highly structured and uniform in scope across the class, and roles on the team and subgoals are typically specified to the students [1]. In contrast, Senior/Capstone projects range in scope and complexity from team to team depending on the sponsor, team size and composition can vary, and subgoals must be generated and managed by the students themselves [2,3]. Increasing complexity and ambiguity are essential for simulating a more "real-world" design experience; however, they can create conditions for behaviors and situations that are detrimental to the growth of individual team members [4,5].

Certain types of conflict and bad team behavior can develop as the structure of the team design experience is loosened. With student teams allowed to organize themselves, a subset may dictate the actions of the team rather than deciding by consensus [6]. Alternatively, the team may fracture, with different subgroups acting independently and not communicating [7]. Social loafing becomes more prevalent as individual accountability decreases [5]. Other behaviors may benefit the team but inhibit individuals' learning and skill development. For example, the roles taken on previous teams can direct the role a team member is expected to play under the dictum of maximizing their contributions to the overall success of the team [8]. Confidence gained from prior experience—or lack thereof—may also drive a team member to assume a certain role [9,10].

To combat this, we examine methods for promoting an individual team member's skill development, confidence, and goal attainment while contributing positively to their team's cohesion and product. We include three data sources: timely surveys of students' goals, progress towards those goals, and how they align with their perceived contributions to the team; team checklists and manufacturing plans updated in real time to include specific tasks, ownership, status, and any assistance required; and students' reflective documentation of shared knowledge, skills, and mental models. These data are complemented by peer assessments occurring at major project milestones [11]. Combined, these instruments are used to track student and team growth in the context of team dynamics and decision-making processes. Our interest in these data is based on previous studies by our team that have examined the complex interplay between prior student experiences, perceived self-efficacy, and student task choice and/or team task delegation in engineering design project experiences [12,13].

The setting for this study is a unique, Junior-level two-semester Machine Design course sequence, presented in [14], that features a year-long industry sponsored design project. This project is built around individual and team milestones to provide all students with mastery experiences and opportunities for task choice and self-growth. As described in detail in this paper, the project scope, building an automated monoblock pill bottle filling station, is broad enough to require large teams of 9-10 students, thus giving students more opportunities to practice team management, division of labor, and task interdependence while simulating an industry setting [15].

The details of this study are organized in the following sections. "Academic Setting of this Study" provides details of the year-long team design project on which this study is based, along with a brief description of the two semester-long courses and the learning objectives that support and provide context for this project. Next, "Data and Collection Methods" describes the types of data collected for this study and the methods by which they were collected. The "Analysis and Results" section explains our methods for parsing and analyzing the data we collected as well as key findings from a comparison of high- and low-performing teams. Finally, in "Discussion" we summarize what we concluded from our results and provide some recommendations for effecting positive change in students' team design project experiences as well as directions for future study.

Academic Setting of this Study

In the following subsections of this paper, we present the academic setting of the present study: a two-semester, junior-year Machine Design course sequence and the year-long design project these courses support. Both the technical and durable student outcomes are presented along with the schedule of assessment, which we utilize to gather data for this study. The setting for this study is an ABET accredited Mechanical Engineering program [16] at a public land and sea grant university in the Mid-Atlantic US with a mid-sized course enrollment (ca. 140 students per year).

Course and Design Project Descriptions

"Machine Design" is typically a one or two semester course sequence, usually occurring in the junior year, that builds upon the fundamentals taught in Statics, Dynamics, and Solid Mechanics while also serving as preparation for Senior/Capstone Engineering Design experiences [17,18,19]. Thus, these courses provide a key stepping stone from a more structured learning environment to a more open-ended workplace-like environment that serves as a culmination of students' undergraduate engineering programs. To accomplish this, many technical skills must be strengthened and reinforced—such as Computer Aided Design, Finite Element Analysis and other simulation tools, experimental testing, and design validation—as well as durable skills such as teamwork, communication, and project management [20].

With these challenges in mind, our previous study examined the development and assessment of a two-semester junior-year Machine Design course sequence and, in particular, a year-long team design project spanning both courses [14]. Briefly, the scope of the design project is to build a *Monoblock Pill Bottle Filling Station*, shown in Figure 1. The purpose of this machine is to take empty pill bottles loaded in bulk, fill them with a precise number of pills, screw the caps on, and deposit the filled bottles into a receptacle. Furthermore, once the students load the materials and start the program, the machine should run autonomously. Thus, in addition to the mechanical aspects of Machine Design, skills such as microcontroller programming, motor control, and feedback using integrated sensors are also required for this project.

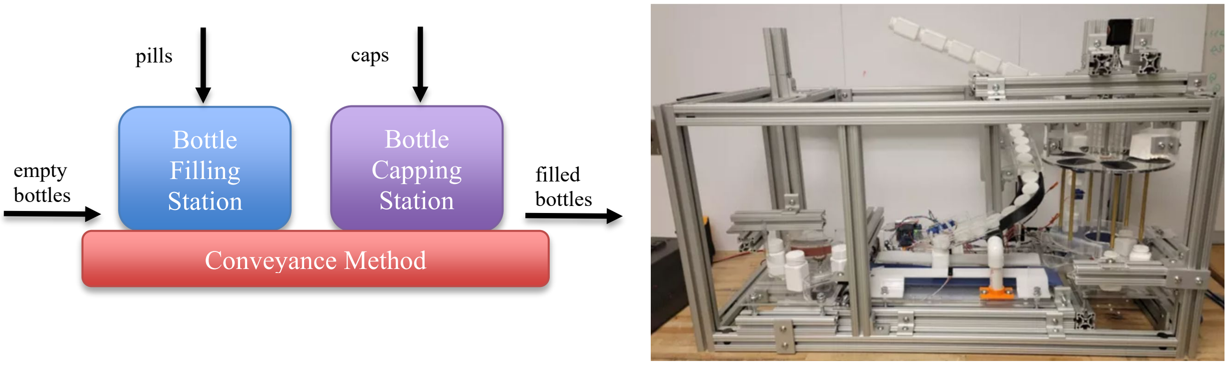

Figure 1. A schematic of the mechanisms involved in a Monoblock Pill Bottle Filling station. Empty bottles and caps are loaded 12 at a time, as well as at least 360 pills. Once the machine is activated, the bottles move through the system using a conveyance method, first to a station that fills the bottle with precisely 30 pills, then to a station where the cap is placed onto the bottle and screwed on tight (left). A final prototype from one of the student teams, primarily supported by 80/20 extrusion, 80/20 compatible fasteners, and laser-cut, 3D printed, or machined parts (right).

Schedule of Assessment

As discussed in our previous paper [14], the primary purpose of the two-semester Machine Design course sequence and design project is to bridge the gap between foundational coursework and design experiences and capstone/senior design. This requires the introduction of new technical content—such as kinematics and dynamics of complex machines and mechanical failure analysis—and a more open-ended, multidisciplinary design experience. We also continuously interweave self-taught skill mastery experiences, both individual and collaborative. These endeavors resulted in an array of technical and non-technical learning objectives whose rationales are given in [14]. A particular learning objective, "Work effectively on large, collaborative design teams", is the focus of this study. Both the team and individual data collected and analyzed in this study are in the context of the team design project experience.

Table 1 shows the design project schedule over its two-semester span, which is utilized by the present study to time its data collection. Overall, the design project follows a four-phase design process [2] (Phase 1: Problem Definition, Phase 2: Conceptual Design, Phase 3: Detailed Design, Phase 4: Design Validation) and is scaffolded by requiring teams to achieve set milestones every 2-3 weeks alongside individual skill exercises throughout both semesters [1,21]. Data gathered for this study coincides with major project milestones, as described in the following paragraphs.

Table 1. Design project schedule for fall and spring semesters

Week	Design Project Tasks	Individual Skill Exercises	Student Data Collection
Fall Semester			
1	Benchmarking conveyance options	Machine Shop safety training	Team norms and individual goal statements
2	Benchmarking filling/capping options	Arduino programming	
3	Prototyping warm-up: example conveyance mechanisms		
4			
5		Machine Shop mill training	

6	Midterm Design Review #1		CATME peer review
7	Concept generation and selection		
8			
9			
10	Midterm Design Review #2		CATME peer review
11	Detailed design Proof-of-concept construction		Individual reflection
12			
13			
14			
15	Final Design Review		CATME peer review Individual reflection
Spring Semester			
1	Manufacturing plan	Manufacturability exercise	Team midpoint assessment
2		Arduino-based motion control	
3	Manufacturing Review		
4	Detailed design: fabrication and motor installation		
5			
6			
7	Midterm Design Review #1		CATME peer review
8	Installation of sensors and safety features	Soldering	Individual reflection
9			
10			
11	Autonomous operation		
12			
13	Midterm Design Review #2		CATME peer review
14	Design testing and validation		
15			
16	Final Design Review		CATME peer review Individual reflection

Major design reviews are highlighted in red in Table 1 and consist of written documents and oral presentations that are evaluated by a panel of 3-4 industry experts in fields of manufacturing and automation. These reviews occur at the end of each design phase and at major prototyping milestones such as completing the primary motion elements or adding sensors and feedback control to the programming. Peer and self-evaluation using the CATME evaluation system (Comprehensive Assessment of Team Member Effectiveness [11]) are synchronized with these reviews. The milestones listed under the column "Design Project Tasks" help further divide the phases into smaller steps that gradually become broader as the project progresses. These periodic deadlines ensure that students are at relatively the same point in their design process and skill development when we ask for reflections and self-assessments [5,15].

Along with these team milestones, students must successfully complete several individual mastery experiences, listed in the column "Individual Skill Exercises" of Table 1. These skill exercises are evaluated using a specifications grading system: students must demonstrate competence in each of the required skills and may keep retrying any failed demonstrations until they pass. Each skill is graded on a pass/fail basis, and students must pass every skill to pass each course [21].

Data and Collection Methods

For this study we collected data from students throughout the Fall 2022 semester, as listed in the column "Student Data Collection" in Table 1 and described in the following subsections. All of these items are required (i.e. graded) elements of these courses: individual and team assignments and self-reflections. These course elements are assigned in a standard educational setting alongside quizzes and homework problem sets.

Individual and team goal statements and self-assessments

In the beginning of the fall semester, teams meet for the first time and establish their team norms during week one. At minimum, these norms must include statements in three core areas: (1) communication practices, e.g., whether they are using text, email, and/or GroupMe; (2) specific details about team meetings, including frequency, method (Zoom or in-person?), and specific times; and (3) how they plan to address internal conflict [22].

Along with the team norms, students describe their own goals (what they hope to get out of their team design project experience) and strengths/contributions to their teams. These individual goals and self-assessments are discussed with their teams, along with a TA facilitator, to develop a structure whose purpose is to enable every team member to contribute their strengths and learn the skills they aspire to [23].

At the beginning of the spring semester, the team norms and individual goals and contributions are updated as part of a project midpoint assessment. This is again a team effort to reach a consensus on how the team performed during the first half of the project and what they can do to be successful in the second half. For this assessment, teams are asked to describe why any norms were varied or kept the same, to identify any strengths and weaknesses they exhibited during the first half, and to describe how the team will address their weaknesses.

Individual reflections

In contrast to the team self-assessments, students are periodically asked to reflect on the knowledge and skills they have developed during the design project to that point and how they have incorporated them into their teams' models for success in their endeavors. Furthermore, they are asked to comment on the confidence they have in their own perspectives and how effective they have been at influencing their team's trajectory [12].

Specifically, they are asked the following questions:

1. Personal Growth Goals: Please describe your individual growth goals for the team design project, i.e. what do you personally hope to get out of this experience. Your goals may be the same as those you reported in Milestone 1 [at the beginning of the fall semester] or the Initial Prototyping quiz [at the midpoint of the fall semester], or they may have evolved; either way is fine. These goals may be technical in nature or may focus on teamwork or management skills, for example.
2. Contribution Reflection: Reflect on the contributions you've made to this team design project and how closely they align with your individual growth goals. How would you describe the progress you've made towards these goals?
3. Influence on Team's Path to Success: Reflect on how your personal contributions, attitude, and mindset have been incorporated into your team's model for success in your design project. Think about how your team's process and mindset would have been different had you not been on the team.
4. Self-Confidence: Describe the confidence you have in your own skills, ideas, and mindset and how effective you feel you have been as a teammate bringing these to the team.

This reflection takes the form of a quiz posted on Canvas (our university's learning management system). These reflections occur at the midpoint and end of each semester of the project, as shown in Table 1.

Peer and self-evaluations through CATME

Peer and self-evaluation using CATME [11] is a regular part of all design courses within the undergraduate program in mechanical engineering. CATME evaluations are typically required of all students 2-4 times throughout a course or project, and the two courses involved in this study are no exception. Peer and self-evaluations are integral to cooperative learning in group projects to provide individual accountability [24]. We use students' self- and peer evaluations to gauge their orientation towards design tasks, their level of engagement in the design project, and their technical, communication, and project management skills. CATME evaluations produce multipliers (with the standard being 1.0) that the teaching assistants take into consideration when assigning individual grades to team-based course elements. For this project, CATME evaluations occur alongside the major design reviews highlighted in red in Table 1.

Team Checklists and Manufacturing Plans

Teams are required to maintain a list of all their activities, who is doing what, and what the current status of each activity is. Major components/assignments are broken down into discrete tasks, each of which is assigned a supervisor and one or more team members. Progress is noted using one of the following options: C – complete, IP – in progress, or NS – not started. An example Team Checklist is shown in Figure 2.

Component/ Assignment	Tasks	Assigned To	Supervisor	Progress	Completion Date	Notes	Week
Team Norms		All	Katie	C	9/1		
Benchmarking			Katie	C			
	Create/Format Table	Aaron		C	9/2	Insert any visuals	1
	Perform Research	All Members		C		Describe what was found	
	Format the links	All Members		C		Use a reference editor	
Prototyping Warmup			Aaron	C			
	80x20 frame	All Members		C	9/5		
	Rotary Table	Samantha, Joe, Mike	Samantha	C	9/16	Starting work this thursday (9/15) - will finish before 9/23	
	Conveyor Belt	Mary, Tommy, Tom	Tom	C	9/23		
	Lead Screw	Katie, Bobby, Rick		C	9/29	Started work 9/13 to figure out game plan and made frame. Will work on carpentry week of 9/19	
	Lead Screw Mount	Rick		C	9/29	Realized on 9/22 that a mount need to be created for threaded part of lead screw. Rick is process of making it to be milled	2

Figure 2. An example Team Checklist from one of the design teams showing the first two weeks of the fall semester. Note, all team member names have been altered.

Starting in the spring semester, as teams transition their prototypes from "proof of concept" to precision-machined and fully functional, they must maintain a Manufacturing Plan that serves as a hub for their manufacturing activities. A key requirement of this plan is that each member of the team must "own" at least one custom fabricated part, meaning they are in charge of the drawings, manufacturing, and answering any questions. Fabrication Methods include Machine Shop (metalwork and welding), 3D print, laser cut, carpentry (includes foam cutting), and stock components (including alterations thereof). Status is one of the following: not started, designing, ready to fabricate, fabrication in progress, and complete. Students must also keep track of any dependencies of their part's design, being mindful of how a change in one part can effect a change in another. An example Manufacturing Plan is shown in Figure 3.

Part Name and Link	Owner	Fabrication Method	Status	Purpose	Dependencies
Conveyor Belt Base	Aaron	Laser Cut	Complete	Allow belts to maintain stiffness	80/20 framing underneath, roller location relative to drive motor
Conveyor Belt	Bobby	Stock Components	Complete	Allows belts to move by motor	Belt base and rollers
Guide Rail Holders	Karen	Laser Cut	Complete	Allows bottle to not fall off and get filled/capped	Conveyor belt width and loction of capping mechanisms
Cap Dispenser	John	3D Print	Complete	Allows caps to align properly on bottles	Height of 80/20 box
Cap Tightening	Mike	3D Print	Complete	Fastens dispensed caps onto filled pill bottles	Tightener dimensions
Storage Box	William	Laser Cut	Complete	Holds complete assembly of bottles	Length of conveyor belts and width of bottle dispenser
Bottle Dispenser Magazine	Cory	Laser Cut	Complete	Holds 12 bottles for manufacturing	Height of 80/20 box
Bottle Dispenser	Nancy	Laser Cut	Complete	Pushes bottles onto conveyor belts	Distance between piston and magazine as well as magazine and
Star Rotary Piece/Base	Michelle	3D Print	Complete	Transfers bottles between conveyor belts	Distance between centers of conveyor belts and length of 80/20 frame
Pill Dispenser	Ray	3D Print	Complete	Drops 30 pills into bottles that pass underneath	Height of 80*20 box

Figure 3. An example Manufacturing Plan from one of the design teams showing the ownership and status of each component of the prototype. Note, all team member names have been altered.

Each team shares their Team Checklist and Manufacturing Plan with their TA advisor and updates them in real time, documenting what design project tasks are in planning, underway, or completed. Furthermore, each task has a point of contact and description of what skills or resources are required. Also noted is if assistance is required, particularly for larger or more complex tasks. The Manufacturing Plans are shared via Google Drive with Design Studio TAs and staff who can update them as parts become ready, for example from a 3D printer or laser cutter, and refer to and comment on mechanical drawings. To ease their access, all part files must be linked in the first column of the Manufacturing Plan. Maintaining these documents is a graded portion of every rubric used throughout the design process.

Analysis and Results

Design Project Outcomes

This paper presents analysis and results related to data collected during Fall 2022, the first semester of the year-long course sequence for the academic year 2022-2023. There are 144 students enrolled in the course, divided into 15 teams of 9-10 members each. There are 8 TAs for the course, so each TA advises 2 teams. At the time of publication, teams are at the halfway point of the project, having worked together for one semester already. Some sample student projects are showcased in Figure 4. At this stage, teams have produced proof-of-concept prototypes for the purpose of: (1) early validation of their chosen design concepts, (2) rough sizing and spacing of parts for the next step (design for manufacture), and (3) providing visual aids and demonstrations for their final design review of the fall semester [14]. To quickly produce a prototype that demonstrates their ideas, teams are encouraged to utilize rapid prototyping techniques such as carpentry, foam cutting, fiberglass molding, laser cutting, and 3D printing. Teams also have access to a supply of 80/20 compatible fasteners and mounting components as well as rod and tube stock that can be cut and bent into shape. On the electronics side, teams are provided with Arduino kits, stepper motors, breadboards, and other components to create push button-driven motion elements such as conveyor belts and rotary tables. This gives teams and reviewers a preview of how their systems will operate autonomously by the end of the spring semester.

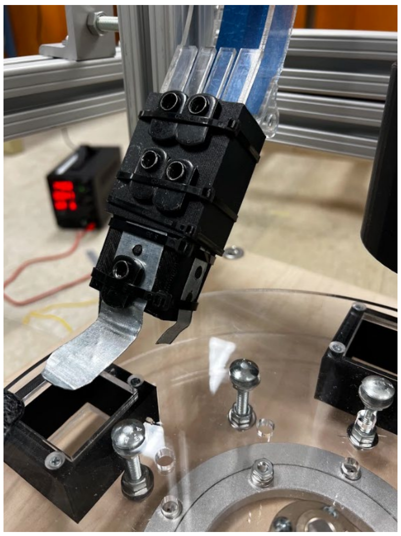
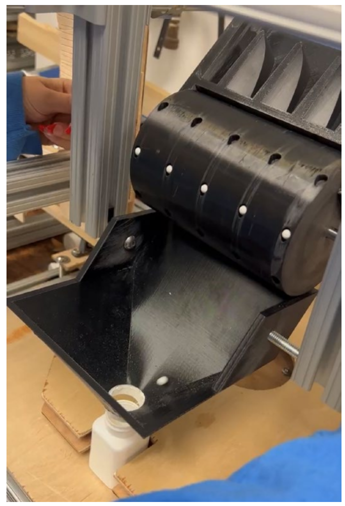
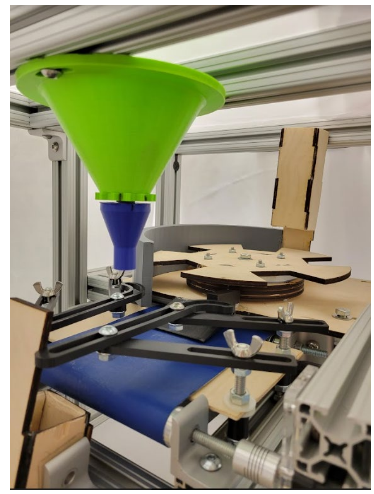
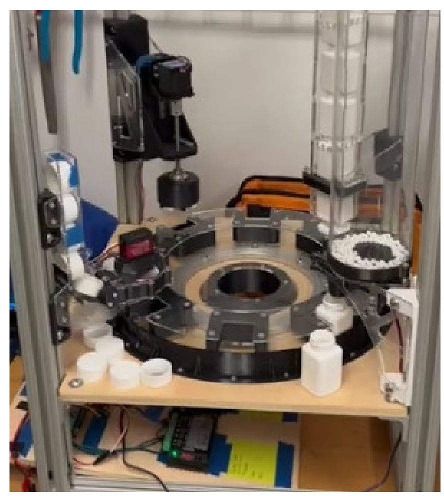

Figure 4. Examples of student team proof-of-concept prototypes built from 80/20 stock parts, laser- and hand-cut wood, 3D printed parts, and fiberglass forms. Clockwise from top-left: substation for dispensing and placing the cap, funnel and indexed cylinder for pill filling, transition from rotary index table to conveyor belt, complete bottle filling monoblock.

The focus of the analysis presented in this paper is our comparison of data collected from a high-ranking team and a low-ranking team, according to their weighted design review grades. The rubrics for these design reviews cover their progress on their prototypes, weekly meetings with their TA, design review presentations, and design reports in terms of the design process, project management, and communication. The high-ranking team received a 98.96% and the low-ranking team received an 89.46% weighted design review grade. The class average was a 94.80%.

To provide some qualitative context, a sample of industry reviewer team evaluation comments from the Final Design Review at the end of the fall semester is given in Table 2. These reviewers attend an in-person design showcase where they watch the team presentations and live demonstrations of their proof-of-concept prototypes; they also have access to the teams' slides ahead of time. The industry evaluators organize their feedback under the same three categories of design process, project management, and communication.

Table 2. Sample of industry reviewer team evaluation comments

Prompt: Comment on how students functioned effectively on a team
Comments on the high-ranking team: "Good discussion about project labor division, nice advancement together as a team" "Good project plan and distribution of effort. Nice response to challenges."
Comments on the low-ranking team: "Team should start putting a lot more focus on how individual stations will coordinate between themselves." "Team should add a lot more time for prototyping and design iteration." "Seemed to have good breakout of tasks to get job done so far, would like to have seen more development of full project concept."

Evidence of Individual Progress Towards Goals

Table 3 lists some of the individual student goals submitted at the beginning of the fall semester, divided between the high-ranking and low-ranking teams. Students are responding to the prompt: "Reflect on your strengths and opportunities for growth in this course. Share your thoughts with your teammates. Together, develop a plan that allows for every member to contribute and improve their own skills during the project." Thus, students present their individual goals in the context of how they can contribute positively to their team and own growth.

Table 3. Sample of personal growth goals written at the start of the fall semester

Goals from members of the high-ranking team: "I would like to improve on programming related with Python and MATLAB. I would to like to learn more on the documentation side of project building. I can build projects but annotation is a weakness." "I would like to learn more coding so I can help with the coding half of the project and would like to learn everything else necessary to complete the project." "I would like to learn Arduino and improve my coding skills in addition to getting more experience with more complex SolidWorks modeling."
Goals from members of the low-ranking team: "A goal of mine is to try and improve my communication in a work environment and ensure that everyone is on the same page when designing. I do not believe this is a weak point for

> myself but it is a valuable skill that can always be improved. I also wish to delve deeper into programming since that is a skill that I feel needs to be sharpened."
>
> "My personal goals for this project are to improve my SolidWorks skills and get experience working with the electronic components."
>
> "I will be focused on programming the most since I have some experience with programming in high school robotics. I struggle a bit with hands-on assembly."

Many students' personal growth goals centered on technical skills such as manufacturing, CAD, and Arduino programming, with some students focusing on leadership and project management skills. These trends are similar across the high- and low-ranking teams.

Through the Team Checklists, teams are given the opportunity to document and comment on individual members' contributions and interactions. Presented in Figures 5 and 6 are excerpts from the high-ranking and low-ranking teams' Team Checklists, respectively. The most striking difference between these two samples is the high level of detail contained in the former's, while the latter's is entirely superficial. In fact, in the low-ranking team's checklist, the only aspect broken down into subgroups of team members is the Prototyping Warmup, an exercise that explicitly requires each team to divide and conquer the assignment. On the other hand, the high-ranking team's checklist breaks down individual tasks within the assignment and spreads the workload across many team members. They also provide notes on status and any design issues for each task.

Component/ Assignment	Tasks	Assigned To	Supervisor	Progress	Completion Date	Notes	Week
Milestone 6							
	Revised Bottle Dispensing shoot CAD (2 iterations)	Aaron		C	11/30	2 iterations - final design completed 11/30	15
	Pill Fill Funnel CAD	Katie, Tom, Mary, Bobby		C	11/30		14
	Pill Fill Spout 3D Printed	Tom		C	11/30	Spout 3D printed awating funnel	
	Pill Fill Funnel Printed	Tom		C	12/7	submitted to Fab Lab 12/5, began printing 12/6, received 12/7	15
	Pill Fill Mounting	Bobby		C	12/7		
	Rotary Table Powered by Motor	Rick, Joe, Mike		C	?	connected to power 12/5, found issues, but resolved 12/5, issues with torque	
	Capping Motor + Lead screw	Samantha		C	11/30		
	Cap-placer mechanism	Samantha		C	12/6	Took 3 iterations to determine correct dimensions	
	Cap Motor mounting	Tom		C	12/8	Being printed today	
	Pill Fill Spout CAD	Katie		C	12/5	determined a redesign of the one spout portion would be better than creating another peice	
	Pill Fill Mounted	Katie, Tom, Mary, Bobby		C	12/9	Pill Fill mounted to frame in position using wood peice 12/11 funnel mounted with 3D printed peice	

Figure 5. High ranking Team Checklist showing the task breakdown related to Milestone 6 of the design project, which required completing their proof-of-concept prototypes for the Final Design Review. Note, all team member names have been altered.

Component/ Assignment	Tasks	Assigned To	Supervisor	Progress	Completion Date	Notes	Week
Team Norms		All	SPOC: Joe	C	9/1		
Benchmarking				C			
	Create/Format Table	Everyone	Everyone	C	9/2	Insert any visuals	1
	Perform Research	Everyone	Everyone	C		Describe what was found	
	Format the links	Everyone	Everyone	C		Use a reference editor	
Prototyping			SPOC	C			
	80x20 frame	Tommy	Tommy	C	9/5		
	Rotary Table	Joe, Susan, Jimmy, Matt	Joe, Susan, Jimmy, Matt	C	9/21		2
	Conveyor Belt	Peter, Amy, Michelle	Peter, Amy,	C	10/4		
	Lead Screw	Don, Michael, Tommy	Don, Michael,	C			
	Write-Up	All		C			
Review 1		All	SPOC	C			
	Presentation	Allen, Joe, Jimmy, Peter,		C			3
	Design Report	Susan, Michelle, Matt, Amy, Tommy		C			
Design Generation				C			
	1 Concept	Design Report Team		C			
	2 Concepts	Presenters		C			4
	Write up	All		C			
Design Selection		All	SPOC	C			
Review 2		All	SPOC	C			
	Presentation	Susan, Michelle, Matt, Amy, Tommy		C			5
	Design Report	Allen, Joe, Jimmy, Peter, Matt		C			
Advanced Prototyping				IP			

Figure 6. Low ranking Team Checklist showing the task breakdown for the entire span of the fall semester (week indications in the last column are inaccurate). Note, all team member names have been altered.

Since these stark differences in Team Checklists could be solely attributed to poor project management documentation, we also examined individuals' reflections on how they were progressing towards their goals. These reflections were submitted at the end of the fall semester after the Final Design Review presentations and reports were completed. Table 4 provides a sample of responses to the prompt regarding personal contributions to the team and how they aligned with their individual goals. All of the prompts are listed in the previous subsection "Individual Reflections".

Table 4. Sample of individual reflection responses

Prompt: Reflect on the contributions you've made to this team design project and how closely they align with your individual growth goals. How would you describe the progress you've made towards these goals?
<u>Responses from the high-ranking team:</u> "I did not really contribute to the design project coding as I would have liked, simply because it was easier and quicker to utilize the team members more confident when we had deadlines for milestones. However, I did use my current strengths in CAD and technical writing to help with designing components of the project and completing the project report. Since I did accomplish at least getting better with coding via the class individual assignments, I would

love to use that to create the code needed to deliver pills to our bottles since that was the design component I was working on this semester." "I got great experience with all aspects of prototyping and was able to make myself an integral member of the team, spending countless hours per week working closely with my teammates to get the job done. Next semester I'd like to specifically get more experience with the Arduino coding/wiring, but this will be easy to achieve." "I have made a lot of contributions to my personal subgroup of cap and close including designing both of the mechanisms. I have also made significant contributions to the electrical and coding side of our project. I have made great progress towards these goals, I have learned a lot about how to use motors and how to wire them safely. I will focus on learning about sensors in the spring." "I did not make very much progress towards my goals. This semester I stayed in my 'comfort zone', only working on tasks I was confident in my ability to do. While that may seem smart, and helpful to the team, it does not benefit me because I'm not learning anything. In the spring semester I want to focus on taking on tasks that will better me as an engineer. I know it can seem difficult and scary to learn a new skill, but doing (and making mistakes) is the best way to learn."
Responses from the low-ranking team: "My progress has been on par with my goals. I plan to focus on being less controlling of my group mates. There is a lot of value in self-discipline and I need not stress myself out when others don't reach the same level." "I was able to help with some of the wiring however I still do not have as strong grasp on the topic as I would like. Towards the end of the semester I stepped up in terms of leadership due to current leaders not carrying their weight." "I did a lot of the manufacturing which was one of my goals as well as design. I put in the work to make sure our team didn't fall behind. As far as coding, I did not do as much as I wanted because I had to spend so much time on making the project and designing, but I did get wiring experience so next semester I want to do more coding." "[A] strategy I used to stay focused and motivated was setting rewards for myself when I achieved certain milestones or goals. For example, I might treat myself to a coffee or a small indulgence when I finished a particularly difficult part of the project. These rewards helped to keep me motivated and gave me something to look forward to as I worked towards my goals."

The high-ranking team members' responses typically fall into one of two categories: either they were able to pursue their own goals or they stayed in their "comfort zones", performing roles they had prior experience with. The latter outcome was either driven by choice or the perceived needs of the team. Students on the low-ranking team mention dysfunctional behavior such as lack of effort, leadership, and communication.

Assessment of Teamsmanship
Student responses to the final CATME evaluation of the fall semester, due two days after the Final Design Review, were analyzed to compare individuals' self-evaluation comments to their comments about their overall team. Table 5 lists some self- and team evaluation comments from

members of the high- and low-ranking teams. The self-evaluations are responses to the prompt: "Please provide constructive comments about your fellow teammates as well as yourself. The purpose of these comments is to give you the opportunity to explain how you rated your peers and if there was behavior or experiences in particular that influenced you when doing your peer and self-evaluations." Students' evaluations of their teams are given as confidential comments to the instructor.

Table 5. Sample of individual self- and team evaluation comments using CATME

High-ranking team member 1: Self-evaluation: "I always get my work done ahead of time and account for issues in code and CAD, and I communicate (maybe too much) what's going on with my piece of the project 24/7." Team evaluation: "This team is amazing. Best team I have had for a design project ever - 100%." **High-ranking team member 2:** Self-evaluation: "I believe I did great this time helping out every meeting with my subgroup." Team evaluation: "I think my team worked really well this last few weeks, especially with meeting up to work on the rotary table." **High-ranking team member 3:** Self-evaluation: "I helped work on the physical prototype and set meeting times in my own subgroup. Provided good ideas for the prototype in my subgroup." Team evaluation: "I think the group is working well together and has a good working prototype. I don't see any issues with the group."
Low-ranking team member 1: Self-evaluation: "Did a good job keeping our group organized as well as providing insight on most aspects of the construction of our project." Team evaluation: "Please give me some input as to which group I get put into." **Low-ranking team member 2:** Self-evaluation: "I was very active in completing my subgroup tasks, as well as helping the rest of the team with their components. I also communicated regularly to make sure components were being completed on time." Team evaluation: "I think we were working well in our subgroups for this project, but probably need to put more effort into communicating between subgroups moving forward. Other than that we work really well together." **Low-ranking team member 3:** Self-evaluation: "My contributions to the final project have been sufficient. I have worked evenly with my subgroup to complete not only our group's component (tightening & capping) but to have to work on other subgroup's (rotary table)." Team evaluation: "Our group become more divided by the week. The communication is lacking if there is any at all. Meetings are not scheduled accordantly and are changed last minute. Communication is hostile and there remains no accountability."

All students' self-evaluations are positive, highlighting their personal contributions to the teams' efforts. Team evaluations tend to be more critical within the low-ranking team, with a particular focus on dysfunction such as poor communication and organization.

We also examined individuals' reflections on how their contributions strengthened their teams' collegiality and output. These reflections were submitted at the end of the fall semester after the Final Design Review presentations and reports were completed. Table 6 provides a sample of responses to the prompt regarding personal contributions to the team and how they promoted their team's success. All of the prompts are listed in the previous subsection "Individual Reflections".

Table 6. Sample of individual reflection responses

Prompt: Reflect on how your personal contributions, attitude, and mindset have been incorporated into your team's model for success in your design project. Think about how your team's process and mindset would have been different had you not been on the team.
<u>Responses from the high-ranking team:</u> "I think I brought a decent attitude to the team and was happy to help with whatever I was asked to do." "Honestly, my team worked very well together. While I did contribute, I think with the amount of people we had, I was not necessarily needed every step of the way. I think I did help with keeping things on track and occasionally doing parts of assignments when no one else was free." "I think that my personal contributions, attitude, and mindset have helped our team succeed. I always try to stay positive and have helped teach other team members how to use things where I could."
<u>Responses from the low-ranking team:</u> "I helped to guide people into doing higher quality work and continuing to work hard throughout the semester and not have big lulls. I helped the team massively with determination and diligence in doing things the right way the first time." "I instilled the mindset that I refuse to fail this project and set a standard that we must have a working and functional design. I did not want to be the faulty group that was expected at the beginning of the semester. If I were on a different team, we would not have a working design as of right now." "I brought a fun/light-hearted attitude while building the prototype which I think kept spirits high when we ran into adversity. I believe the light-hearted attitude and don't-quit mindset very positively affected the team by maintaining a strong group motivation and boosted team chemistry which overall made us work more efficiently."

From these teams, all students reflect positively on their personal contributions, attitude, and mindset and how they influenced their teammates. Students on the low-ranking team, however, also allude to struggles or adversity that they helped overcome.

Discussion

This paper presents the methods used to collect and analyze individual team members' personal goal attainment and teamsmanship data in the setting of a year-long junior-year design project in an accredited Mechanical Engineering program. The project, which involves the design, manufacture, and validation of an automated pill bottle filling machine, is scaffolded on team milestones and individual skill exercises (see Table 1). This same scaffolding is used to schedule periodic team and individual reflections as well as CATME peer evaluations; all of these items are required course components. Additionally, teams met with their assigned TA advisors weekly to discuss their progress and concerns, which required maintaining a Team Checklist of ongoing team and individual tasks.

In this study, we examined several sets of data generated by the students and directly compared samples from a high-ranking team to those from a low-ranking team, where the ranking was determined by their design project grade. The key takeaways from this data analysis, to be discussed in further detail below, are:

- Weekly updated Team Checklists are useful collaborative tools for documenting the division of labor and skill development across the team.
- Team dysfunction, such as uneven division of labor, poor leadership, and lack of communication, leads to individuals deprioritizing their own goals to assume more managerial duties and/or plug the gaps in their teammates' efforts.
- Nevertheless, many students are able to make strong progress towards their individual goals despite team dysfunction.

In general, the clearer the division of labor and the more detailed the notes and concerns written in the Team Checklists, the stronger the team overall. This is reflected in the design review grades (as determined by the TAs), CATME comments, and industry evaluator comments. These evaluators praised the high-ranking teams in the class explicitly for their division of labor, coordination between sub-teams/components of their prototypes, and ability to overcome difficulties—each of which are strong skills to have in industry. Descriptions of good teamwork, collaboration, and a strong positive and productive environment consistently appeared in their evaluations of their own teams. Thus, the Team Checklists seem to be a strong motivator for teamwork for those teams who took full advantage of it. Even on weaker teams, this documentation forces individuals to be accountable and provides a record of their accomplishments for later reflection. We believe this form of documentation to be critical on larger teams working on more complex projects where real-time communication may be more limited.

At the outset of the design project, students' individual goals are similar across all teams, as to be expected. Common goals include developing hands-on prototyping, programming, CAD, communication, and leadership skills. In the reflections given at the end of the fall semester (the halfway point of the design project), however, differences appear in how students feel they have made progress towards their goals. On the low-ranking team, many students reported having to deprioritize their own goals in order to make up for their teammates' lack of effort or assume more leadership or managerial duties against their wishes. On the other hand, many students reported trying to make the most of a difficult team situation by adjusting their goals and being a strong teammate despite not feeling reciprocated [25]. Some approaches include rewarding themselves upon successfully completing a task and supporting other team members who are also struggling with their team. We also found that some students on the high-ranking team struggle to pursue their own goals because the team needs them to perform a certain role usually based on their preexisting skill set.

The range of student and team outcomes we see in these data indicates the strengths of this study as well as some caveats to be addressed. The variety of data collection methods reveal the complexity of how students balance their own goals versus their teams' goals in response to how their teams are performing overall. These methods include team and individual reflections, peer evaluations, and self-reported weekly progress updates; together these provide multiple perspectives on how individual and team progress is achieved. One caveat to our results as presented is that they are, at this time, preliminary and based on only one semester's worth of student data. Furthermore, this is only the second year running this year-long design project experience, and so changes to the scoping and pacing of the project are still being made. Second, we do not include quantitative data in our study other than to determine high- and low-ranking teams based on their design review grades. We considered including CATME evaluation scores in our analysis; however, we found that these numbers did not correlate strongly with team performance. For example, high performing teams can be very critical of members who are not overachieving, and low performing teams often inflate their rankings to compensate. That said, the results of our evaluation align with the overarching goals of this study, specifically as they relate to the evaluation and documentation of individual and team performance. Future work will focus on conducting a more comprehensive evaluation with external reviewer(s) and a larger study sample size.

It should be noted that the data collection process outlined in this study can be adapted to shorter terms (e.g. single semester) and smaller teams (e.g. 3-5 students). The most straightforward way to accomplish this is to utilize just the fall semester schedule outlined in Table 1. This schedule features frequent project milestones and periodic design reviews to provide a continuous impetus to the teams, which is important for projects of any duration. These events also provide natural opportunities for individual and team reflections and peer evaluations to occur. Weekly updates like Team Checklists and Manufacturing Plans can be scaled to any sized project while still motivating students to make continuous progress.

In conclusion, this study presents a collection of individual and team assessments that can be utilized to monitor and evaluate teamwork and goal attainment on team design projects. The assessment tools described in this paper, and in particular how they align with the project milestones, may be of interest to other educators seeking to promote and reward positive interdependence and trust on student design teams. This emphasis means students benefit more from team design projects in the development of their engineering skills and identities.

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