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Collaborative Interactions on a Senior Capstone Design Project - Impact of PLM Tools and Strategies

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Abstract

The introduction of product lifecycle management (PLM) software into the global manufacturing community has elevated the need for trained engineers to apply these tools to improve efficiency and collaboration. In many mechanical engineering university curricula, students are only exposed to computer-aided design (CAD) courses. However, with product data management (PDM), computer-aided engineering (CAE), and computer-aided manufacturing (CAM) utilities increasingly integrated into the design process, students need additional education opportunities to implement this software effectively. This paper investigates the benefits and challenges of undergraduate mechanical engineering students applying an integrated, collaborative PLM system with CAD and PDM features to senior capstone design projects. A human subject case study explored three main objectives: improved collaborative interactions, heightened team creativity and product designs, and tradeoffs between the quality of the final design product and additional hours of student training for PDM software usage. Surveys were administered throughout the course to measure student satisfaction, team performance, software use, collaboration and team efficiency. The key performance indicators showed that the final product of the design teams who utilized the integrated CAD/PDM system fell short in multiple areas compared to those who did not adopt it. Overall, the graduating students demonstrated ambivalence toward adopting new design software and preferred using utilities introduced early in their engineering education. The results of this investigation show that introducing PDM software into small engineering design teams may produce different benefits than its use in large teams and long-term projects. Further, a need exists to bring PLM concepts and tools earlier into the curriculum to encourage student development.

1. Introduction

Throughout the early 21st century, the engineering industry has experienced dramatic changes across business units due to the digital revolution. For example, product lifecycle management (PLM) software has pushed companies to improve collaboration among their divisions to increase design, manufacturing, and business efficiency. PLM software can fall into many categories, including computer-aided design (CAD), computer-aided engineering (CAE), computer-aided manufacturing (CAM) and product data management (PDM). Figure 1 shows the connections of several engineering design processes, with specific stages represented by the type of PLM software utilized. The design cycle begins by introducing requirements and specifications for a product. The requirements are divided into technical and customer requirements, driving the product design through the validation and verification stages. After the requirements and specifications are identified, the initial product ideation occurs, where the preliminary product design is achieved. The early designs are then sketched and 3D modeled in CAD software. After a CAD model is conceived, simulations can be conducted on the model through CAE software. CAM software can be used to optimize manufacturing processes to mass-produce the product. PLM software can be used in each of the phases of the engineering design process to form a product's digital twin, a digital representation of the product.

PDM software is the central repository for all product-related data, including CAD models, CAE simulations, and CAM programs. Businesses can choose to integrate different PLM software based on their specific needs. For example, a company that produces a product with a simple design and limited failure modes may only need to use CAD software. However, a company that creates products with long bills of materials and complicated designs may need to integrate some combination of CAE and PDM software to satisfy their needs. For this research, the PLM system that will be implemented and examined is an integrated CAD/PDM type, where product data created in the CAD software is stored and accessed in the PDM software. This integrated system can reduce the need for external storage of product data and streamline collaborations by allowing multiple users to work on designs and models while keeping a history of previous revisions provided there is a trained workforce available able to apply the technology.

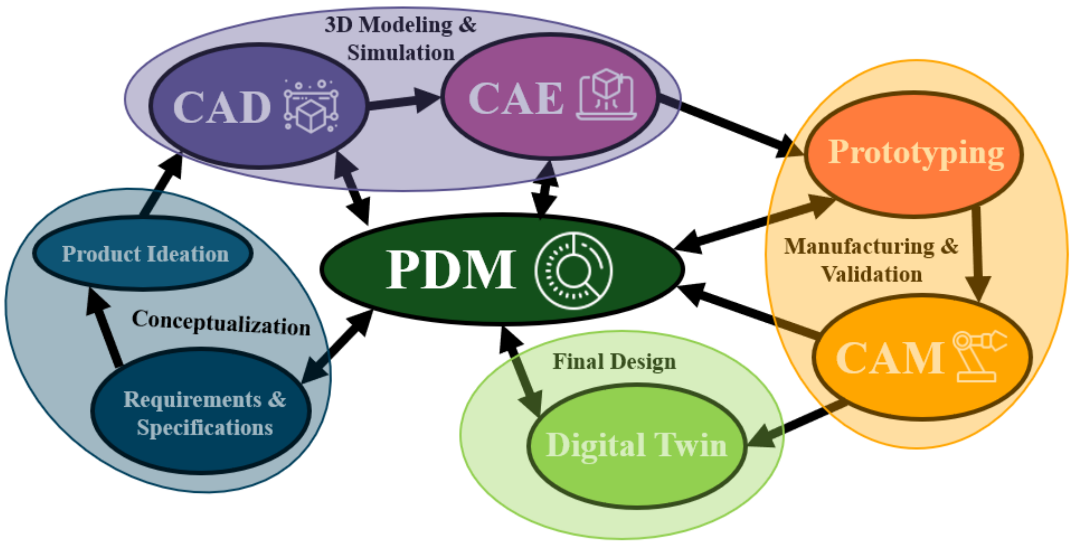

Figure 1. PLM-Integrated Engineering Design Process.

One of the results of expanded PLM integration into product-based companies is the need for well-trained employees in these new software packages to utilize them to their fullest potential. The reach of new PLM software has extended into all departments, including engineering, manufacturing, testing, marketing, and human resources. The integrated CAD/PDM system described earlier has been primarily used by engineers when designing and testing products. However, many companies need more proficient workers in these CAD/PDM systems. A PLM software company, Autodesk, recently published the 2023 edition of *State of Design & Make*, a global annual study for industry professionals in the product design and manufacturing industry. [1]. According to their report, 56% of respondents said their companies have hired employees who need to gain the skills required for the job. One of the leading causes of this shortage when referring to mechanical engineers is the need for PDM education in their undergraduate programs nationwide. Caldwell and Mocko highlight this finding in his study of PDM education in academia by sharing that few universities are teaching PDM for projects and research, and many students need to be adequately exposed to or accustomed to using PDM to enable collaborative design [2]. Buchal also conveys this sentiment, stating that although PDM is a growing software tool, it has yet to be implemented in most undergraduate engineering curriculums [3].

This research investigates the adoption and application of PLM tools in a one semester BSME Senior Capstone Design course to examine the advantages and challenges. The remainder of the paper is organized as follows: Section 2 introduces PLM utilities in higher education. Section 3 lists the research hypotheses and discusses the survey instruments used to prove them. Section 4 explores the case study of an aeronautical fixture designed to measure drag force by Senior Mechanical Engineering (ME) students using PLM tools. Finally, the conclusion is offered in section 5 with complete references afterward. The appendices contain the research survey, final deliverable results, and the final report rubric for the design project.

2. Use of PLM Utilities in Higher Education and Gap

The introduction of PLM software into engineering education has taken many forms, ranging from dedicated courses to seminars or integrated into class projects. In many ME departments, 3D modeling or CAD software is a mainstay in their curriculum, and some universities have PLM minors, certificates, or concentrations with multiple designated courses and activities as shown in Figure 2. The pyramid lists five of the most common PLM integration mediums in engineering education in the central column, with the types of PLM software being integrated on the left side of the pyramid. The "Integration Frequency" arrow conveys that the lower blocks on the pyramid have a higher integration frequency across mechanical engineering programs than the higher blocks. Several ME programs have begun experimenting with integrating PDM software into design courses [4] [5] [6] [7] [8]. The rarest PLM software integration mediums are major, minor and certificate programs, as they require several designated PLM software courses that are infrequently developed.

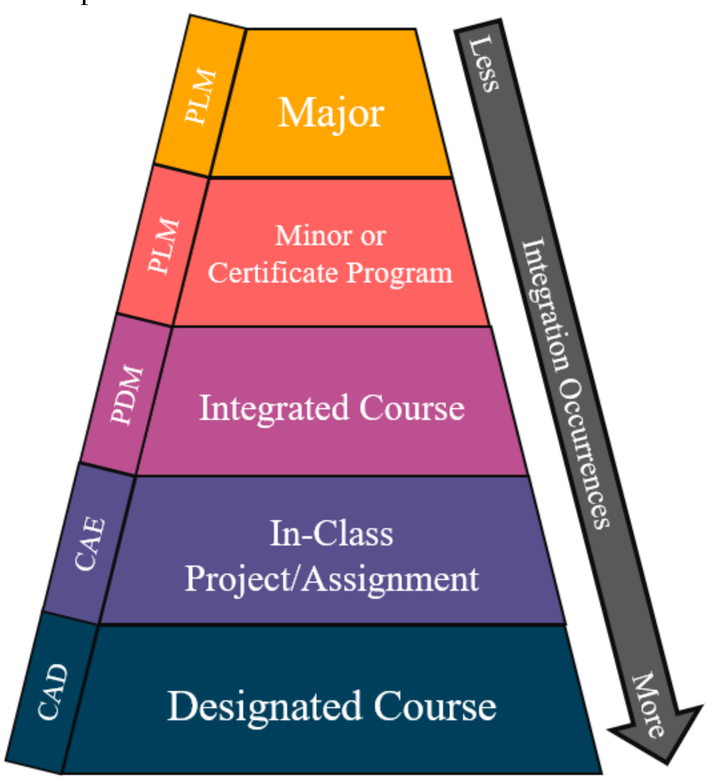

Figure 2. Common PLM Integration Mediums in Mechanical Engineering Education.

Purdue University offers a PLM Certificate Program in their technology Digital Enterprise Center [9]. The Digital Enterprise Center features a Virtual Product Integration Major, a Product Lifecycle Management Minor, a graduate course in Product Lifecycle Management, and the PLM certificate. Del Re *et al.* provided a case study on PLM integration into an introductory freshman-level course. Other PLM certificates focus more on the entire product lifecycle. At Northwestern University, Kellogg School of Management offers a two-month product management program with structured coursework to develop effective product strategies and expertise in creating a framework for implementing and communicating product strategies for product-based companies [10]. Similarly, Cornell University offers an online, two-week course highlighting how a product manager must prepare for a successful product launch and development post-launch [11]. Stanford University's product management courses are split into the graduate certificate program and the professional program, each to teach students the fundamentals of product management [12].

Engineering departments have begun experimenting with integrating PLM software into core courses. At Washington State University, Torick *et al.* developed and integrated a PDM system into their introductory CAD course. The University of Genova introduced CAD and CAE software into a project-based learning (PjBL) in a second-year Design of Automatic Machines course. Three main factors used to measure the PjBL's effectiveness were student interest, knowledge gained, and project development using an anonymous survey. The study concluded that integrating a CAD/CAE design tool into a PjBL activity is an effective strategy for teaching students' industry tools for application in their future careers.

Clemson University's PLM Center (PLMC) is analyzing methods to integrate PLM software and processes into the BSME curriculum. Some current software includes MATLAB, NI LabView, Siemens Simatic, and SolidWorks with a link to Python. However, there is room to inject PLM software and concepts at different levels and areas including laboratories and design courses. *Morris et al.* are exposing students to the benefits of PLM software integration in a team-based, undergraduate design course where students develop a digital twin for a scaled, tracked, robotic vehicle. The team integrated NX and Teamcenter into their guided and student-led projects to facilitate their digital twin design and improve collaboration as a team, while surveys were used to measure the student's understanding and career preparedness of PLM topics.

PLM integration into engineering education can effectively prepare students for their future careers; however, PLM integration into engineering programs is limited [13]. This research aims to identify an area of the curriculum where PLM tools can be integrated and tested for effectiveness. A case study explores the integration of CAD/PDM system into a core required course.

3. Research Hypotheses and Survey Instruments

Three hypotheses have been created to evaluate PLM tool effectiveness and student perceptions in a Senior Capstone Design Course.

H-1: Offering training in advanced PLM tools to engineering design teams will improve their collaborative interactions.

H-2: Observed team creativity and product design quality are influenced by heightened virtual design skills gained.

H-3: The tradeoff between additional PLM software usage hours and design quality is positive.

To obtain student perceptions, an IRB-approved weekly survey was created and deployed to the students to gather data on key performance indicators about the integration of PDM tools in the senior capstone design project considering those hypotheses. The survey, located in Appendix A, asks the students to describe how their team collaborated during the previous week, rate their contentment with their work role on a scale of 0-10, and rate their team member's level of engagement and work ethic in the previous week on a scale of 0-10. H-1 will be evaluated using the results of this survey. H-2 and H-3 will be evaluated using a combination of the survey results and final prototype testing and presentation results.

4. Case Study – Design of Aeronautical Fixture for Undergraduate Education Laboratory

The Senior Capstone Design course is traditionally a semester-long, sponsored design project for senior mechanical engineering students. For this case study on the design of wind tunnel equipment, the client was a faculty member in mechanical engineering, and the students were co-advised by the lab coordinator and graduate student. The project required the students to design, fabricate, and validate a wind tunnel sting balance to measure the aerodynamic drag of different geometric bodies in the Mechanical Engineering Undergraduate Lab low-speed wind tunnel. The low-speed wind tunnel test area and the existing non-functional sting balance with the aero sphere are shown in Figure 3.

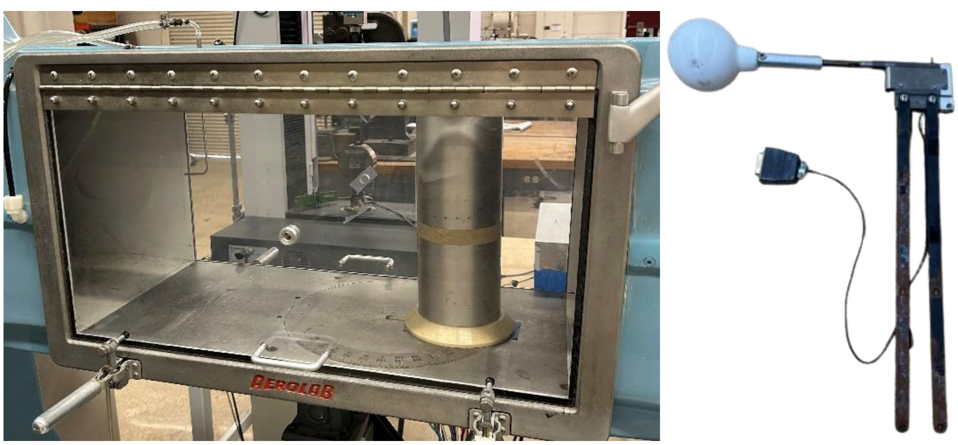

Figure 3. (a) BSME Learning Laboratory Low-Speed Wind Tunnel Test Area and (b) Existing Sting Balance.

The student teams were required to submit and present midterm and final reports of their progress. To evaluate research hypotheses, the class was divided into half, and half the student teams were required to use CAD/PDM tools to assist in their design project. In comparison, the other teams selected any software. Weekly student survey results were analyzed to assess improvements in collaborative interactions, increasing team creativity and product design quality, and observing tradeoffs between additional student training hours for PDM software usage and design quality.

4.1 Senior Capstone Design Course Setup

The class section consisted of eighteen students, split randomly into two teams of five and two teams of four. All four teams were given a presentation on the functions and abilities of NX and Teamcenter, the integrated CAD/PDM system that was implemented into the course. After the presentation, two teams were required to utilize the system exclusively in all aspects of the design process. The other two teams could employ any software they chose to assist in the design process. For the rest of the paper, Team 1* and Team 2* will be referred to as the teams that used the integrated CAD/PDM system, and Team 3 and Team 4 are the teams that could use any software they like. Throughout the semester, the teams presented their progress to the advisors weekly while receiving limited guidance in creating their products.

During the first few weeks of the semester, the teams worked on setting up their team organization, assigning roles, creating a schedule, and preliminary concept generation. They used standard design tools such as a c-sketch, quality function deployment (QFD), and requirement traceability matrix (RTM) to weigh the requirements and create original concepts. The students were provided with a list of twelve customer requirements and goals to guide their design. The requirements for the sting balance force measurement device are listed below in Figure 4. Additionally, all teams researched patents and searched industry standards to guide their design.

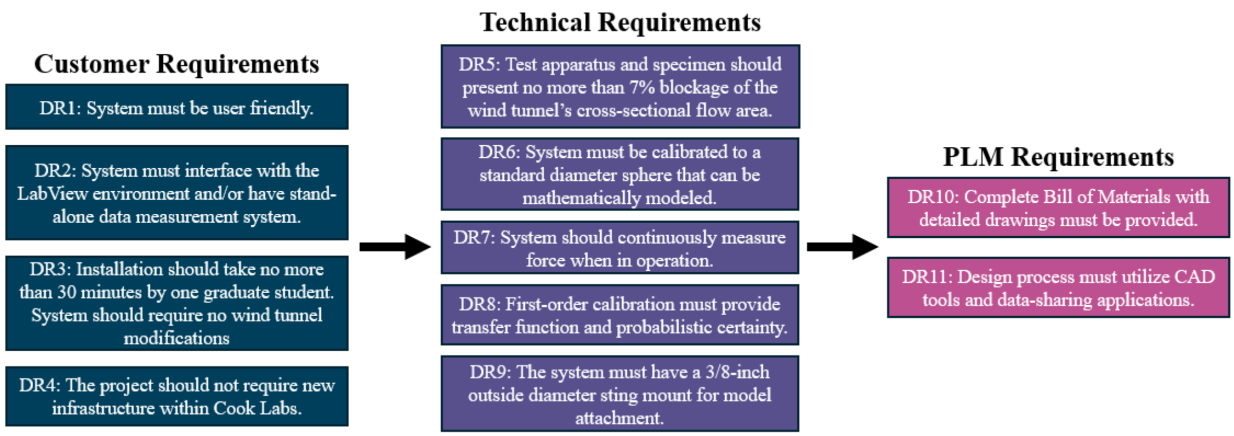

Figure 4. Sting Balance Design Requirements

4.2 Design Project Results

After working on their preliminary designs for around five weeks, each team gave the advisors and customers a midterm presentation to update the stakeholders and gather vital feedback to implement into their prototype development for the rest of the semester. The stakeholders evaluated each team according to a midterm presentation rubric containing several criteria, such as design methodology, use of engineering tools, quality of proposed solution, and communication skills and presentation, each with varying weights. The evaluators were asked to give each team a grade between 0-5 based on their judgment of the quality of each criterion. The average scores of each team were roughly the same for the midterm presentation, and each team received valuable feedback to be implemented into their designs moving forward. After the initial designs were presented and reviewed, two leading solutions were focused on going forward: strain gauge and load cell. Teams 1* and 2* began using the integrated CAD/PDM system to design their product, each choosing a different solution. Team 1* decided to build their strain gauge system that measures voltage against applied drag force, and Team 2* worked with the load cell from a jewelry scale to calculate drag force. Teams 3 and 4 used SolidWorks as their CAD software and Microsoft Teams as their PDM software separately to assist with their designs. Students on Teams 3 and 4 learned and used during the 3D modeling course required during engineering student's first year. Team 3 used a load cell to measure the tensile drag force produced from a three-linkage reverse moment arm. Team 4 employed a similar concept, except instead of the three-linkage design, they used bearings and a load cell to measure the compressive drag force exerted on the sphere. By the end of the semester, each team produced a unique design that was evaluated during the midterm and final presentations. Over the following weeks, each team developed final prototypes using their respective CAD/PDM system and various manufacturing processes, and the final designs were tested in the wind tunnel. Each team's final prototype is displayed in Figure 5.

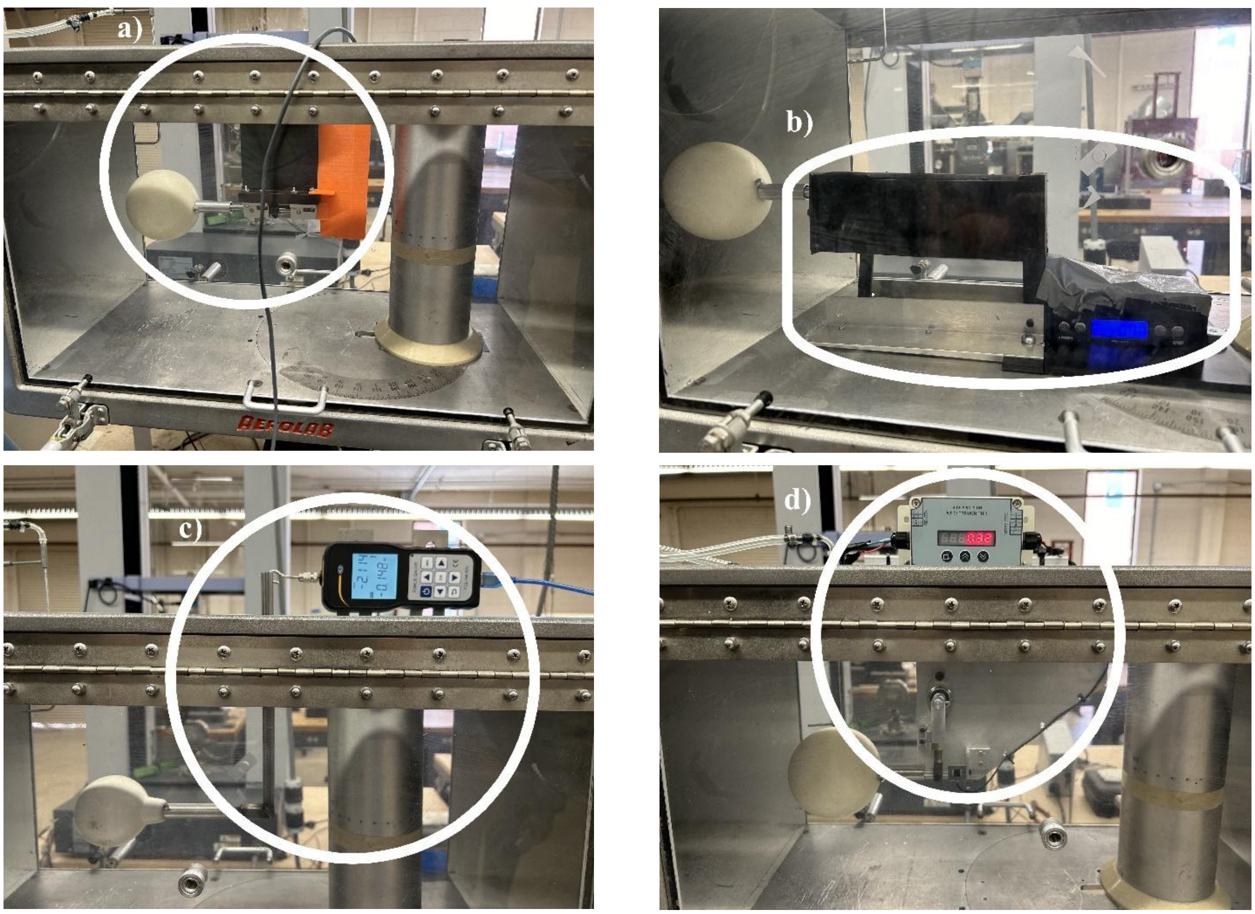

Figure 5. Final Prototypes in Wind Tunnel – (a) Team 1* with Strain Gauge and Wheatstone Bridge Circuit, (b) Team 2* with Jewelry Scale Force Sensor, (c) Team 3 with Custom Linkage and Off-The-Shelf Load Cell and (d) Team 4 with Integrated Load Cell and Digital Display

First, the prototypes were installed into the wind tunnel and tested at three different velocities. At each velocity, the teams were required to provide a theoretical, calculated force that the device should expect to see while the prototype's actual drag force was measured. Data was recorded at wind tunnel velocities of 10, 20, and 30 meters per second, and the results for each team are shown in Table 1.

		Wind Tunnel Velocity	Pitot Tube Pressure	Measured Force	Calculated Force	Absolute Error
	Test Points (TP)	[m/sec]	[in H20]	[grams]	[grams]	[grams]
Team 1*	TP 1	10	0.24	6.34	16.48	10.14
	TP 2	20	0.96	78	65.63	12.37
	TP 3	30	2.16	200	147.26	52.74
Team 2*	TP 1	10	0.24	4.05	17.45	13.4
	TP 2	20	0.96	78	59.67	18.33
	TP 3	30	2.16	196	134.79	61.21
Team 3	TP 1	10	0.24	19.66	21.86	2.2
	TP 2	20	0.96	83.16	87.27	4.11
	TP 3	30	2.16	204.12	194.82	9.3
Team 4	TP 1	10	0.24	21.2	21.26	0.06
	TP 2	20	0.96	82.5	85.27	2.77
	TP 3	30	2.16	193	190.26	2.38

Table 1. Final Prototype Testing Results

The prototypes were then evaluated based on the design requirements from Figure 5, and the results are displayed in Appendix B. As shown in Table 1, Teams 3 and 4 produced results much closer to their respective calculated forces for all three velocity points than Teams 1 and 2. Team 4 also produced force values within 3 grams for each velocity point, which is the most accurate prototype out of the two surpassing designs. From the design requirements, Teams 3 and 4 both met each of the design requirements as determined by the customer. Teams 1* and 2* each had issues with meeting all the design requirements. After each prototype was tested and evaluated, the teams gave a final presentation summarizing their design processes and results. Each team's presentation was assessed using a scorecard like the midterm presentation, which is included in Appendix C. Each evaluator's final scores are displayed in Table 2.

Teams	**Team 1***	**Team 2***	**Team 3**	**Team 4**
Average Score	79	70	88	98

Table 2. Final Presentation Evaluation Scorecard per Appendix C

Like the final testing results, Team 1* and Team 2* finished third and fourth, respectively, mainly due to their lack of an accurate prototype. The following section will discuss observations made throughout the semester and the final survey results. Additionally, conclusions will be drawn from the entire research project, albeit the small sample size of only four teams.

4.3 Observations and Hypothesis Discussion

Although the teams that used the integrated CAD/PDM software were outperformed in terms of the final prototype and testing results, there were other areas of the design process that they excelled in, including engagement and work ethic. To evaluate H-1, a few of the key indicators from the student weekly survey for each team were compiled. As discussed earlier, team members were asked to rate their work role contentment and teammate's engagement and work ethic. The averages of each team's weekly work role contentment, engagement, and work ethic scores are displayed in Table 3. On average, students on Teams 2* and 3 were happier with their work role compared to Teams 1* and 4. Also, students on Teams 1*, 2* and 3 graded their teammates' engagement and work ethic higher than students on Team 4. Since Teams 1* and 2* were required to learn and use new CAD/PDM software, they were forced to collaborate at a high level, which drove their engagement and work ethic scores. Similarly, survey submissions showed Team 3 collaborated well together using software they had all been trained in over a full semester during their first year. The advisors observed Teams 3 and 4 splitting the design process into individual tasks because they did not need to learn new CAD software. The difference between Teams 3 and 4 ratings were their communication and cooperation as a team. Some students on Team 4 conflicted with the others regarding their effort level, which reduced their key indicator scores across the board. The survey results and key indicators show that H-1 is satisfied.

Key Indicators	Team 1*	Team 2*	Team 3	Team 4
Work Role Contentment	9.2	9.9	9.8	8.2
Engagement	9.9	9.9	9.8	8.7
Work Ethic	9.9	9.9	9.8	8.7

Table 3. Key Survey Indicator Average Team Scores (scale 0-10) per Appendix A

To identify the success or failure of H-2 and H-3, all four teams were evaluated by the advisors on a scale of 1 to 5 on metrics such as team collaboration, design quality, design deliverables met, PLM tool use, total software usage hours, design skills gained, and design creativity, with the results being displayed in Figure 6. The team collaboration, design quality, PLM tool use, total software usage hours, and design skills gained metrics were supported by the survey results. The design quality, design deliverables met, and design creativity metrics were decided based on the final prototype testing and design requirements verification testing, per Appendix B.

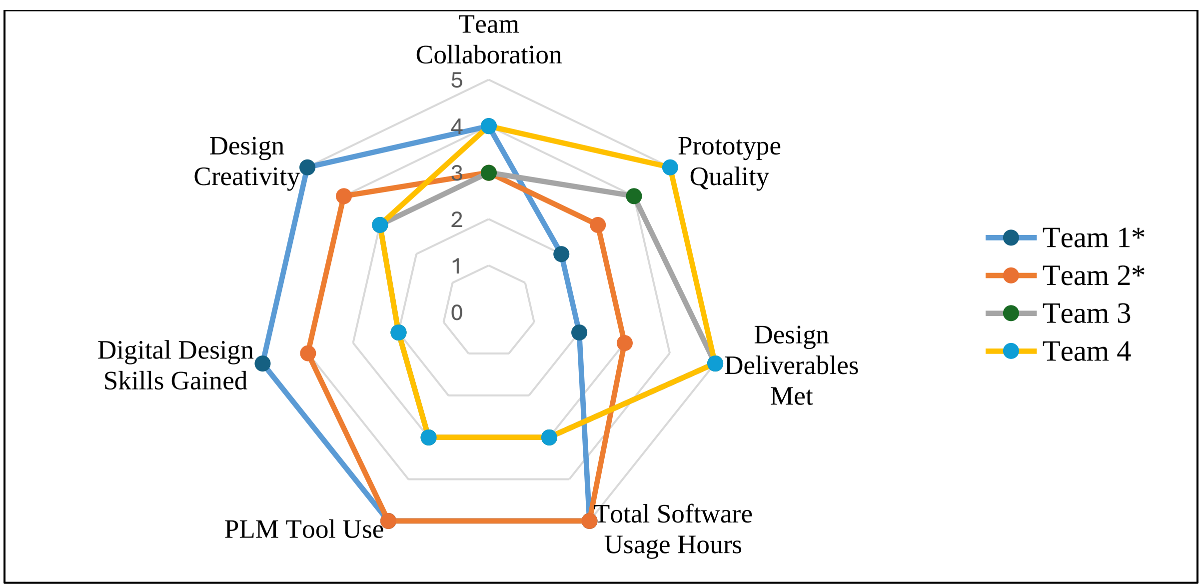

Figure 6. Radial Plot of Team Performance Metrics; Ratings include 1 (Poor), 2 (Fair), 3 (Good), 4 (Very Good), and 5 (Excellent).

As can be seen from the plot, Teams 3 and 4 were graded higher in design quality, and design deliverables met metrics. In contrast, Teams 1* and 2* received more excellent scores in PLM tool use, and design skills gained due to their use of innovative software to support their designs. Additionally, it was observed that Teams 1* and 2* were more creative in their design processes when compared to Teams 3 and 4, each of which used an out-of-the-box load cell sensor as the force measurement device, which was the main factor in their design creativity grades thus satisfying H-2. It was also observed that Teams 1* and 2* spent more time using PLM tools than their counterparts. Overall, the teams that used the innovative PLM tools created less successful prototypes but may have gained more design skills with PLM tools and advanced design concepts. Therefore, the data did not support the hypothesis for H-3.

5. Conclusion

Implementing integrated CAD/PDM software in a Senior Capstone Design course produced mixed results compared to the initial hypotheses. The teams who were trained in the advanced PDM tool were observed to have improved their collaborative interactions according to their experiences through the survey results (H-1). Further, team creativity was heightened by increased collaborative opportunities, as shown in the design decisions of all four teams and their collaborative interactions (H-2). However, the tradeoff between additional software usage hours and design quality was not necessarily favorable, resulting in Teams 1* and 2* spending more time learning the software rather than focusing on their designs (H-3). Conversations with the graduating students revealed that they preferred using software tools introduced early in their engineering education. The free response entries of the student survey results for Teams 1* and 2* showed that more time spent using the PLM tools increased their collaboration on other aspects of the design process. The next step to improve the methods of this study is to provide the students using the integrated CAD/PDM software with more comprehensive training before the project begins, allowing them to spend more of their time using the advanced PLM tools to design the product.

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Appendix A. Participant Survey

ME 4021 Weekly Progress Survey

Question 1 - What is your name?
(Free response)

Question 2 - Please describe how your team collaborated during the previous week. How often did the team collaborate (# of hours)? What design process did the team collaborate on (concept generation, 3D modeling, validation, etc.)? What software or tools did the team use to collaborate throughout the week? Please be as specific as possible.
(Free response)

Question 3 - Please rate your contentment with your work role in the previous week on a scale of 0-10.
0 - Team member is dissatisfied with their role and assigned work within the team.
10 - Team member is very happy with their role and assigned work within the team.
Slider from 0-10

Question 4 - Team Member #1's Name
(Free response)

Question 5 - Please rate team member #1's level of engagement in the previous week on a scale of 0-10.
0 - Team member is not participating in team meetings and design activities, and is not communicating with teammates.
10 - Team member is engaging in team meetings and design activities, and is communicating with teammates on a consistent basis.
Slider from 0-10

Question 6 - Please rate team member #1's level of work ethic in the previous week on a scale of 0-10.
0 - Team member did not make any progress toward their written goals for the previous week.
10 - Team member fully completed exactly what they said they were going to do from the previous week.
Slider from 0-10

Question 7 - Team Member #2's Name
(Free response)

Question 8 - Please rate team member #2's level of engagement in the previous week on a scale of 0-10.
0 - Team member is not participating in team meetings and design activities, and is not communicating with teammates.
10 - Team member is engaging in team meetings and design activities, and is communicating with teammates on a consistent basis.
Slider from 0-10

Question 9 - Please rate team member #2's level of work ethic in the previous week on a scale of 0-10.
0 - Team member did not make any progress toward their written goals for the previous week.
10 - Team member fully completed exactly what they said they were going to do from the previous week.
Slider from 0-10

Question 10 - Team Member #3's Name
(Free response)

Question 11 - Please rate team member #3's level of engagement in the previous week on a scale of 0-10.
0 - Team member is not participating in team meetings and design activities, and is not communicating with teammates.
10 - Team member is engaging in team meetings and design activities, and is communicating with teammates on a consistent basis.
Slider from 0-10

Question 12 - Please rate team member #3's level of work ethic in the previous week on a scale of 0-10.
0 - Team member did not make any progress toward their written goals for the previous week.
10 - Team member fully completed exactly what they said they were going to do from the previous week.
Slider from 0-10

Question 13 - Team Member #4's Name
(Free response)

Question 14 - Please rate team member #4's level of engagement in the previous week on a scale of 0-10.
0 - Team member is not participating in team meetings and design activities, and is not communicating with teammates.
10 - Team member is engaging in team meetings and design activities, and is communicating with teammates on a consistent basis.
Slider from 0-10

Question 15 - Please rate team member #4's level of work ethic in the previous week on a scale of 0-10.
0 - Team member did not make any progress toward their written goals for the previous week.
10 - Team member fully completed exactly what they said they were going to do from the previous week.
Slider from 0-10

Question 16 - Is there anything that you would like us to know regarding the results of this week's survey? If not, put N/A.
Free response

Thank you for your time and responses. Your responses will be part of an ongoing research study being conducted by Dr. John Wagner and Frederick Rowell. Specific questions about this research can be addressed to Dr. Wagner at jwagner@clemson.edu.

Appendix B. Technical Requirements Verification Scorecard

		Team 1		Team 2		Team 3		Team 4	
	Requirements	Yes	No	Yes	No	Yes	No	Yes	No
1	System must be user friendly with respect to an engineering student's ability to operate and gather data in a highly efficient and reliable manner.		X	X		X		X	
2	The system must interface with the LabView environment and/or have a stand-alone data measurement system which requires no new additional lab equipment interfaces.		X	X		X		X	
3	Installation of the system in the Low-Speed Wind Tunnel should take no more than 30 minutes and must be able to be installed by one graduate student. The system should require no modifications to the Wind Tunnel.	X (6:53)		X (6:56)		X (1:42)		X (3:59)	
4	The test apparatus and specimen should present no more than 7% blockage with respect to the Wind Tunnel's cross section flow area.	X		X		X		X	
5	The system must be calibrated to a known geometry (sphere) that can be mathematically modeled. A known drag model that accounts for the probabilistic variation must be provided. Each team will use a standard diameter sphere for the calibration. **Witness three velocity points during wind tunnel demonstration test day.**	X		X		X		X	
6	The system should continuously measure force when in operation within the wind tunnel test section.	X		X		X		X	
7	First order calibration with the respective transfer function documenting all the variations and probabilistic certainty of the provided calibration.	X		X		X		X	
8	Complete Bill of Materials with detailed drawings that are accurate and easy to follow must be part of the deliverables. Enough detail must be provided to support manufacturing of all components.	X		X		X		X	
9	Design process must utilize CAD tools and data sharing interfacing technologies.	X		X		X		X	
10	The project should not require new infrastructure within the Cook Labs (i.e., the project should enhance a current lab or use a current lab asset).	X		X		X		X	
11	Project must be executed within one semester and a 100% functional system must be validated at the end of the semester.		X		X	X		X	
12	The system will have a 3/8-inch outside diameter sting mount for model attachment.	X		X		X		X	

Table B.1. Final Prototype Technical Requirement Verification Results

Appendix C. Final Presentation Rubric

Criteria	Weight	Scores and Attributes					
		5	4	3	2	1	0
Problem Understanding	6	Team displays a complete understanding of the problem statement and technical requirements.	Team displays an above average understanding of the problem statement and technical requirements.	Team displays an average understanding of the problem statement and technical requirements.	Team displays a below average understanding of the problem statement and technical requirements.	Team displays a lack of understanding of the problem statement and technical requirements.	Team displays no understanding of the problem statement and technical requirements.
Use of Engineering Knowledge	5	Team demonstrates an above and beyond application of engineering principles and knowledge.	Team demonstrates an above average application of engineering principles and knowledge.	Team demonstrates an average application of engineering principles and knowledge.	Team demonstrates a below average application of engineering principles and knowledge.	Team demonstrates little applications of engineering principles and knowledge.	Team fails to demonstrate application of engineering principles and knowledge.
Use of Engineering Tools	5	Team presents extensive and encapsulating use of engineering tools (CAD, PDM, CAE, etc.).	Team presents considerable use of engineering tools (CAD, PDM, CAE, etc.).	Team presents ample use of engineering tools (CAD, PDM, CAE, etc.).	Team presents some use of engineering tools (CAD, PDM, CAE, etc.).	Team presents little use of engineering tools (CAD, PDM, CAE, etc.).	Team presents no use of engineering tools (CAD, PDM, CAE, etc.).
Quality of Solution	10	Team presents a strong solution that completely meets the given technical requirements.	Team presents a strong solution that somewhat meets the given technical requirements.	Team presents an average solution that somewhat meets the given technical requirements.	Team presents a below average solution that somewhat meets the given technical requirements.	Team presents a below average solution that does not meet the given technical requirements.	Team presents a solution that will not work or meet the given technical requirements.
Verification and Testing Results	7	Team presents extensive verification and testing results and device meets all technical requirements.	Team presents extensive verification and testing results and device meets most technical requirements.	Team presents adequate verification and testing results and device meets most technical requirements.	Team presents adequate verification and testing results and device meets some technical requirements.	Team presents little verification and testing results and device meets some technical requirements.	Team presents little verification and testing results and device meets few technical requirements.
Uncertainty Calculations	5	Team displays highly accurate uncertainty calculations and graph for device.	Team displays accurate uncertainty calculations and graph for device.	Team displays somewhat accurate uncertainty calculations and graph for device.	Team displays somewhat accurate uncertainty calculations for device.	Team displays inaccurate uncertainty calculations for device.	Team does not display uncertainty calculations for device.
Communication Skills (Verbal/Slides)	6	Team displays excellent communication skills through the quality of slides and verbal presentation.	Team displays above average communication skills through the quality of slides and verbal presentation.	Team displays average communication skills through the quality of slides and verbal presentation.	Team displays below average communication skills through the quality of slides and verbal presentation.	Team displays poor communication skills through the quality of slides and verbal presentation.	Team displays unacceptable communication skills through the quality of slides and verbal presentation.
Presentation	6	Team displays excellent professionalism and time management throughout the presentation.	Team displays above average professionalism and time management throughout the presentation.	Team displays average professionalism and time management throughout the presentation.	Team displays below average professionalism and time management throughout the presentation.	Team displays poor professionalism and time management throughout the presentation.	Team displays unacceptable professionalism and time management throughout the presentation.

Table C.1. Final Presentation Evaluation Rubric