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Enterprise PDM as Digital Backbone in a Large First-Year Engineering Course

Prof. Travis J. Fuerst, Purdue University

Travis J. Fuerst is currently an Assistant Professor of Practice with the School of Engineering Technology at Purdue University, West Lafayette, Indiana. He received his BS in Computer Graphics Technology in 2000, and his Master of Science in Product Lifecycle Management (PLM) in 2002 from Purdue University. Travis is a certified Project Management Professional (PMP) and certified in Change and Configuration Managment (CM2) through The Institute for Professional Excellence (IpX).

Dr. Jorge D. Camba, Purdue University

Jorge D. Camba is an Associate Professor in the School of Engineering Technology at Purdue University in West Lafayette, IN.

Angshuman Mazumdar, Purdue University at West Lafayette (COE)

Angshuman Mazumdar is a current Ph.D. student in the department of Computer Graphics Technology, at Purdue University (West Lafayette, IN). His research focus is on agent-based simulation, video game simulation and design, and virtual reality simulation and design. He obtained his M.S. in Computer Graphics from Purdue University, and has a Bachelor of Technology in Electronics Engineering from Vellore Institute of Technology, India.

John Koellisch, Purdue University at West Lafayette (PPI)

Engineering Graphics Education for the Digital Enterprise: Enterprise PDM as Digital Backbone in a Large First-Year Engineering Course

Abstract

The advent of Industry 4.0 and digital enterprise environments has brought new light into well-established concepts such as Product Data Management (PDM) and Product Lifecycle Management (PLM) systems, which form the information backbone of the entire enterprise. As companies continue their digital transformation efforts, there is an expectation for the new generation of engineering and technology professionals to become proficient in these environments and be ready to contribute on day one.

In this paper, we describe our current efforts and experiences engaging industry partners in the development and delivery of a process-based curriculum for a large first-year engineering parametric solid modeling course with over 800 students. We discuss the evolution of the curriculum over time and how industry leaders in the PLM industry partners became active stakeholders by providing support, technology, and developmental resources.

The course emphasizes parametric solid modeling but relies on a PLM infrastructure that was customized for classroom use, yet it replicates a fully functional enterprise environment, including file management and version control, change management, and user access. Formal processes were defined via PLM for all course activities, assignment submissions, and student interactions. Student support is provided by a team of teaching assistants who leverage various tools and processes to minimize response times, provide feedback, and optimize the overall quality of the services.

We discuss how students embraced and adapted to the tools and processes taught in the classroom, and how some university engineering design build clubs voluntarily implemented them in their workflows. We also describe the challenges faced over the years during the implementation, and our strategies to overcome these obstacles. Our goal is to provide a roadmap for other institutions and curriculums to replicate our initiative.

Introduction

Modern engineering education emphasizes computer aided techniques to digitize manufacturing – a concept coined as “Industry 4.0” [1]. In this context, engineering students are expected to contribute to an interdisciplinary approach to engineering education which enables real-world problem solving, decision making, and commitment towards learning [1].

In their research, the authors [2] considered curriculum development as fundamental for engineering education and must align with the real-world goals. An important pillar for building an engineering education curriculum is the implementation of technologically advanced labs that align with industry practices and standards. Engineering concepts such as product development and supply chain management demand learning by experience and foster an environment of intrinsic knowledge development for a task [3]. A major framework that defines engineering education is Kolb’s Experiential Learning Cycle [4], which can be used to evaluate the processes outlined in the course. This methodology was presented as a cyclic four-stage learning cycle, with each stage focused on a specific learning style which targets the learner’s cognitive processes. In the course curriculum design outlined in this research, each stage has its standout

primary objective, and the other pillars contributed as a secondary (and sometimes even tertiary) learning objective. Kolb stated that learning focusses on transformation of experience into usable knowledge. [4] This theory introduces the concept of "learning" in engineering as a continuum, rather than discrete, pockets of time. A learner is guided through various stages that enable them to tackle the engineering problem and apply observation, conceptualization, and experimentation, for an experience-based learning.

Over the past decade, the availability and affordability of software tools such as Autodesk Fusion and OnShape [1] as well as the popularity of various high school engineering and robotics programs such as Project Lead the Way have introduced students to basic engineering concepts, design principles and practices, project management, and technology. In many cases, however, the sound product design fundamentals that are necessary to thrive within industry are lacking. Students must be able to embrace these technologies with a level of competency to not only use them effectively, but also ensure quality, safety and serviceability throughout the lifecycle of the products they are designing.

This paper builds on our previous paper [5] where we described the development of an industrial software infrastructure for the delivery of a large freshman level engineering graphics course. In this study, we report the pedagogical changes of the course, how the course has been architected to enhance higher learning [6][7], the use of industry enterprise PLM system, and engagement of industry experts and partners to infuse skills that better prepare undergraduate engineering students for their future internships and ultimately their career. Insights gained through our results and the lessons learned continue to drive the evolution of engineering technology education in general, and our curriculum in particular, in the areas of product design in the context of PLM. In this paper, we describe the structure and evolution of the course and discuss lessons learned and our efforts to incorporate these tools as part of the course administration.

Background

The current state of industry specific technology should be considered as a crucial cornerstone when developing curricula that teaches and implements concepts such as "Industry 4.0." In [8], the authors investigated the development of an engineering education policy and the development of industry powered engineering programs. They suggest that dynamic and interactive engineering curricula are important for future engineering education. Similarly, in [9], the authors examined the core principles behind "experience-led engineering degree." Their study looked at six different universities' engineering programs to identify the common elements to integrate problem-based learning (PBL) in the classroom. They concluded that the key drivers of integration include decreasing drop-out rates, stimulating learning motivation, and supporting the development of new competencies.

The authors acknowledge that academic staff with relevant industry experience are crucial to the learning of vital skills by the students. However, there also exists a decrease in such faculty, thus moving away from the concept of experience-led engineering degree. In [10] the authors found that one of the major drawbacks when developing a structured education system is the lack of industry expertise of the educators.

The benefits of learning in a realistic environment and its ability to encourage participation in the learning process were described years ago by [11]. In [12] the authors conducted a role-playing experiment where students engaged in industry practices. In these types of experiments, educators establish the context and ecosystem that resembles a real-world problem that needs to be tackled via interdisciplinary teaming and problem solving. Role-playing experiments have been effective in getting students to actively explore the underlying context of the engineering ecosystem, the stakeholders involved, and the dynamic complexities involved in solving engineering problems. In this regard, the use of engineering processes, terminologies, tools, and context enables such role play in learners. The authors found that the students were able to express an innate understanding of their roles in an engineering environment when exposed to role-play scenarios with the participation of industry figures [12].

Industrial technology also encapsulates working in interdisciplinary teams to accomplish objectives. Interdisciplinary engineering education is geared towards teaching students with varied expertise to solve goals by working within the same context [10] [13] Most interdisciplinary education is, in fact, focused on collaborative teamwork. Indeed, modern classroom environments require students to be considered as part of a functioning engineering ecosystem, with well-defined roles, requirement objectives, timelines, and meaningful outputs. This methodology contributes to the experience-led learning curricula that a modern classroom aims to establish and train students to be industry-ready right when their formal education is complete.

From a practical standpoint, implementation is only one aspect of the task at hand. The other aspect that needs to be considered when implementing a “realistic learning environment” is whether the knowledge is accurately being transferred to the learner. Without an impactful strategy to convert practical (or tacit) knowledge into recorded (or explicit) knowledge, the process of learning may not yield the most effective results. This is where the concept of “Knowledge Transfer” comes into play. Knowledge Transfer is the process of transference of practical skills in between one organizational setting to another [14] [15]. The concept of knowledge has been categorized as implicit (knowledge generated by experience) or explicit (knowledge formally recorded and codified via traditional means) [16]. Codified knowledge is transferable due to the collaborative nature and scientific outputs. Implicit knowledge requires higher individual input and transference via oral modality [17]. In [18], the authors found that individuals with industry experience have higher importance and involvement in knowledge transfer activities between students and firms.

The authors in [14] proposed four dimensions which can be utilized to classify the knowledge transferred: degree of formalization, actor’s relational involvement, information flow direction, and time of relationship. University curricula and teaching methodologies should consider these established dimensions when creating an ecosystem that effectively prepares learners for industry roles. The length of the engineering programs, the university’s roadmap, and the available resources to the educator are the major factors that can be helpful in setting up such an ecosystem. The authors in their discussions state that knowledge transfer occurs via two means of knowledge flow: channels, which are the media responsible for non-ad-hoc and unidirectional knowledge flow, and processes, which are relational and social configurations of learners, with

multi-directional knowledge flow. In the context of industry and academia, the channels are direct routes via which information is exchanged (there is a clear source and recipient), whereas processes lie in the interaction zone of source and recipient, where the people involved are responsible for taking the knowledge in the channel, and dispersing it (such as an industry veteran in a professor position, communities of practice, etc.)

According to [19], the best knowledge transfer ecosystems have "a combination of personal support, self-reliant working, and the opportunity to have access to content or knowledge management systems" [19]. Their study highlights the importance of the human interaction element in the knowledge transfer between educational entity and industry. However, such transfer also faces challenges. One of the primary barriers identified by [20] involves the lack of time (budgeted time) and operation on different time scales (immediate results versus long term results) between academia and industry. The lack of incentives, especially for individuals coming from the field of academia, and the metrics for success in the industry do not align. Another issue mentioned is that the nature of knowledge being transferred is perceived as "not cutting-edge," since companies hardly risk using cutting edge technologies all the time. This is an important fact to consider when developing curricula, since the focus would lie on establishing a strong foundation and grasp on the basics with engineering education that produces industry-ready students.

Course Composition & Redesign

"Graphical Communication and Spatial Analysis" is a required engineering course that is offered throughout the academic year (Fall, Spring, and Summer semesters). Combined enrollment is typically over 1,200 students per year. This student population is composed of all four stages of undergraduate education year (freshmen, sophomore, junior, and senior). Students belong to various majors across different schools of the university. The following distribution is based on enrollment numbers in Spring 2024 (January 2024 – May 2024) and Fall 2024 (August 2024-December 2024) semesters.

In Spring 2024 (SP24), the total number of students enrolled were 488. Sophomores made up the largest majority of the enrollees (54%) followed by Juniors (30%), Freshmen (9%), and finally Seniors (7%). First Year Engineering was the most common major (60%), followed by Mechanical Engineering (ME) (6%) and ME Technology (8%), Aeronautics & Astronautics Engineering (4%), Robotics Engineering (4%), and Supply Chain and Sales Engineering (3%). In Fall 2024 (FA24), a total of 843 students enrolled in the course. Sophomores again comprised the majority (51%) followed by Juniors (32%), Seniors (6%), and Freshmen (11%). Likewise, First Year Engineering once again had the highest students (28%), followed by Mechanical Engineering (ME) (27%), Aeronautics & Astronautics Engineering (22%), ME Technology (9%), and Robotics (2%).

At Purdue University, the First-Year Freshman Engineering course has been a staple in the engineering curriculum for over 30 years and has been absent any significant modifications in the past 10 years. With the rise of Industry 4.0 and the gradual evolution of AI and generative

design on the horizon students must be better prepared to comprehend product development in the context of evolving technologies. Students must, in a sense, “level up” on the competencies they are expected to have mastered by the time they enter the workforce.

To maximize the effectiveness of this course in the context of these external forces, this course was influenced by the IMPACT program. Since 2012, the university has offered a cohort-based Faculty development program known as IMPACT which features a Faculty Learning Community (FLC) model to promote effective teaching practices. Through this program, faculty regularly engage with instructional design experts to redesign one course. The support staff work one-on-one with faculty to identify core learning outcomes and help to design content that capitalizes on intrinsic motivation to increase student engagement, competence and learning gains [7]. The course redesigned through this program is tracked over several semesters to assess results and gauge the overall effectiveness of the program.

The course presented in this paper was improved by refining the learning outcomes based on Blooms Taxonomy [21], incorporating scaffolding to provide the appropriate level of support to learn more complex concepts with the ability to apply them in the correct context [6][35], and integrating meaningful assessments to more accurately gauge competency [21]. By leveraging these instruments in the course, students were able to transition from simply remembering previously learned knowledge to applying knowledge to actual situations. The six major learning outcomes, each with a handful of learning objectives that further define the knowledge or competence, are outlined below.

Explain the Product Design Process.

- Distinguish between the different product design processes.
- Explain the most appropriate design process for a given project.
- Leverage project management techniques to manage individual and group work.
- Explain the importance of freehand sketching as a communication tool for the designer.
- Construct clear freehand Multiview and pictorial freehand sketches to convey design ideas.

Explain the Role of Parametric Solid Modeling in the Product Lifecycle.

- Summarize the history of Engineering Graphics.
- Illustrate the future of geometric modeling in the product lifecycle.
- Work within a Product Data Management (PDM) system to support design, collaboration, and geometry re-use to simulate an industry PLM setting.

Demonstrate proficiency in the use of high-end Computer Aided Design (CAD) applications.

- Effectively utilize a CAD system.
- Create 3D geometry from 2D sketched geometry.
- Construct features using advanced modeling techniques such as Patterns and Transformations.
- Interrogate a simple Technical Data Packages (TDP) to interpret GD&T in the form of Model Based Definition (MBD)
- Construct and simulate digital mock-up visualizations and kinematic simulations.
- Demonstrate ability to work across CAD systems to build a product.

Comprehend design intent in the design of a product.

- Analyze a part/product based on its use, context, and variants to build in appropriate design intent.
- Create models using parameters to create variants and populate part libraries.
- Develop product structures that allow for product variation and re-use.

Describe Product Data Management (PDM) and its role in Parametric Modeling.

- Describe the concept of Product Data Management.
- Explain the difference between PDM and PLM.
- List the primary functions of PDM.

Follow instructions using listening, reading and analytical skills.

- Effectively follow instructions in a working/learning environment.
- Utilize instructions to complete this course successfully.
- Decipher confusing instructions and know how/when to ask for clarification.
- Stay organized to be able to find what you need when you need it.

Each of the six objectives mentioned above, draws inspiration from multiple fundamental experiential learning and teaching concepts such as Kolb' Experiential Learning Cycle [4], Zone of Proximal Development [34], and Industry-Academia Knowledge Transfer Models [14], with each having a primary focal point. The explanation of product design process and role of parametric solid modelling leans heavily into transfer of industry standards and processes into elements (curriculum and operations) of the course. They also contribute to the Concrete Experience stage of Kolb's Cycle, which allows students to build their foundational knowledge. The demonstration of CAD application contributes to the students understanding their learning and proficiency in attainment of application of theoretical concepts, which primarily serves the Reflective Observation and Abstract Conceptualization stages. This also provides them with a skill to master, and a way for instructors to gauge competency. Comprehension of design intent primarily serves the Active Experimentation stage, to aim for the best outcome. Finally, the ability to describe PDM feeds back into the knowledge transfer pipeline (specifically the process aspect) which enhances social relationships of learners. The last learning objective contributes to the overall development of the student as an integral contributor to the engineering ecosystem and a competent member of society.

To ensure students are learning to design in the context of quality, safety and serviceability, the CM2 Standard for Change and Configuration Management has been woven into the course structure. Partnering with the Institute of Process Excellence (IpX), concepts, processes and technology have been structured reflect those used by some of the top engineering companies within industry. The CM2 standard provides the framework for the software tools and processes utilized in the course which reinforce concepts, assignments, and projects. The course leverages Siemens Teamcenter as the repository for all student work leveraging a modified CM2 closed loop change process for all student submissions providing students with invaluable experience in an enterprise PDM system. Siemens NX and Autodesk Fusion 360 are used within the established framework to teach product design practices and demonstrate CAD interoperability between CAD systems in the context of the PDM system. Finally, an Anark Collaboration server is used by students to access engineering Technical Data Package (TDP) information related to the models and project items they are required to build in the course. Each of these elements will be described in further detail. The utilization of industry standard tools and approaches contributes to the knowledge transfer channel (where the students of the class act as the recipient) and the instructors act as the knowledge transfer process [14] that creates a multi-directional knowledge dispersion setup in the lecture and lab sessions. The multi-directional nature is due to the fact that the course approach is based on industry knowledge but feedback from students allows the instructors to tailor specific aspects for a classroom setting (such as condensing of roles, elimination of workflow stages for simplicity, etc).

Over the last decade, through the School of Engineering Technology (SoET) partnering with the IT, the university has been able to grow the necessary IT skill set to deploy and manage the enterprise applications required to support the course with the help of industry experts from the software providers as well industry counterparts and SoET graduates from companies such as IpX, Siemens, SAIC, Toyota, Essig, and Razorleaf. These companies and individuals not only view themselves as partners, but also stakeholders in the education of future graduates. Without their extensive knowledge of not only the software and processes, but also the emerging industry trends, the implementation of these tools and concepts in a course of this size would not be possible.

Discussion

The full realization of the CM2 framework and technology stack has taken four regular semester and two summer sessions to be fully realized along with several other instructional changes based on after action reviews conducted internally with the instructor team and with students during the last lecture meeting at the end of each semester.

The foundation of the course provides in-depth theory on parametric modeling best practices, design for change, PDM, and PLM, all in the context of CM2. Application-specific tutorials (termed as "Guided Assignments") walk students through how to apply the theory and concepts to a specific modeling application by illustrating the construction of various models in a progressive manner. New concepts and features are introduced in each tutorial, which is built on the previous one. Students' progress from effectively manipulating the 2D sketcher and parameterizing features models leveraging design intent to build out entire part families that cement the concept of design for change. This compartmentalization of the learning process aims to provide students with manageable chunks of structured information, where each subsequent learning experience draws from a previous one. This concept has been termed as "scaffolding" and can be explained as "process that enables a child or a novice to solve a problem, carry out a task or achieve a goal which would be beyond his unassisted efforts" [35]. This concept's roots can be traced back to the theory of Zone of Proximal Development (ZPD) [34], which sheds light on understanding the gap between the skills that a student has mastered and the skills that they have the potential to master, with the help of guided instruction. [35][36] This concept also sheds light on the importance of learning via purposeful social interactions, which guided the instructor's design of lab and lecture operations. Figure 1 demonstrates this concept of "scaffolding" in terms of models that students create – each model consists of major computer aided design concepts, and every successive model builds upon previously learned concepts. As an example, model 1 teaches the "Extrude" function to students, and model 2 teaches a specific case of extrude known as the "Revolve" function, in the CAD suite. The lab instructors provide in-class discussions on how model 1 could have also been built using the "Revolve" function, and the considerations that enable a modeler to pick one or the other. This illustrates the guided social interaction aspect of ZPD, and utilizes the "Reflective Observation" component of Kolb's Experiential Learning Cycle [4], to create mental links between learning concepts. In addition to that, students must apply specific design intent to each sketch and parameterize specific dimensions to ensure the model behaves in a predictable manner when a specific change is applied. A predefined material is also applied to each model giving it a known mass. The models are first evaluated on having the correct mass then by how the model behaves when specific

parameters are modified based on the given design intent. This structure allows for students to understand submission standards, relation of design parameters with assignment learning objectives, and achievement of design intent – all contributing to their knowledge gained via experience (serving the "Concrete Experience" stage of Kolb's Experiential Learning Cycle).

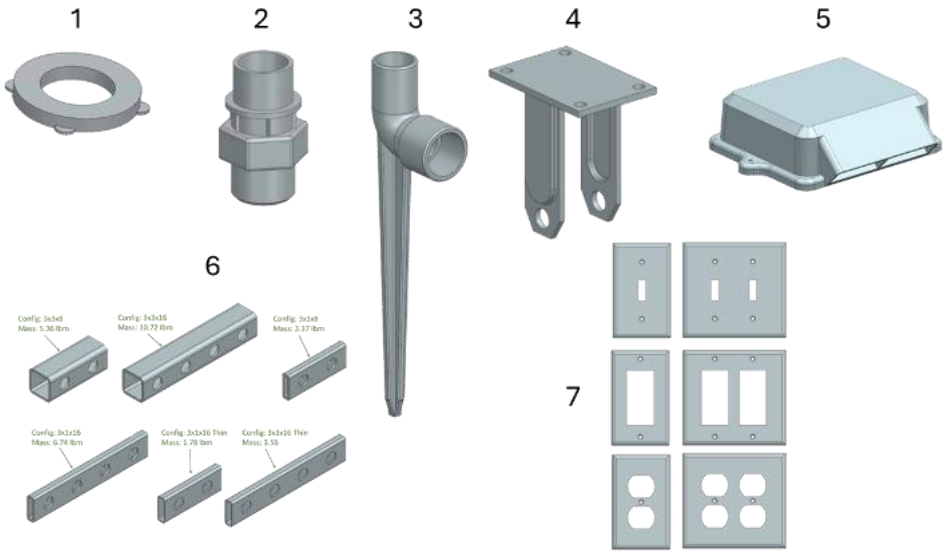

Figure 1: Models used in the course

Initially, the course relied exclusively on tutorials and an open-ended course project to evaluate student learning. However, as students progressed through their respective majors to upper-level courses, it was discovered that many students were unable to effectively apply their modeling skills to new modeling scenarios. As a result, a decision was made to incorporate assignments of increasingly higher levels in Bloom's Taxonomy [21][7], and a midterm and final lab practical exams. The practical exams are designed to evaluate the student's modeling capabilities though a high stakes assessment based on CAD certification exams of NX or SolidWorks.

In the first semester, we found that students were not able to successfully transition from a step-by-step tutorial to an assessment. In the following semester (Spring 2023), a practice assignment was inserted into the course structure before the midterm practical exam to allow students to transition and get feedback from the instructional team. The practice exercise had no effect on the overall scores for the course, as shown in Figure 2, and was further enhanced during the third semester, with negligible effect.

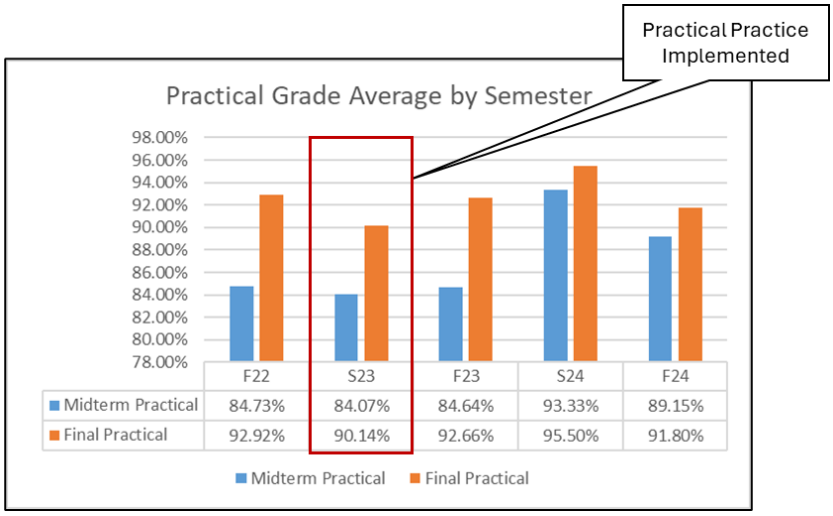

Figure 2: Average Practical Exam Scores – Practice Practical Exam Implemented

Based on the data collected as well as feedback from students and instructional staff, the course was reworked to include a weekly Do-It-Yourself (DIY) model each week starting in week three of the semester. The DIY assignment uses similar modeling techniques to the given tutorial and is delivered using a TDP through the web-based Anark Collaboration Server, as shown in Figure 3.

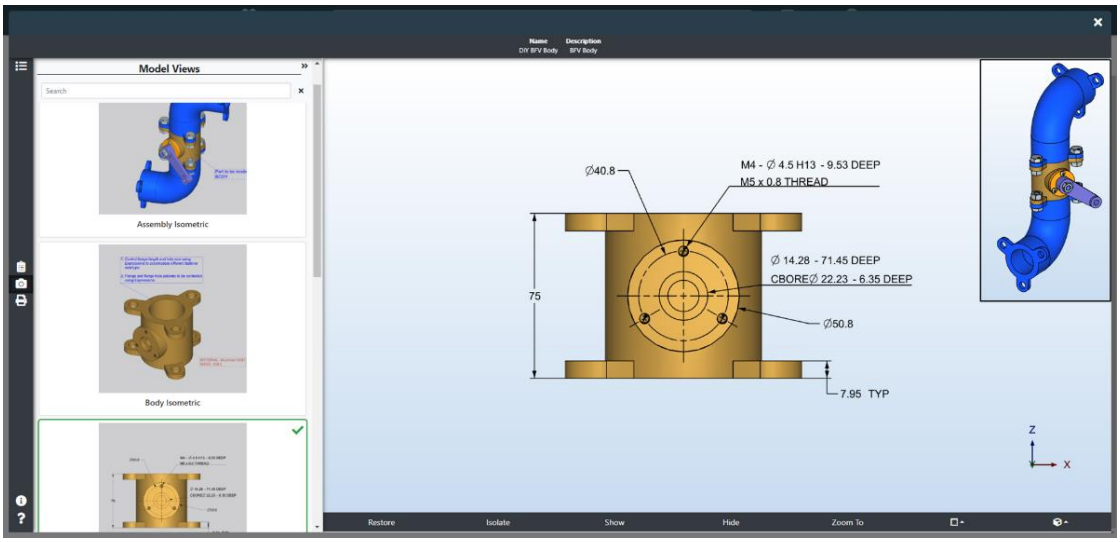

Figure 3: DIY Butterfly Valve Assembly as displayed in the Anark Collaboration Server

The TPD provides a 3D MBD with documented design intent. The design intent is often a descriptive note of how the model should behave (morph) when the required parameters are manipulated. The design intent presents the "challenge" aspect of the part to the student, to gauge their current skill mastery without assistance (as defined by the ZPD), and allows for instructors to address the gaps that limit the student from reaching a higher level of skill mastery. The set of DIY assignments is built upon one another week-by-week to culminate in the butterfly valve

assembly. Students are required to model the DIY parts based on the given dimensions, design intent, and use parameterization of the dimensions provided. The model is then evaluated based on the mass (tolerance of +/- 0.5g) and correct model behavior. The design portion of the DIY assignment is completed in week six just before the midterm practical exam to provide students with the necessary scaffolding [6] of information pertaining to the design processes, design standards, and design intent. This enables the student to translate and apply concepts learnt in the tutorials to a more student-driven (and reduced instructor guidance) workflow.

The DIY assignment setup allows students to engage in all the four stages of Kolb's Experiential Learning Cycle, in rapid (and short) iterations, for a set duration (usually going from week three to week six). This scheme encourages students to recall learned information from instructor videos, book tutorials, and online resources (Concrete Experience); understand and evaluate the design intent of the DIY part based on the TDP to identify any potential inconsistency between their learned information and assignment requirements (Reflective Observation); initiate the design process with relevant design parameters and design processes and relate back to applicable concepts learned in guided assignments (Abstract Conceptualization); and finally, utilize the CAD tool to incrementally design and test for design intent preservation of the part (Active Experimentation). The Active Experimentation stage is further enhanced by the fact that each of the created DIY parts culminates in an assembly (in week eight), thus ensuring that students are always working towards a clear end goal. Students are encouraged to design the part by allowing for downstream modifications, should the final assembled model have issues (such as misaligned features, inverted parts, scaling issues etc.) The DIY assignments also provide students the opportunity to engage with the instructional staff through questions about the best techniques and tools to fulfill design intent requirements, thus moving students to the application level of Bloom's Taxonomy [21]. An environment of collaboration with peers is also fostered, enabling for faster problem solving via purposeful social interactions. [35][36] From the instructional point-of-view, this engagement with the students allows the lab instructor to understand the current skill mastery level of each section (experienced instructors can even drill down to a per-student basis), and thus adjust for additional (or reduced) guidance during lab sessions.

The implementation of the DIY assignments in the Spring of 2024 had a significant impact on both the midterm and final lab practical exams with almost a 9-point jump on the midterm practical exam and just under a 3-point jump on the final practical exam from the previous semester (see Figure 4). The dip in scores in the Fall 2024 semester is attributed to improved rigor in grading through the implementation of dedicated graders.

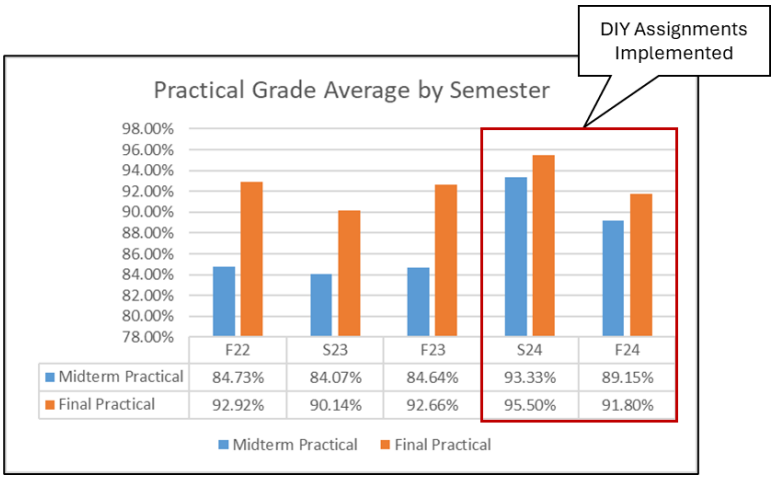

Figure 4: Average Practical Exam Scores – DIY Assignments Implemented

The midterm practical exam is comprised of a single part that is provided to students through the Learning Management System (LMS) testing utility. It is a timed, 60-minute practical exam conducted in the student's lab during week 7 of the semester. Students must model the given part with correct design intent, parameterization, and apply a specific material (drawing from their experience in Guided Assignments and DIY Assignments). Design intent is communicated on the drawing with a note that appears to contradict the given dimensioning scheme. In the example of a lab practical exam problem set shown in Figure 5, students are instructed to ensure the slot remains a constant distance from the right edge when the model is modified. However, it is dimensioned from the extrusion on the left. The ability for students to build their models based on design intent rather than the documented dimensioning scheme validates the fact that they comprehend the design intent. The correct mass is then recorded though a multiple-choice question. Subsequent questions require simple design changes which should result in a specific mass if properly modeled. The model is then evaluated by a member of the instructional staff to score specific design intent features.

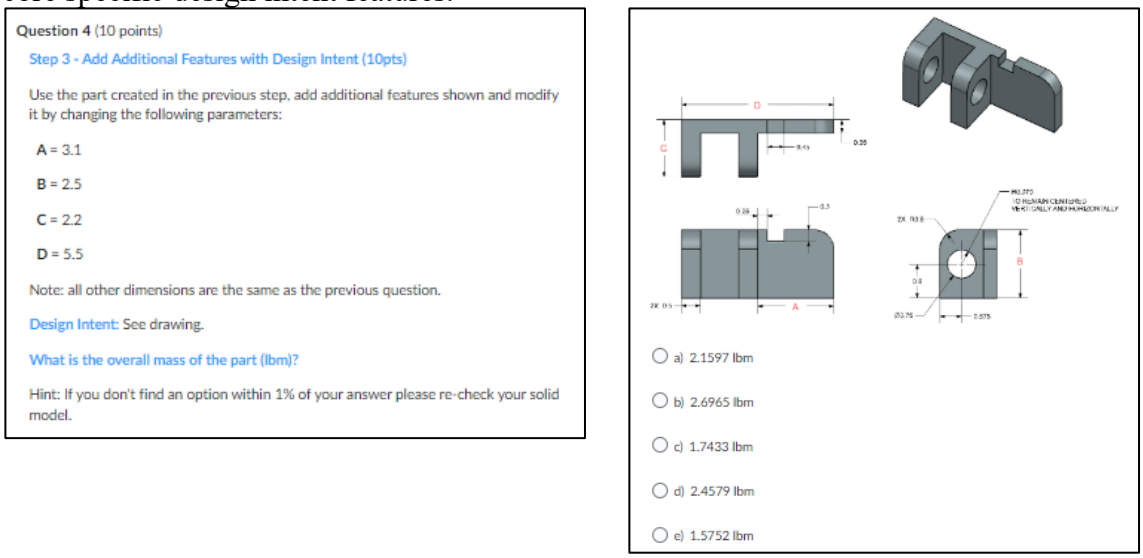

Figure 5: Example Lab Practical Exam Question

The second half of the semester focuses on assembling of parts and assembly modeling. To initiate assemblies, students once again learn via a tutorial (Guided Assignment). All the parts required to complete the assembly are provided via the PDM system. Students must construct the assembly in context of PDM as if given standard parts. Therefore, every student uses the same set of part masters, and only creates a unique assembly level file. This approach enforces the concept of reusability that is then used to illustrate part traceability through PDM. It also ensures that students are exposed to data management concepts (such as intellectual property security, user permissions, data handling, etc.) in a passive manner, thus engaging them in meaningful discussions and enabling them to conceptually place their work (and themselves) in a larger engineering ecosystem where the instructors become their immediate source for acquiring insights into real-world application of such concepts [14].

Upon completing the assembly tutorial, students complete the final DIY (Figure 3) assignment by putting together the butterfly valve assembly using a single level assembly and accessing the parts they created and stored in the PDM system. If they find a part model does not fit properly within their assembly, students can make corrections and re-submit the part for the assembly evaluation as part of the change process, facilitating Reflective Observation (identifying inconsistencies between old parts and new assembly) and Active Experimentation (making appropriate updates to old parts and new assembly while preserving design intent) stages of Kolb's Experiential Learning Cycle.

The final stage of the scaffolding process pertaining to part creation (to meet the course outcomes and prepare students for the final project) involves a final tutorial-based assignment (Guided Assignment) which introduces the application of 3D annotations on parts. These annotations can be used for documentation as part of MBD or a 2D drawing. Although Geometric Dimensioning and Tolerancing (GD&T) is briefly discussed in the course, it is not applied to the models as it is beyond the scope of the course. The model students create and annotate in preparation for the final project is shown in Figure 6.

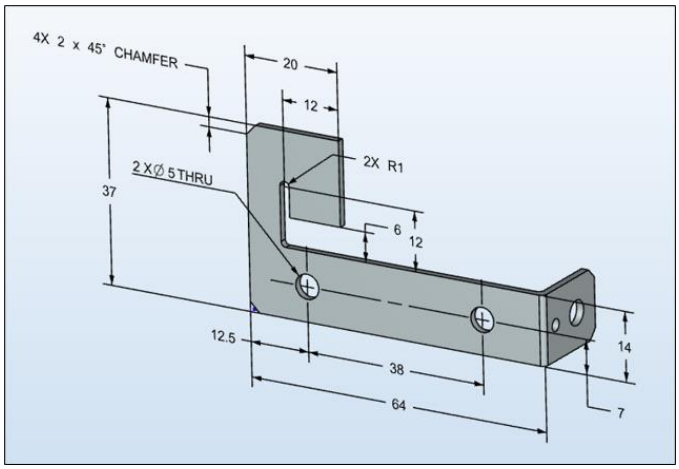

Figure 6: Breaker Bracket (to teach 3D Annotations)

In preparation for the final project, one final DIY assignment is provided that details the creation of a multilevel assembly. Students are asked to assemble a cart by creating a series of sub-assemblies with parts provided in the PDM system. Students retrieve the parts from the PDM system and build an assembly structure in the CAD application based on the product structure given in the Anark Collaboration server as shown in Figure 7. The completion of this task (and the 3D annotation assignment) signifies the end of the Guided Assignments that teach students the core concepts and creates a foundational knowledge base going into the project. The final project was developed and structured to mimic independent contractors (students) completing a work order (the project) provided by an external entity (the instructor). This period of the class reduces instructor guidance to a suggestive dialogue rather than explicit instructions, thus encouraging students to tap into their existing knowledge. As the DIY parts, the project parts also engage all four stages of Kolb's Experiential Learning Cycle, with an increased sense of "challenge", i.e., the incorporation of the entire class pipeline (create and annotate parametric parts, assemble into sub-assemblies, prepare them for final top-level assembly), and relevant documentation (progression check-in with lab instructor) on a weekly basis.

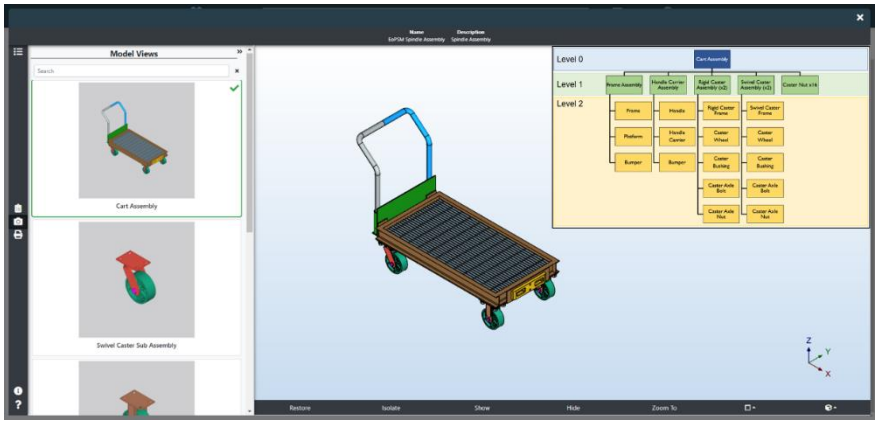

Figure 7: Cart Assembly (to prepare students for multi-level assemblies)

The culmination of the course, towards the end of the semester, is geared towards a multi-level assembly, with each of the subsequent tutorials and DIY assignments preparing students to model, annotate and assemble the final project: the Little Blazer Engine (LBE) shown in Figure 8. The project is used to evaluate the student's competency in the skills learned throughout the semester as it pertains to modeling for change, creating assemblies, storing product data in a PDM system, and using Change Orders for sign-off and evaluation. Students apply the knowledge gained throughout the semester to design and assemble a Little Blazer Engine based on the provided documentation while working in a collaboration-based environment (thus leaning into the final objective of the Zone of Proximal Development, where the instructor provides the student with more freedom of control, as they reach their expected level of potential). Instructional staff provide standard parts and critical feedback each week, to facilitate reflection and experimentation each week (serving Reflective Observation and Active Experimentation stages) and ensure students are working in a collaborative environment, with their superiors and peers.

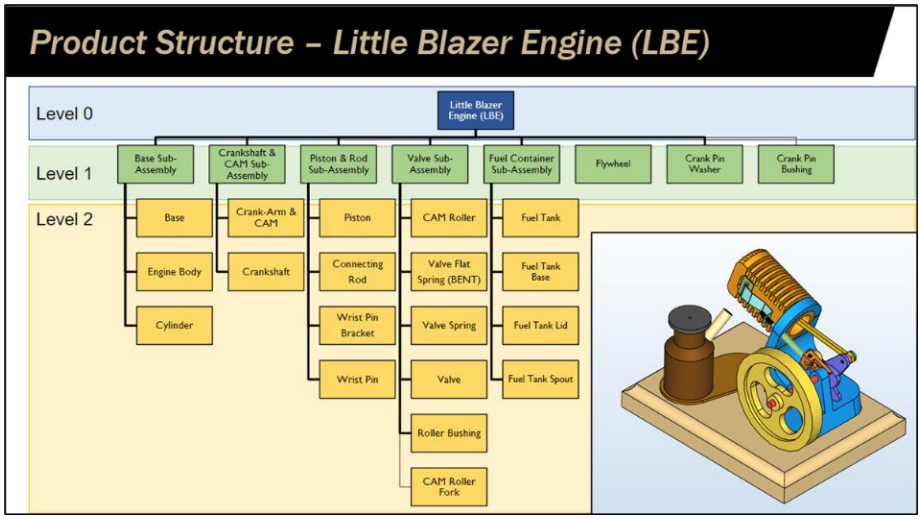

Figure 8: Final Project – Little Blazer Engine.

The project is broken down over the course of the last six weeks of the semester starting in week nine and ending in week fourteen with the final LBE Top Level Assembly (TLA) submission in PDM. Each week students model the individual components of one of the required sub-assemblies and assemble them along with instructor provided parts stored in the PDM system. Students are encouraged, but not required to initiate their TLA the first week and store it in the PDM system so they can add each week's sub-assembly to it as the semester progresses. As a requirement, a designated part in each of the sub-assemblies must have 3D annotations applied to reflect what was provided in the Anark Collaboration server. The Anark Collaboration server provides a TDP for each week's sub-assembly detailing the overall dimensions for each component, how it assembles to the larger TLA, and any special instructions required for assembly as shown in Figure 9.

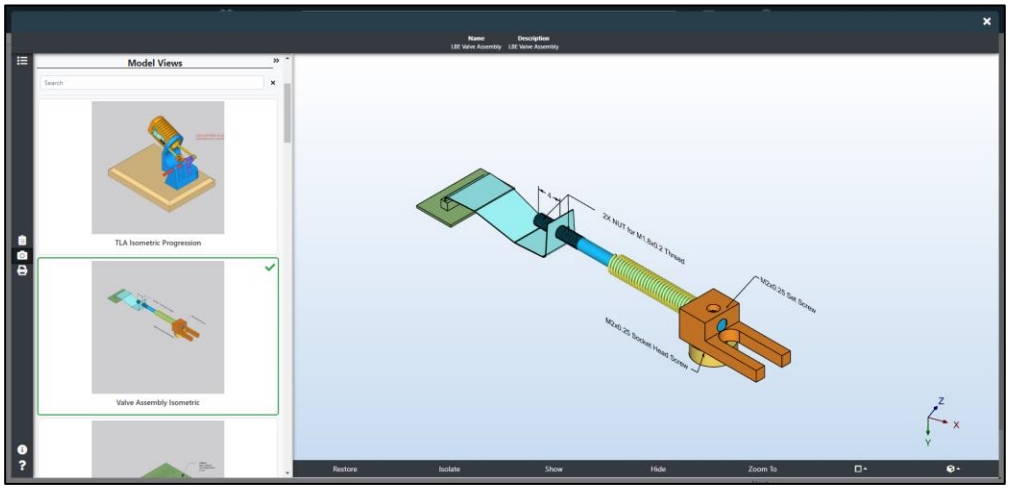

Figure 9: LBE Valve Sub-Assembly TDP

The final TLA submission requires all components to be present and that the engine be capable of making one complete rotation of the flywheel that properly actuates the piston and valve sub-assemblies to demonstrate understanding of assembly constraints and kinematics motion.

The final lab practical exam is administered in the last lab session of the semester. It is a 90-minute assessment that mimics the midterm practical exam with one addition: once modeled, the part must include four 3D annotations in three of the primary views to demonstrate competency in applying documentation to a model.

Validation

This research is framed around formal educational topics (such as Zone of Proximal Development, Kolb's Experiential Learning Cycle, Bloom's Taxonomy) as foundational knowledge for curriculum development, course delivery, and instructional guidance. The final designed course curriculum can be further generalized by extrapolating the key highlights to Kolb's Experiential Learning cycle. [4] The four stages, and the subsequent relation to the course curriculum design, can be summarized as follows:

a. Concrete Experience – This stage enables a learner to have a hands-on experience, via a new experience or a reimagination of an existing experience. The core of this stage lies in engagement in activity. In the context of the curriculum, learners position themselves within the context of the class which mimics the individual being a new recruit at a mid-size engineering company (complete with personnel roles, locations, schedules, practices, and processes). With that context established, the curriculum is designed to provide an ordered set of tasks (textbook material, self-paced learning material, Guided Assignments, Do-It-Yourself assignments, and Extra Credit Assignments) in repetitive time intervals (weekly). This approach enables learners to settle into a rhythm, driven by the concept of "learning by doing" [22] i.e., skill development via the pursuit and attainment of relevant and meaningful goals.
b. Reflective Observation – The experience engagement is followed by reflection on the task and evaluating the results. It primarily involves the discussion generation phase, which enables learners to identify (if any) the discrepancies from the actual and expected learning outcomes. Reflection is set in motion by the assignment feedback (based on the score distribution) and enhanced further by students engaging in office hours and help sessions, help forms, and the course contextual chatbot. The assignment feedback was also designed to provide detailed information on any discrepancies, as well as establishing the importance of executing every step of a process correctly.
c. Abstract Conceptualization – After the experience and discussion phases, the learner is faced with the task of drawing conclusions. The learner classifies the learning outcomes which add to their already existing knowledgebase. The Do-It-Yourself (DIY) assignments are the primary drivers. These assignments build on the core concepts in the Guided Assignments which learners are expected to identify after the reflection phase. Discussions also lead to the refinement of the concepts which enable the learners to cultivate critical thinking on understanding the best practices in Computer Aided Design (additive versus subtractive workflows, parametric modeling, order of operations, etc.)

d. Active Experimentation – The final stage of the cycle is the testing stage where learners apply the conclusions derived in previous stages to new experiences and test the extent to which they have understood the concepts. This stage enables them to enact a plan of action to convert theoretically derived concepts to practical tasks. In the curriculum plan, it is achieved through Do-It-Yourself Assignments, projects, and practical exams, which follow the same patterns displayed in guided assignments, thus mimicking the material learners already are familiar with. However, Do-It-Yourself assignments have significantly fewer instructions and constraints on design, thus encouraging the exploration of best practices.

The cyclic nature of Kolb's Learning Theory and the repetitive nature of the content enable students to always be learning within an ecosystem, where they are trained on basic concepts and allowed to discuss and reflect on the lessons learnt, and then apply these lessons to achieve specific objectives and goals. The more engaged they are, the more familiar they become with the process, thus making it second nature in a longer time of the full semester.

Conclusion

The course described in this paper represents a step forward in the development of a digital enterprise curriculum that emphasizes design for change. Not only has our approach increased student's level of competency in their ability to design for change in the context of Industry 4.0, but many students have vocally expressed a newfound desire to continue a focus in design as they progress through their major and into their future careers. Additionally, the PDM/CAD Experience Survey data further validates a level of understanding of the importance of CAD and PDM in the greater Industry 4.0 and PLM landscape. Having a foundational knowledge of these tools and processes sets engineering students apart from their peers and provides employers with a future workforce that is already familiar with the necessary practical methods and technologies, not only theoretical principles.

Since the Fall 22 semester, Siemens has facilitated the NX Design Associate certification exam to our students through Accelerator Academy. Prior to the Fall 2024 semester only a handful of students felt confident enough to attempt the exam. At the conclusion of the Fall 2024 semester, 51 students requested to take the exam, which is double that of the four previous semesters combined. We believe that this datapoint, though anecdotal, is significant enough to validate the course design and instructional methodology.

Finally, many students have carried the knowledge gained into their extracurricular design build club activities that compete at the national and international level. Students have incorporated design intent and design for change into their processes and many are now using PDM as the backbone for their data management. In addition, a new student-run PDM Club has been recently founded that provides services to manage collective data management and change control processes for all tenant clubs leveraging the PDM Club infrastructure.

Based on our experience over the last few semesters with the project and recommendations IMPACT to provide students with an appropriate level of autonomy [7], we intend to open the entire project set of assignments in week 9 of the course to allow students the ability to work at their own pace. In the Fall 2024 semester, the project was made fully available in Week 11 with

several students taking advantage of the opportunity to complete the project. As an incentive to complete their work early, students are excused from lab attendance once their entire project is completed and properly submitted.

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