2018 ASEE Annual Conference & Exposition
June 24–27, 2018, Salt Palace Convention Center, Salt Lake City, UT
Paper ID #23689

Product-based Learning: Bundling Goods and Services for an Integrated Context-rich Industrial Engineering Curriculum

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Product-Based Learning: Bundling Goods and Services for An Integrated Context Rich Industrial Engineering Curriculum

Abstract

This work-in-progress paper reports on the redesign of the undergraduate Industrial Engineering (IE) curriculum at The Pennsylvania State University around a set of complex products that bundle goods and services together to facilitate an integrated product-based learning approach. Unlike the relatively disjointed silo-style approach to learning individual topics that has been the cornerstone of engineering programs nationwide, this approach enables students to learn technical content in an integrated manner, providing a common thread throughout core courses. Ultimately, the goal is to improve student motivation and learning as they understand, discover and practice the connectedness and mutual dependencies of core subjects in the successful realization and delivery of goods and services. A description of how the faculty team worked together to envision and implement product-based learning throughout the curriculum is provided, along with examples of implementation in the first few courses, student feedback and early lessons learned.

Introduction

Like other departments in The Pennsylvania State University College of Engineering, the Harold and Inge Marcus Department of Industrial and Manufacturing Engineering (IME) welcomes its incoming undergraduates as juniors and has two short years to deliver disciplinary content beyond core requirements in mathematics, sciences, engineering fundamentals and a general first course in engineering design. This relatively short contact time is particularly challenging in learning industrial engineering concepts, tools, and methods across all of the core industrial engineering (IE) areas of human factors, manufacturing, operations research, and service. Although students have exposure to mathematical optimization tools that are useful to solve problems within each area of the program, the linkages and interconnection between areas are rarely made obvious to students. There is currently little coordination between faculty in different areas to formulate or deliver educational materials, and students tend to quickly pigeonhole themselves into one area. Those with an interest in manufacturing, for example, do not consider service issues as particularly relevant to them and those with an inclination towards the service industry do not understand why they should endure the manufacturing portion of the curriculum. This false dichotomy persists even though it was addressed long ago by one of the most famous advisers to blue chip companies. Peter Drucker predicted that "…*traditional Manufacturing companies will look to restructure themselves as systems companies in which the starting point is not making the goods, but service to enable the customer to get the fullest benefit from the goods*", Panchak [1]. A notable illustration of Drucker's vision is the transformation undertaken by the Apple Corporation. Known some thirty years ago as the manufacturer of the venerable Macintosh computer, this dominant market player is now known for its revolutionary iPhone system: an exquisitely designed and manufactured piece of hardware, surrounded by a vast array of services including telephony, web access, audio visual content, appointment calendar, health monitor, GPS, banking service, etc. These, in the words of Drucker, "*enable the customer to get the fullest benefit from the goods*", and clearly, have led to tremendous profit margins for Apple. Many other examples of bundling products and services can be found in the manufacturing sector (e.g., aerospace, automotive, medical device, and more), where products and services are envisioned, produced and marketed with a variety of options and packages that add value and service life.

Our premise, and the focus of this paper, is that complex products and carefully coordinated activities across the curriculum, can provide the essential foundation for curriculum reform in industrial engineering that is needed to enable students to learn technical content in an integrated manner with a foundation of professional, real-world problems, unlike the relatively disjointed silo-style approach to learning individual topics that currently exists.

In the sections that follow, a brief review of related literature is presented first. Following this, approach and methods undertaken to design and develop product-based learning throughout the undergraduate curriculum are presented. Examples of course activities and the flow and integration across the curriculum are provided. Preliminary results and lessons learned are included in the discussion of courses that have been reengineered to date. Other critical elements to success, such as the project team and infrastructure needs, are also discussed. Finally, a summary is provided along with plans for future work.

Related Literature

A problem-based learning pedagogy of engagement provides a strong foundation for curriculum redesign. Smith, *et al.* [2], citing additional studies indicating the importance of engagement for student learning, including The National Survey of Student Engagement [3], specifies core features of problem-based learning originally identified by Barrows [4]. In particular, two key core features are utilized in our curriculum redesign: (1) problems provide the organizing focus and stimulus for learning, and (2) problems provide the vehicle for developing clinical problem-solving skills. These in turn, lead to another core feature of curriculum redesign that enables students to gain new information and knowledge through self-directed learning.

With the goal of developing real-world problems integrated across multiple courses, an expansive framing of context is needed. Engle, *et al.* [5] contend that knowledge transfer for students is encouraged when the learning context is both recognized by the student as providing information that can be used in the future (e.g. upper level courses) and connected backward in time to past learning contexts (e.g. prerequisite courses). Further, expansive framing, such as that proposed in the complex products herein, can create connections for students where knowledge relevant in one setting will be recognized as also relevant in other settings. This integration and interconnection across core courses in the IE curriculum is believed to be key for students' future problem-solving abilities. Lastly, a National Research Council report [6] cites work from Yildirim, *et al.* [7] indicating that teams of students working with open-ended, real-world problems can improve students' problem solving.

Approach

As described previously, the successful strategies that integrate product and services offerings demonstrated by industry inspired the redesign of approach to the organization and delivery of core elements of the industrial engineering curriculum so that students understand, discover and practice the connectedness and mutual dependencies of these core subjects in the successful realization and delivery of goods and services. As shown in Figure 1, a real complex product provides the context for activities underpinning product-based learning.

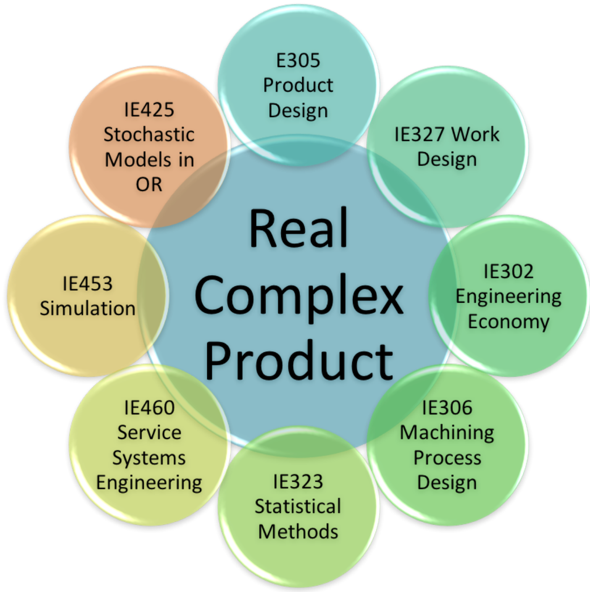


Figure 1. Integration and synthesis through a real complex product.

For example, entering juniors in IME will have activities attached to Design and Manufacturing principles (IE 305) and Ergonomics (IE 327) on the design of parts, sub-assemblies and assemblies of a product as well as the preparation of design function deliverables necessary to drive the subsequent manufacture and assembly of the product. As they acquire Engineering Economics (IE 302), Manufacturing Systems (470) and Mathematical Modeling (IE405, IE 425, IE453) expertise, they will then concentrate on decisions regarding the optimal make/buy mix of product components and the design and implementation of manufacturing processes needed for the realization of in house components. Likewise, Supply Chain and Service Engineering (IE 460) knowledge will then be applied to the global sourcing of "buy" components and the design and management of services attached to the product. In other words, the product consisting of its physical goods and bundled services will serve as the glue that will enable our students to realize the connectedness and complementary nature of these core IME methods for the successful realization and commercialization of goods and services. Just as journalism students learn to practice their craft on the school newspaper, IME students will run the closest thing to a Manufacturing and Services company.

This product-based learning and content delivery approach relies on the careful identification and use of a set of products that reflect the global dimension of product design and manufacturing, as well as the symbiotic relationship between manufactured goods and the consumer services built around the goods. Discussed later, it also relies heavily on a strong diverse and inspired team.

Selection of Real Complex Products – Several considerations came in to play in the selection of products that would support the variety of considerations and thread through the curriculum across many courses. The team, including the undergraduate program coordinator and faculty from all areas of industrial engineering, participated. Product complexity, costs and logistics of storage were also considered. It was decided that the products selected would change each year, but that prior products would be recycled into the program every other year, in order to minimize the burden on faculty in preparations that result each time a new product is introduced. For the first year, a set of five different power hand tools (two different brands) and two home-use pressure washers (electric powered and gas powered) were selected.

Figure 2 illustrates one potential sequence and flow of the power tools products as the basis for integrated learning through the curriculum. In Human Factors, students focus on grip design. As students acquire Engineering Economics, Manufacturing Systems and Mathematical Modeling expertise, they then concentrate on decisions regarding the optimal make/buy mix of product components, inventory management, and the design and implementation of manufacturing processes needed for the realization of in house components. Similarly, Supply Chain and Service Engineering knowledge is then applied to the global sourcing of "buy" components and the design and management of services attached to the product. Throughout activities, students maintain and upgrade a portfolio documenting all the work and deliverables produced in various classes around these products. This portfolio will help them realize the connectedness and complementary nature of core IE concepts, methods and tools for the successful realization of a complex product.

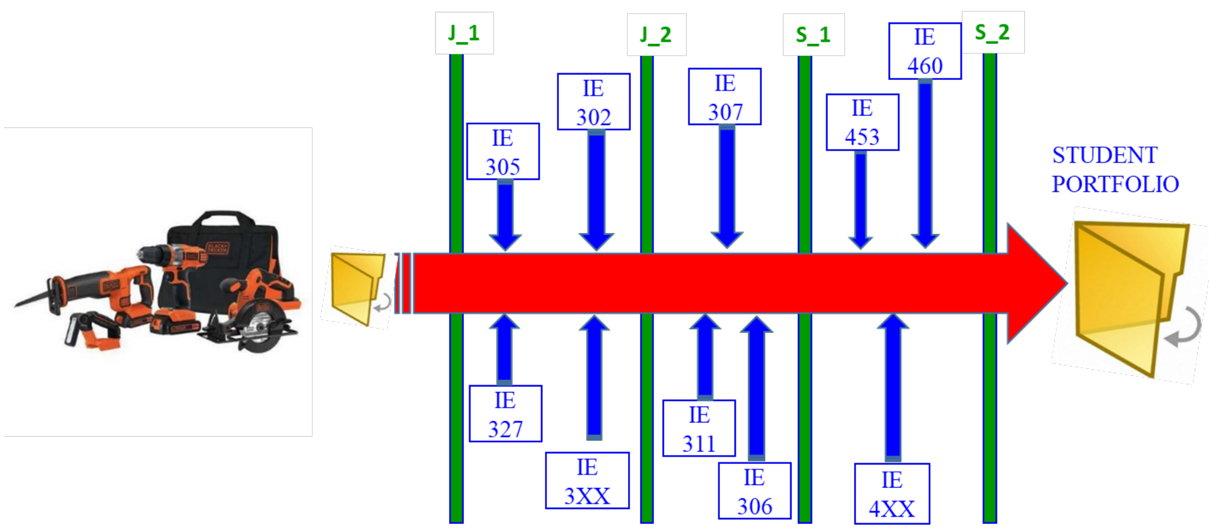


Figure 2. Curriculum flow and integration supported by complex products.

Course Methods, Results, and Discussion

The project launched in the fall semester of 2017 with an initial focus on six core courses in the IE undergraduate curriculum. Descriptions of methods (activities), results, and reflections for each course follow.

IE 305 Product Design, Specification and Measurement – exposes students to the principles required for designing a product and developing the specifications for its components and the methods for product verification and checking conformance to specifications. Eighty (80) junior level students undertook the dissection and CAD modelling of the power tools and pressure washer. These tools were well suited for the course redesign due to two broad considerations.

First, the realization of these products reflects current industrial practices of the global economy; these practices include the range of design, manufacturing and services required to support the successful realization and commercialization of a product. Second, manufacturing processes involved in the production of a range of components included in these products map quite well with the manufacturing capabilities of our laboratories; students are therefore able to undertake the subsequent prototyping of some of these components.

The class includes four (4) laboratory sections of 20 students each. Within each Laboratory section, students were free to assemble into five (5) groups of four (4) students each. The products included two (2) power washers (one gas powered and the other with an electric motor) and two (2) sets of battery-driven hand power tools. Products were randomly assigned to each section during each section's assigned Laboratory meeting time. The objective of this class exercise was twofold. First, it allows students to demonstrate their mastery of essential CAD modeling tools. Second, it gives them an opportunity to work and interact within and between groups. With a product in hand, each group of students proceeded with the careful documented disassembly of their product (a class activity where cell phones proved an invaluable recording tool), followed by the partitioning of sub-assemblies and parts among students. Once this initial activity completed, the task was to reverse engineer each of the parts using measurement tools from the metrology lab and recreate solid models of each part. With solid models at hand, the groups would then put together a product assembly and then generate common design outputs including an assembly model, exploded assembly, bill of materials, assembly charts and individual part models. Figure 3 shows the CAD assembly surrounded by the exploded sub-assemblies of the gas power washer model produced by students in Section 1. Figure 4 shows the set of power tools assembled by Section 2 and Figure 5 shows the bill of materials and exploded assembly of one of the power tools produced by Group 3 of Section 2.

Figure 3. Gas pressure washer model assembly surrounded by exploded assemblies of main sub-assemblies produced by students. (Courtesy of IE 305 section 1 students)

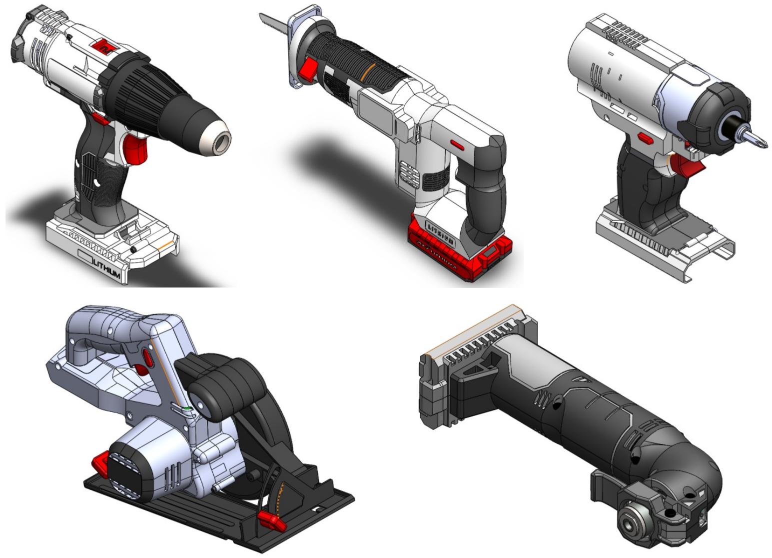


Figure 4. Assemblies of the set of Porter Cable hand tools produced by students (Courtesy of IE 305 section 2 students)

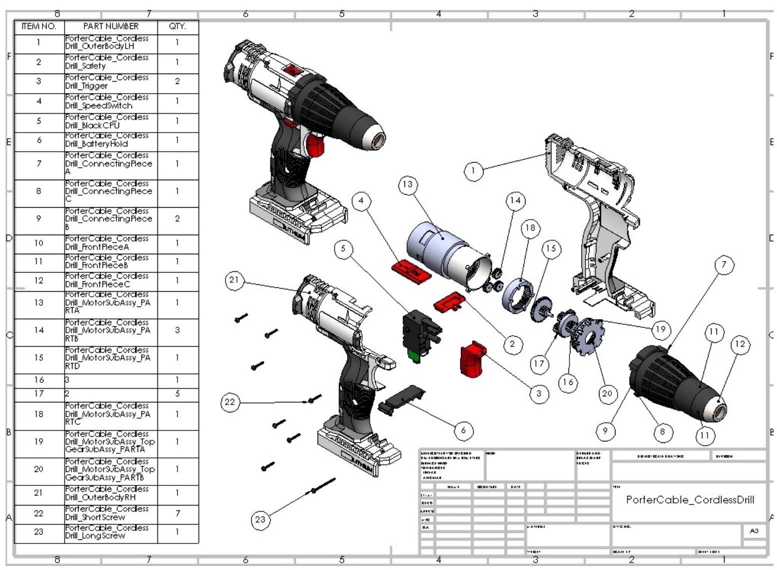


Figure 5: Bill of materials and exploded assembly of the Porter Cable drill produced by students (Courtesy of IE 305 Group 3, section 2 students)

The successful conclusion of this exercise led to four primary observations:

1. Student enthusiasm: Enthusiasm was high upon being handed their own product. The professor who has taught this course for many years, likened student reaction to being reminiscent of children being handed a gift. Enthusiasm, questions and interaction among students and instructor were also very high during the disassembly of the product. This phase of the work reinforced many of the lecture concepts as students discovered first-hand how parts assembled and fitted together into intricate sub-assemblies and assemblies. Use

of cell phones to record various states of disassembly during this process was very high and proved invaluable for the subsequent productions of assembly chart models.

2. Timing and logistics: Activities described above and the deliverables were initiated six weeks before the end of lectures and the beginning of exam week. This was too short, particularly in light of the fact that the work undertaken for this CAD project is programmed to be done outside of regular class and laboratory hours. A better way must be found to start this activity earlier in the semester by integrating some of the CAD project activities into the first seven weeks of Laboratory instruction of Solidworks software. Selection, acquisition, distribution and support of disassembly activities for ten different power tools and two pressure washers proved a little too overwhelming for just one Faculty and one Teaching Assistant. More help is needed to support this type of activity.

3. Product variety and complexity: The deliberate decision to select two power tool sets from different makers and two pressure washers with different power drive technology introduces a diversity of designs for each course section and eliminates the need for policing the unauthorized sharing of files and work between groups. However, diverse products come with different complexities that need to be managed. In the case of a class section assigned a set of five (5) hand power tools, each group of four (4) students in the section became responsible for a distinct power tool and could work independently to create that model. The groups came together at the end to assemble the set of five tools in a common file and that effort required minimal collaboration and exchange of files. The situation for the pressure washers was different. A look at Figure 3 shows that the gas pressure washer assembly is significantly more complex than a simple drill. First, the complete washer needs to be disassembled into a set of five (5) sub-assemblies with roughly equal amount of work and complexity; each subassembly is then assigned to a group of four (4) students. That is a near impossible task as the subassemblies vary wildly in number of parts and complexity as shown in Figure 3. Next, each group proceeds with the disassembly of its assigned sub-assembly but must coordinate, with one or more groups, the design and measurements of functional mating surfaces used by the subassembly to mate with other subassemblies. Collaboration within and between groups to finally put together an assembly of the complete pressure washer is significantly more involved than that required in the hand power tool sets. As the students proceed with their work on the more complex product, they ultimately discover that their product requires significantly more collaboration and coordination within and between groups and begin to resent this disparity. We need to find a better way to manage these disparities in order to minimize student frustration and maintain a degree of fairness in the assignments. A potential approach may involve the conservation of product diversity and complexity together with the use of an auction type bidding system for sections to bid for a particular product and reap a bonus commensurate with the difficulty and complexity of work they choose to undertake.

4. File repository: Our plans were for a file repository that would facilitate the storage and retrieval of the work done in this class as students move to other classes and activities. The logistics of handling the coordination of so many different projects during this initial launch has not afforded us the time to implement this phase. Files are currently being stored at a central location and will be made available to subsequent steps of this project.

Students who have successfully completed this phase of the curriculum move on to select a manufacturing processing class during the spring semester. Our processing laboratories support three broad categories of manufacturing processes. These processes include solidification processes (casting, welding), deformation processes (metal removal) and additive manufacturing processes. In order to facilitate the continuation of this project, we intend to mine, from the products just modeled by students, three (3) subsets of parts compatible with the manufacturing capability of our Laboratories. The first subset will seek to identify, from all products (pressure washers and hand tool sets), parts amenable to be produced by solidification processes. This subset of parts will support activities such as mold design, solidification analysis, casting and welding practice addressed in our solidification class. The second subset will mine parts amenable to be produced by deformation processes. It will be made up mainly of rotational and prismatic metal parts extracted from the various products and amenable to production on our CNC turning and machining centers out of simple raw material forms such as bar and rectangular stock. This will minimize the cost and difficulty of production of these parts. Finally, the third subset will include complex and intricate plastic parts (e.g. power tool handles etc.) which are ideal for prototyping analysis using the various processes in our additive manufacturing laboratory. The files for these subsets of parts will be made available to processing classes. As students build knowledge in these classes and project selection time arrives, they will be able to reach into this repository of parts, rediscover and use some of the parts they modelled in CAD to now address problems associated with the actual production analysis /realization of these parts. This way, the connectivity between various engineering disciplines and its significant influence on the successful realization of a product will progressively take shape in the student's mind.

IE 302 Engineering Economy – introduces students to principles and methods for analyzing the economic feasibility of technical alternatives leading to a decision or recommendation. The focus of activities for the engineering economy course made use of the motor of the hand power tools. A subset of the students in this course had dissected and developed CAD models in the design and manufacturing course (IE 305) that was also taught in the same semester. Due to the timing of the common product dissection in IE 305, the engineering economy connected assignment was undertaken in the last two weeks of the semester. A make versus buy small case study was developed for this motor, putting the students in the production manager roll. The learning objective was to determine the motor price for each vendor, incorporating global shipping and port costs and time value of money, that will make it economically indifferent to making the motor in house. Students needed motors delivered to their facility in Philadelphia, Pennsylvania and were asked to consider possibly buying motors from three different countries, China, Panama and Germany, and one domestic location, Dallas, Texas. The scenario gave students a cost per motor for in-house production, based on costing information found for the actual motor in the power tools. They were tasked with including all shipping costs, e.g. freight rates plus port fees, handling charges, tariffs, etc., and to consider the time value of money by assuming their company will pay for all shipping and motor costs when the motors leave the vendor factory by withdrawing money from the corporate investment pool at a specific annual percentage rate – so, this money was tied up during shipping time. The case study objective was to determine the maximum price per motor from the vendors in each location that would make the company indifferent to buying it from a vendor or making it in-house. Because only about 35-40% of the students were simultaneously taking engineering economy and the design and manufacturing course, material was developed and presented to the entire class to set a minimum foundational understanding of the common product. The CAD models of the hand power tool (Figure 5) were presented along with an explanation of the dissection and modeling process in IE305 to provide context for the motor costs analysis needed in IE 302. Additionally, students were given some direction to reasonable web sites where basic shipping information could be gathered (Figure 6).

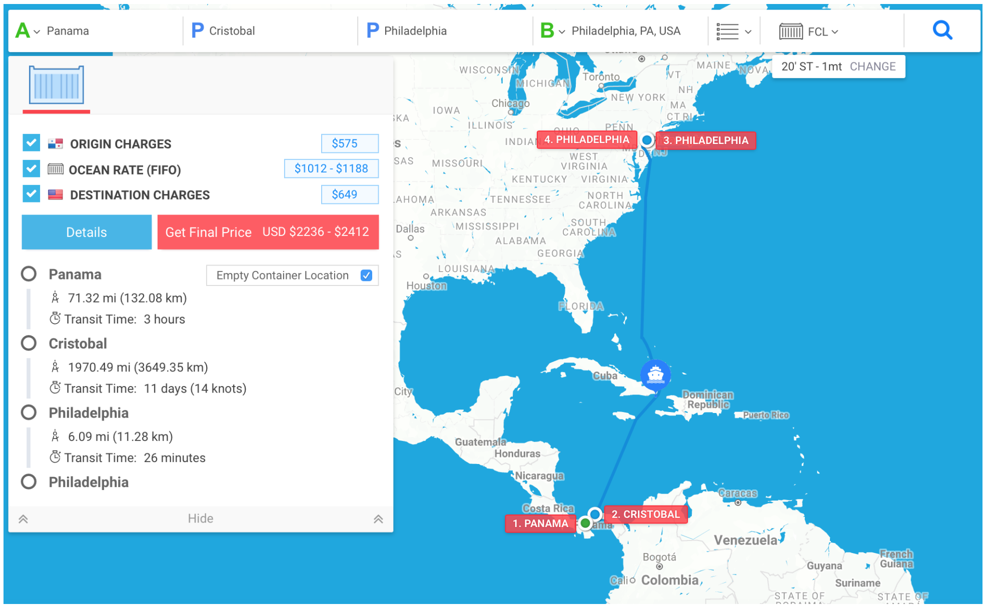


Figure 6. Example of basic relevant shipping data (screen shot from https://www.searates.com/reference/portdistance accessed 12/3/17).

A senior undergraduate student researcher who took the engineering economy course the previous year worked with the course instructor to interface with the IE 305 course teaching team and undergraduate researchers of other courses involved in the launch to research background data relevant to the case study. Having this student involvement provided important perspective and direction for the case study to make it appropriate for the new-to-the-major junior students. Based on interactions during office hours, students were appropriately challenged by the more open-ended nature of the assignment, and the ultimate 'ah-ha' moments when they put it together were satisfying.

Preliminary assessment information was collected at the case study conclusion regarding students' perceptions of the common-product concept. Student responses to an open-ended question regarding what they found most surprising or interesting about the economic analysis of this problem, included surprise at the number of separate shipping fees that vary between locations and add to the freight charge and surprise that shipping from China took about one month according to a website estimate. These were interesting real-world insights they gained. Students were also asked, "How do you think linking the Industrial Engineering classes by having a common product will impact your academic experience?" From sixty student responses, 43.33% said it will help see a "real-world situation" and better understand the "big picture." Another 31.67% think it will show why you need all different courses helping to see the coordinated and connected nature of courses, while an additional 21.67% believe it will help them consider many factors and facets of the common product. One student did not think the common product will impact the academic experience, although the student did think it will make material more related across courses. Perhaps the most interesting comment was from a senior student, taking the course out of the typical sequence, who indicated that while doing this make versus buy assignment he/she had a "full circle moment" by realizing the impact of all the skills and knowledge gained in all the courses that can be used when starting a career. This preliminary feedback suggests that the stated project goals were shared by student impressions.

Future improvements to the case study in IE302 include the ability to present the assignment a bit earlier in the semester and provide even more opportunity for students to explore the input data needed to answer the make versus buy question.

IE478 Retail Services Engineering – provides an introduction to retail services operations, process models, and application of information technologies to enhance productivity and profitability. During the time we were defining and refining our project on Product-based Learning (spring semester of 2017, prior to official launching), one of the professors in the team tried some of the elements of it in this senior-elective/graduate-level course. The course had an enrollment of fifty-eight (58) students consisting of roughly equal undergraduates and masters students. The class was divided into 15 teams of 3 to 4 students each. As an instructor, "bundling goods and services" was a new topic both from a curriculum and pedagogical perspective. First step was to integrate the concept into the syllabus, which was done through a series of homework assignments and the final project. Specifically, each team was assigned to play the role of engineering consultants hired to develop a new line of "SmarTools" by a fictitious large retailer, NMI. These assignments and project are summarized below.

Assignment #1 – Market Research for New Product-Service Bundle

In this assignment, teams were asked to focus on the OEMs/brands of power tools that would compete with the new line of products to be launched by NMI. Each team was assigned three power tools OEMs/brands to gather information about their US market share, prices of top-10 tools. They were also asked to investigate if the price varied by channel and/or zip code. They were also asked to investigate the price of power tool "kits" compared to the price of the tools purchased individually. Teams had to identify major customer segments for these products and which option would be of more "value" to each segment.

The setting was that NMI's top management has a "stealth" strategy to brand its new line as "SmarTools" and by providing IoT coupled with cloud hosted services that are geared for commercial and do-it-yourself customers. Student teams were asked to use techniques such as Voice of the Customer (VOC) to identify potential services by surveying their friends and family and to get an estimate how much they would be willing to pay for such services. Each team was asked to propose five innovative IoT-cloud services that could be considered by NMI for SmarTools and check for any patents related to the services they propose. Based on this they had to suggest bundles of SmarTools and services targeted at specific customer segments along with a rationale and target pricing. Last step in this market research assignment was to identify products currently in the market that will be competing with their proposed SmarTools along with a brief table for comparison and their reasoning.

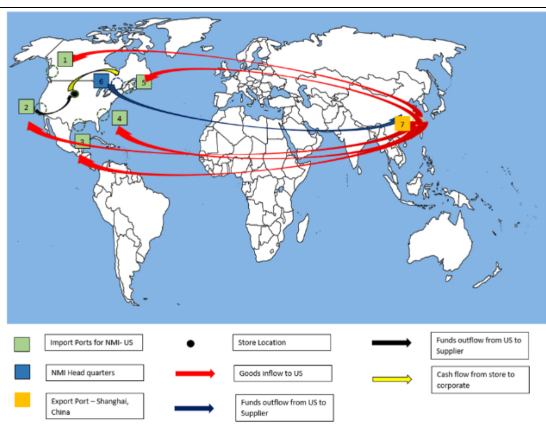
Assignment #2 – Cost Estimation, Make vs. Buy, and Supplier Selection

		Part				
		Tool only w/o service	Tool + Service Bundle (A)	Tool + Service Bundle (B)	Tool + Service Bundle (C)	Tool + Service Bundle (D)
		380	(380+30)	(380+40)	(380+50)	(390+50)
Sr. No.	Part Cost	380	410	420	430	440
Fixed Cost ($)						
1	Facility Cost (Warehouse Cost, 20000 sq. ft.)	200000	200000	200000	200000	200000
2	Miscellaneous (15% Processing cost, taxes, insurance, etc.)	30000	30000	30000	30000	30000
3	Service 1 & Service 2	0	100000	100000	100000	100000
	Total Fixed Cost ($)	230000	330000	330000	330000	330000
Variable Cost (% Part Cost) ($)						
1	cost of the product	300	300	300	300	300
2	Transportation and Handling Costs(15% By Sea)	45	45	45	45	45
	Service 1 Cost	0	10	10	10	10
	Service 2 Cost	0	20	20	20	20
	Total Variable Cost ($)	345	375	375	375	375
	Breakeven Quantity	6571	9429	7333	6000	5077
	Market Share(%)	0.03909	0.05608	0.04362	0.03569	0.03020

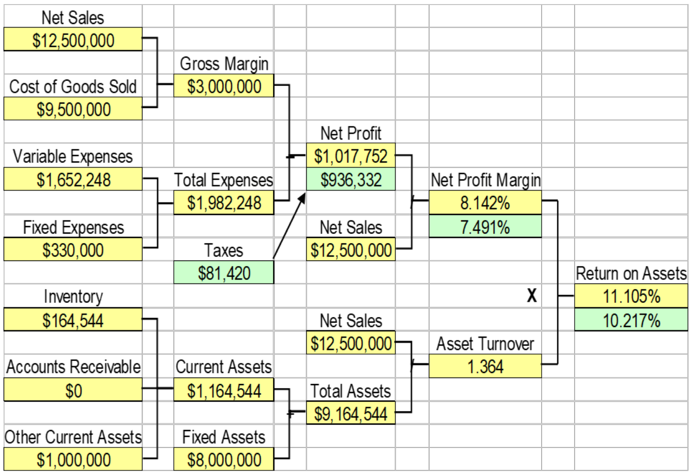
In this assignment teams were asked to focus on identifying the components that contributed to approximately 80% of the cost for the new line of SmarTools brand of power tools to be launched by NMI. To keep the effort manageable, they had to focus on any three tools from the earlier assignment. They had to select any two components that could be made using processes in an IME manufacturing lab and estimate the fixed cost and variable cost of making these components. This required drawing on what they have learnt from other courses, use process cost estimates from published sources, talk to experts, etc. For the "buy" analysis they had to identify two domestic and two global suppliers for each of these components, and estimate the fixed cost and variable cost of buying these components.

They had to determine the break-even point for each make vs. buy decision. Moreover, analyze the impact of bundling tools and services on break-even points, for any two services. Based on this they had to estimate the market share that would be needed for SamrTools to break-even. Each team had to discuss the pricing from the earlier assignment in the context of the break-even points and market-share it represents along with the impact of bundling the services.

Assignment #3 – Final Project – NMI SmarTools

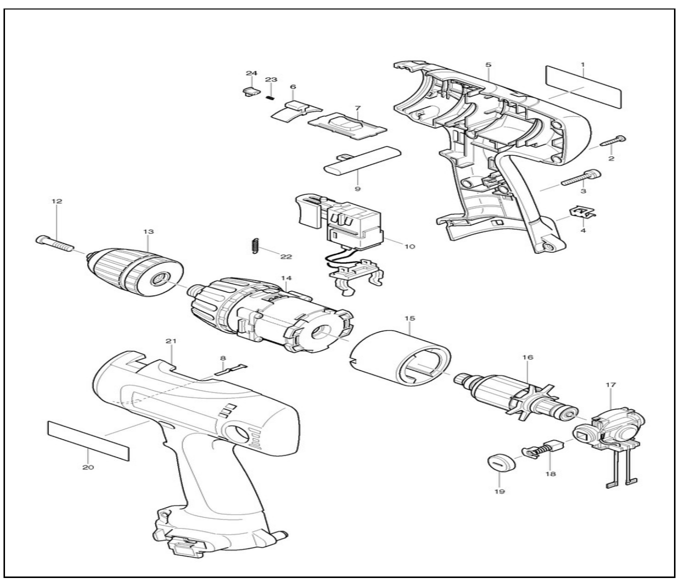


Each team had to prepare a report for the CEO of NMI detailing the concept of SmarTools and identify the opportunities and challenges of entering this market. Report was to include an Executive Summary of strategy (price range, product choice, bundling, break-even points, and market share) based on previous assignments. Each team had to construct three scenarios ("Best Case", "Worst Case", "Average Case") based on sales estimate for a three-year period, and develop a strategic profit model that included fixed costs, variable costs, inventory cost of goods in stores, in the supply chain, and transportation cost. Additionally, students were asked to develop a "planogram" of store shelf display and graphically present flow of funds and materials on a global map. Students were asked to record a video presentation for a C-level audience.



In their feedback, students indicated they were challenged by synthesizing materials across courses and the calculations required for the models spanned from minute to corporate financial statements. Most students were able to readily see the relevance of what they were doing to practice, which was a huge motivation. From an instructor perspective, one improvement would be to provide a "Quick Reference Guide" of models and formulae that would provide students a good starting point for their analysis in the final project.

IE460 Service Systems Engineering – makes use of quantitative models and methods for analysis, design and control of service systems.



This is a junior-level required course with an enrollment of 96 students. The focus of activities for the service systems engineering course was the set of battery-driven hand power tools. The context of the SmarTools concept previously described in the IE 478 Retail Services Engineering course section was extended to IE 460 through two activities covered in the course. Early in the semester students were given a 250-word description of the business model of the SmartTools bundle. The first activity was a homework assignment where the learning objective was to analyze the product service bundle along various dimensions covered in the course. This was a homework assignment in which student teams were asked to identify various good and service elements along the following dimensions: Business, Core, Peripheral, Goods, Peripheral, Service, and Variant. Teams had to brainstorm three additional potential services that could be provided as a part of the business model along to generate more business or enhance the already existing technology of the set of power tools.

The second activity was a case study with the leaning objective to apply multiple criteria decision-making (MCDM) techniques taught in class to rank the suppliers for various components. This was a case study in supplier selection for some components of the common hand power tools from among four suppliers based on six conflicting criteria. Each member of the team was asked to use multiple criteria decision-making (MCDM) techniques taught in class to rank the suppliers. Each member was asked to give a measure of importance to all criteria based on their own preferences and reported his/her rank order of the suppliers.

Table 1: Suppliers' Scorecard

Item	eReplacement parts.com	mmtoolparts.com	partswarehouse.com	allpartsinc.com
Cost	8	7	1	10
Shipping	5	4	9	3
Quality	6	5	9	4
Customer Service	7	8	6	9
Defects	8	8	9	7
Interchangeability	9	8	10	5

As a team, students were asked to search the internet and identify three possible global suppliers for at least four components from the power tools. Finally, using the same criteria as before, each team was to construct a scorecard to evaluate all the suppliers. Many aspects of these assignments did not lend themselves to be tested in a typical exam but had significant weight as part of the case study in the overall course grade.

***IE 419 – Work Design Productivity and Safety* -** focuses on productivity and safety in the work force. With a focus on the pressure washer product, assignments have been developed that will have students conduct a fault tree analysis based on three possible injuries due to unsafe practices. Activities will have students investigate the possibility of electrocution, laceration, and debris in the eye. These fault tree analyses will be used in a case study to give students practice making fault tree analyses. A simple fault tree is shown in Figure 7.

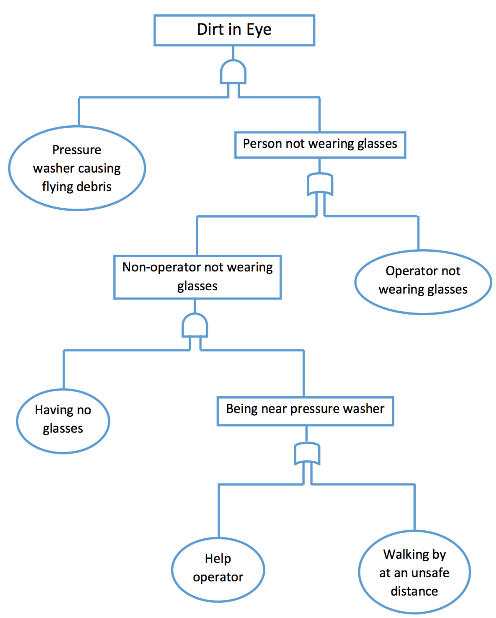


Figure 7. Example fault tree to support human factors considerations of pressure washer.

IE 323 – Statistical Methods in Industrial Engineering - focuses on the study and application of statistics in the solution of engineering problems. An activity was developed in the Fall of 2017, for future implementation, to study the effect of fatigue on the amount of force required to activate a conventional handheld power tool after extended periods of time. The following concepts were used to conduct the analysis: simple linear regression, test of hypothesis, and single factor experiments. Using this data and these concepts, case studies were developed to be used as part of the IME curriculum. Figure 8 provides an example of the analysis possible.

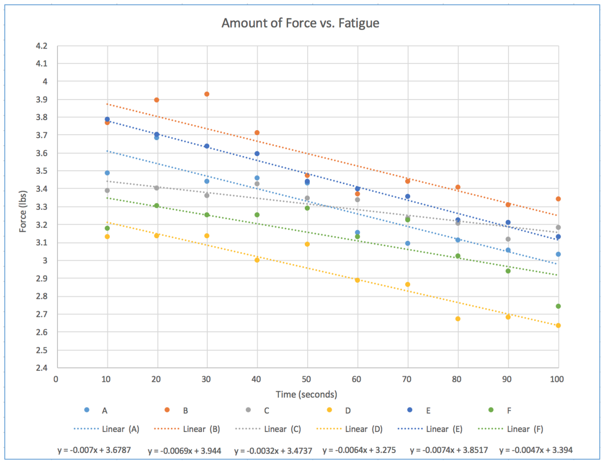


Figure 8. Effect of fatigue on amount of force to activate handheld power tool.

Other Critical Elements to Success

Project Team - First and foremost for successful curriculum redesign, an inspired and engaged team of faculty were required to undertake the significant redesign of core undergraduate courses. Input and collaboration was then sought from the Leonhard Center for Enhancement of Engineering Education in the College of Engineering at Penn State. As the Center's mission is to catalyze the changes that are crucial to maintaining world-class engineering education, Leonhard Center staff met with eight IME faculty over several months to help establish goals and a foundation for the redesign. The IME team then developed a formal curriculum redesign proposal that was funded by the Leonhard Center as an innovation in engineering education project.   While this funding was modest, it was very helpful in paying undergraduate and graduate students who have worked with the faculty team on the development of problems/materials and in obtaining candid feedback. It has also been helpful in purchasing project materials, and providing very modest discretionary funding to participating faculty.

An exciting, and unanticipated aspect of this project, has been that it has brought together several faculty across all of the major sub-areas in the department, who typically have little opportunity for discussion about content and methods in teaching. The department head has been an active participant in the project, having served as an initial catalyst, advocating and supporting progress and expansion, but also purposely not leading, managing, or otherwise squelching input and creativity from participants. Several undergraduate students who have previously taken and excelled in courses that are being re-engineered have worked with the faculty team, being paid as undergraduate researcher assistants, to support the development of new product-based learning activities and materials. External stakeholders have also been very supportive. Specifically, thanks to the Service Enterprise Engineering (SEE) advisory board, activities, four SEE Fellows (Postdocs and Ph.D. Students) and five SEE Scholars (M.S. and B.S. students) have been supported to collect data and develop tools that span multiple courses that cover service engineering related topics at the undergraduate and graduate levels.

Infrastructure - The IME Department is in a unique position to experiment with and develop a workable model of product-based learning. There is access to industrial class facilities in conventional (deformation + solidification) as well as emerging additive (metal + polymer) manufacturing processes. This allows for the in-house design, manufacture and assembly of significantly complex components and products. There is also tremendous talent and facilities to entertain the modeling and simulation of human factors considerations (ergonomic and cognitive), engineering economic activities attached to make/buy decisions, optimization of product mix and services, capacity allocation, facilities layout, global supply chains as well as the design and management of services. Moreover, with a growing number of core courses existing in digital form, there is ability to contemplate a move away from the traditional class/lab format and envision a more creative, efficient and flexible content delivery system that will optimize this product-based learning model.

Preliminary and Planned Assessments

The challenge proposed in this effort is to develop a capacity to foster integrative learning across contexts for all IE students rather than the current fragmentary courses/credits [8]. Until now the capstone design course, IE 480, has nominally served this purpose by providing students with real-world industrial contexts for "thinking and doing". However, given the scope of such an experience, students, at best, can integrate a small fraction of the curriculum in a given project context. Huber and Hutchings [9] have argued that when students pursue learning in a more intentionally connected way then the intellectual and emotional appeal can catalyze a richer learning climate. Further, it can be argued that traditionally the burden of integration has fallen on the students to use their wit and grit to "connect the dots" as they progress through the curriculum [9]. Therefore, our conceptual assessment plan will revolve around the following [9].

- Collaboration among faculty to identify key integration points in the curriculum
- Opportunities for integrated learning within and among courses and contexts
- Faculty's approach to intentional teaching to foster integrated learning
- Quizzes and concept maps that span Bloom's taxonomy especially comprehension and synthesis across courses
- Self-reporting instruments for students and faculty

Here, the term *assessment* is the collection of data/evidence about the effect of integrative learning curriculum, and *assessment methods* that could be appropriate include ethnographic studies, quasi experiments based on matching of demographics of students, and baseline data from previous years for quantifying the impact [10]. Briefly, ethnographic studies by embedding an assessment researcher in student groups could provide invaluable insights into how the change in the curriculum impacts student learning across the targeted two years planned for implementation.

Summary and Future Work

This paper has presented a large undertaking by The Pennsylvania State University Harold and Inge Marcus Department of Industrial and Manufacturing Engineering (IME) to design, develop and implement a product-based learning pedagogy that bundles goods and services for an integrated context rich industrial engineering curriculum. Significant progress has been made, including the implementation of new methods in several courses. An engaged and growing team of faculty, graduate and undergraduate research students continues to learn and grow, with input and guidance from a center for excellence in engineering education.

A growing number of courses and faculty are being on-boarded due in large part to the contagious comradery and modest financial incentives/rewards associated with the project. We are delighted to be forging new methods where our students will break from the current practice of taking courses within different separate areas in IE in a silo-type environment, where they work on small-scope, single-focus homework projects. Going forward, our students will apply specific knowledge and methodologies learned through multiple core courses in different areas of the IE curriculum to a common set of complex products. Core courses in the 3rd-year include IE 302 Engineering Economy, IE 305 Product Design, Specification and Measurement, Manufacturing Processes (IE 306, IE 307, IE 311), IE 327 Introduction to Work Design, and IE 405 Deterministic Models in Operations Research. Core courses in the 4th-year include IE 425 Stochastic Models in Operations Research, IE 453 Simulation Modeling for Decision Support, IE 460 Service Systems Engineering, and IE 470 Manufacturing System Design and Analysis.

Faculty of the above courses work together in cross-area teams to identify and develop the common problem and product contexts that are used by multiple courses. This fosters more collaboration and synergy among faculty members. Integrated product-based learning links directly to the strategic plans of the College of Engineering and the IME Department.

Going forward, we will strive to continuously assess the effectiveness of methods and materials in supporting students' improved abilities to integrate industrial engineering concepts and tools, thereby providing employers with the long sought after skills to think critically, communicate clearly, work well in teams, with extraordinary abilities of systems thinking, considering product and services concurrently. With assessment and refinement, our plan is to share widely with IE programs nationally.

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