



Work in Progress: A Vision for the First "Product Innovation Sequence" for Chemical Engineers

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Chemical engineers who enter the marketplace today are facing a vastly different reality than those who started their careers even five years ago. Keith Watson, (Senior Director, Strategic Marketing, Dow Chemical Company) noted in 2011, *“The attributes needed to compete for employment in the modern chemical industry have changed. However, the curriculum at most traditional Western universities does not necessarily reflect these new dynamics.”* The majority of chemical engineering programs today do not leave room within their curriculum for students to be able to adequately explore the concept of chemical product design and how novel ideas can become the basis for new businesses. In fact, out of the 158 ABET accredited chemical engineering programs in the US, only 25 offer chemical product design classes. This state of affairs presents a stark contrast with mechanical, industrial, and even bioengineering programs, where product design has been a routine part of the curriculum for decades.

In response to this need, the chemical engineering program at the University of Pittsburgh has taken the initiative to re-design its chemical product design senior level course and expand upon it to create a three-year, chemical “Product Innovation Sequence”. This course sequence will start with required courses in both the sophomore and junior year followed by a senior year elective for those students who are particularly interested in this field of study. The novel nature of this curriculum is found in its coupling of scaffolding techniques to encourage students to build and develop their chemical product design skills progressively as they go through the course sequence, the experiential nature of the final senior level prototyping course and the effort to provide mentorship opportunities between students in different years of the course sequence.

One of the key features of this new experiential product innovation sequence for chemical engineers is the showcasing of the role of the customer within the design process which can often be an afterthought in engineering design. In contrast, it is the beginning of thought in this new product design sequence. Specifically, the sophomore level class focuses exclusively on concepts related to the front-end portion of chemical product design including: customer identification and needs, brainstorming and decision making processes. Subsequently, the junior level course in the sequence focuses on the fundamentals necessary to perform chemical product design including formulations, heuristics and life cycle analysis for the development of more sustainable products. This course also includes elements important to small business development such as intellectual property, commercialization plans and how to deliver a business pitch. Finally, in the senior level prototyping course, students will actually be given the opportunity to create a physical prototype of their product and work alongside a faculty mentor on the development of their own business model. This course sequence provides a “safe” environment for chemical engineering students to get a real taste of what starting your own business might be like prior to entering into the marketplace. It is believed that this first-of-its-kind “Product Innovation Sequence” will build not only a culture of entrepreneurship that permeates all levels of education (from sophomores to graduate student TAs to faculty), but also produce a new generation of alumni better equipped to work in today’s marketplace, whether they choose to work within an existing company or venture out on their own.

Rationale for Product Innovation Sequence

Innovation is critical to the US economy, a hypothesis advanced by a seemingly endless series of articles, reports and blogs.^{1, 2, 3, 4} The president firmly believes in this message and has formalized it through “A Strategy for American Innovation: Securing our Economic Growth and Prosperity.”⁵ Here he notes “America’s future economic growth and international competitiveness depend on our capacity to innovate. We can create the jobs and industries of the future by doing what America does best – investing in the creativity and imagination of our people.”

It is clear from these and other readings that the prevailing wisdom places innovation as the critical component to regenerating robust growth in today’s economy. Consequently, innovation is a skill that is highly prized by America’s corporate and investment community. For instance, many companies, including Proctor and Gamble, target innovation as a core value to help promote their company mission.⁶ The question then remains as to where companies, large and small, will find personnel with innovation skills who will be able to create the next generation of products. It is appreciated by many that these skills can and should be taught if we are really going to be able to develop the next generation of innovators. Recently, the American Society for Engineering Education and the National Science Foundation assembled thirty four invited representatives from industry that had an important stake in engineering education along with seven academics to discuss what modifications to the current educational system would be necessary to meet the needs of employers. Pre-workshop survey results indicated that engineers who are graduating from colleges and universities today are lacking skills in areas of increasing importance such as project management, decision making, leadership and communication.⁷

Chemical Engineers and Innovation

Keith Watson, (Senior Director, Strategic Marketing, Dow Chemical Company) noted in 2011, “Traditional career paths have been replaced and those who are most flexible and can adapt the fastest will thrive. A strong technical background, while still necessary, is no longer sufficient to compete on the global stage.”⁸ Today’s marketplace is in desperate need of innovation and individuals who are willing to take the risk necessary to transform ideas or basic research into commercially viable products. Vivek Wadhwa of Singularity University echoes this sentiment, noting with dismay the lack of innovation in many key industrial sectors that underpin the US economy, including energy, automotive technology and healthcare.⁹ This begs the question as to why there aren’t more individuals that are taking up these challenges. Is it because they are not motivated? Or is it perhaps because they have not been taught the skills necessary nor provided with the support required to learn how ideas can be turned into products?

Undergraduate Chemical Engineering students are a vast resource for ideas and new perspectives for designing tomorrow’s products in any field where molecular structure helps govern product performance. Unfortunately, the bulk of the current Chemical Engineering curriculum focuses on an ultimate design experience that is entirely process-related. This situation presents a stark contrast with mechanical, industrial, and even bioengineering programs, where product design has been a routine part of the curriculum for decades. Although, it remains critical for Chemical Engineers to obtain the necessary technical background to perform in the field, the curriculum must evolve to allow teaching of those skills which are essential for a 21st century economy.

These include creativity, decision-making, teamwork, project management and leadership. Watson writes “The ability to demonstrate a range of skills, such as communication, business acumen and project management is crucial to standing out from the field.”⁸ These skills are also vital in managing the innovation process.

Product Innovation Sequence Overview

We propose a completely new, “Product Innovation Sequence” to address the current deficit in Chemical Engineering Education. This Product Innovation Sequence consists of three courses that span from the sophomore to the senior year within the chemical engineering curriculum. This novel course sequence was developed in a collaborative effort between two faculty members, the vice chair for education in the department and the department chair. This team of individuals working together enabled access to department resources and provided necessary support for this curriculum change at faculty meetings. This change to the curriculum was approved by both faculty and also the external advisory board for the department. In addition, as entrepreneurship education is currently a priority within the school of engineering, we found that our new course sequence initiative was well supported and seen as an opportunity to lead the school in curriculum re-design for incorporation of this critical content.

Two of the courses in the sequence (sophomore and junior year classes) are degree requirements while the third senior level class is a newly offered elective. **Importantly, the changes made to the curriculum were done without increasing student credit load.** The sophomore level class, which has a specific focus on professional development skills, replaces a professional elective in the curriculum. The junior level class that focuses upon molecular product design strategies and business plan development replaces the existing senior level chemical product design class and laboratory class (for a combination of three credits). The senior level prototyping class did not require modification to the curriculum as it is listed as an elective. We anticipate that with the nature of the first two classes in the sequence there will be a strong demand by students for this elective level class.

Introduction to Chemical Product Design

This course is the first one in the sequence and is taken in the spring semester of sophomore year. The educational learning objectives for this course are students will be able to (1) utilize documented brainstorming techniques and then select the best idea for further study, (2) collect and analyze customer information in order to generate a customer value proposition, (3) perform a market analysis on a specific technology that identifies what they are looking for, where they found their data and the segmentation of the market and (4) develop essential business skills that can be applied to future courses in the program and benefit them when starting their career. This class focuses on the front end of chemical product design including sorting and selection of ideas, customer ethnography, market analysis and segmentation followed by professional development and business related skills including communication, teamwork, decision making, leadership, finance and project management. Students are taught these concepts through a combination of traditional lectures with active learning components.

Students are evaluated on the basis of class participation, homework, participation in a virtual internship, “Nephrotex”, and a semester long group project. For the group project, students are

assigned a molecular product and asked to complete the customer identification, ethnography and market analysis for the product and then brainstorm on possible variations of the product that could meet consumer needs. This project builds familiarity with concepts presented in class while providing a more structured environment for students.

Taking Products to Market: The Next Step in Chemical Product Design

This course is offered in the fall semester of junior year. This course focuses on building upon the skills from the first course and then incorporating design based elements. The learning objectives for this course are students will be able to (1) demonstrate the principles of molecular design, (2) list formulations within different chemical product industries and how the chemical product design process enabled their development, (3) utilize the ideo model for prototyping to perform a rapid prototype for a product and (4) prepare a business plan and list all the key components that are included within the document. Topics discussed within this course include molecular design, formulations, life cycle analysis, specifications, costing of products and the ideo model for rapid prototyping. In addition, business related principles of intellectual property, analyzing the competition, company types, company strategy, partners, financing, business plans and building an elevator pitch are covered.

Students will be evaluated based upon class participation, homework, in-class activities and a semester long group project. In this group project, students come up with their own ideas for a molecular product and then progress through all the stages that are involved with chemical product design from initial customer identification to generation of a complete business plan.

The first two courses within the “Product Innovation Sequence” are linked to ABET outcomes b, c, e and g which relate to the ability of students to gather and analyze data, design products within realistic constraints, solve engineering problems and communicate effectively.

Chemical Product Prototyping

This course provides an opportunity for students to create a chemical product prototype. Student teams who are interested in taking this elective course will need to present a business plan for the product that they are hoping to design, could be the group project from the junior level class, which will be reviewed for feasibility and potential prior to faculty granting approval for taking this class. We anticipate that although there may be many students interested in taking this elective, total student numbers within the course will be manageable as only student teams with feasible projects will be enrolled in the elective. Student teams will have a faculty mentor that will guide them through the process of taking their molecular design from concept to actual product. Products will also be tested to determine all of its specifications. This course will be run as an independent study, where the faculty mentor for the team will evaluate the students based on their work done in the prototyping lab.

Upon completion of the “Product Innovation Sequence”, student teams will be encouraged to move forward with their molecular product by seeking counsel from the Office of Technology Management to protect their design (through appropriate patents) and then participate in local business pitch competitions for the opportunity to create a company based on their work.

Regardless of whether students take the final course within the “Product Innovation Sequence” we feel that they will have gained a lot of skills related to business development, customer empathy and chemical product design that goes well beyond the training that they are currently receiving within this curricular area.

Novel Pedagogical Features

Building the “Product Innovation Sequence” offered unique opportunities for novel pedagogical features to be included that there was not sufficient time for previously. The new features that this class sequence offers includes: (1) Nephrotex – a virtual internship, (2) Microsoft Project, (3) Customer Ethnography with Devices, (4) Industry Spot Light Series and (5) Hands-on chemical prototyping capabilities.

Nephrotex is a virtual internship that is run throughout the semester in the sophomore level class with students playing the game for approximately one hour of class time per week. This epistemic game was selected to be a part of this class for several reasons: (1) models the product design process, (2) allows the students to serve as interns for a product design company albeit in a virtual setting and (3) provides students the opportunity to get a firsthand appreciation for the role of customers, internal consultants and design constraints within the product design process. At the end of game play, student teams present posters of their design to a group of faculty and graduate students for evaluation.

Microsoft Project was selected to be included in the sophomore course to teach students about project management. This software is commonly used within industry to provide Gantt charts that visually represent tasks associated with projects, important completion milestones and linkages between sub-tasks. Unfortunately, most engineering students enter into the workforce without ever having the opportunity to learn how to use this tool. As part of a homework assignment in the class, students are asked to work with this software and plan out the activities they need to complete to finish the “Introduction to Chemical Product Design” course. It is believed that coupling of this software with a project management task that students can relate to will be a great learning opportunity for students.

While engineering students are often familiar (and comfortable) with starting with idea generation (a technology push approach), they are typically less adept at opportunity analysis (market pull). We treat opportunity as a gap between the desired outcomes of the customers and the current reality, where the gap may require a novel business approach, novel technology, novel alliances, or various combinations to close. Understanding opportunity requires knowledge of modern methods to determine desired customer outcomes, such as ethnography, Ulwick’s job mapping technique¹⁰ and voice-of-the-customer approaches. To enable students to better grasp customer ethnography we will be incorporating activities that were described in a Customer Empathy Workshop by Bally Design.¹¹ Students will need to determine the mechanism for setting the time and a radio alarm on a poorly designed clock radio and then reflect on how difficult these activities were. They will then go through the same series of tasks but with thick gloves and glasses that limit their vision which try to replicate what this process may be like for an elderly individual. This experience will help students relate to placing themselves in the shoes of their customer.

The Industry Spotlight Series will be an important addition to the junior level course. Although we feel it is important for students to learn concepts about generating chemical products, students tend to focus on requirements for job placement. This speaker series, which brings in engineers from industry in a variety of different industries including food, pharmaceutical, paints and coatings, consumer products, electronics and textiles, will give students the opportunity to connect the material they are learning with careers they may have in the future.

The senior level course allows for the generation of chemical product prototypes. To the best of the authors' knowledge, this capability has not yet been reported within chemical engineering education. The chance that students can actually create a physical product from a concept that they have developed will help solidify concepts that were taught as part of the course sequence. We envision that student teams who participate in this hands-on course will also serve as mentors for aspiring students in both the sophomore and junior year of the program.

Assessment Strategy

The effectiveness of the "Product Innovation Sequence" in comparison to the previous single chemical product design class will be measured through both direct and in-direct assessments. Table 1 summarizes the learning outcomes for this implementation along with the assessment strategy that will be utilized.

Table 1. "Product Innovation Sequence" Assessment Strategies

Learning Outcomes	Assessment Strategy
<ul style="list-style-type: none"> Increase the number of students that are interested in entrepreneurship within chemical engineering 	<ul style="list-style-type: none"> Measure number of student teams that select the senior chemical product design prototyping elective after completion of the two required chemical product design classes in sophomore and junior year Measure number of student teams that contact Office of Technology Management about their product designs after completion of the "Product Innovation Sequence" Measure number of student teams that enter into business pitch competitions on campus for their chemical product design after completion of the "Product Innovation Sequence" Tracking of chemical engineering graduates to determine how many select employment in startup companies or create their own business
<ul style="list-style-type: none"> Increase the confidence level students have in their 21st Century Skills 	<ul style="list-style-type: none"> Class based surveys to measure student confidence levels in skill areas including project management, communication, leadership, decision making and teamwork. These surveys will be given to students as part of the sophomore level Introduction to Chemical Product Design class and junior level Taking Products to Market: The Next Step in

Learning Outcomes	Assessment Strategy
	Chemical Product Design class <ul style="list-style-type: none"> • Senior exit survey data to capture students' confidence level in ABET outcomes related to content covered in new course sequence
<ul style="list-style-type: none"> • Provide students with customer empathy skills 	<ul style="list-style-type: none"> • Chemical Product Design concept maps that measure students' understanding of concepts involved in chemical product design (collected from sophomores and juniors in new course sequence and seniors in previous chemical product design class)

We will assess this curricular innovation as it is rolled out in spring 2014 with the first offering of the Introduction to Chemical Product Design class to sophomore chemical engineering students and then over the next several years to follow. We anticipate that the results of this detailed assessment will be compiled together for a future Chemical Engineering Education journal publication.

Challenges

The new “Product Innovation Sequence” will not be without its own set of challenges. We anticipate large class sizes being an issue that will need to be addressed especially in the senior level elective where lab space and equipment are integral to class operation. As stated earlier, we believe that project feasibility screening that is performed prior to enrollment will help deal with this issue. Training for teaching assistants will be important as the material in this course sequence is not traditionally incorporated within most undergraduate chemical engineering programs. Additional challenges include student motivation for learning this type of chemical engineering content, design and funding for equipping the new prototyping lab as well as finding industry speakers for the Industry Spotlight Series. Although all of the challenges that are outlined within this document will require creative thinking on the part of faculty involved with the course sequence, we do not see any of these obstacles as insurmountable.

Conclusions

Chemical product design plays an important part in the chemical industry. However, it has been a field that hasn't been focused on significantly within the chemical engineering curriculum. With the current demand for more innovation skills amongst our engineering undergraduates as well as greater provision of 21st Century Skills, we feel that the “Product Innovation Sequence” will be an opportunity to provide our students with an edge as they compete for jobs within industry. The focus of this course sequence on developing skills related to customer empathy, molecular formulation, hands-on design and business essential skills will help students that participate within this program gain innovation and entrepreneurship skills that will benefit them regardless of the career path that they select. Implementation and assessment of this course sequence over the next several years will provide important lessons on how best to impart this knowledge to the next generation of chemical engineers.

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