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PLM Curriculum Development: Using an Industry-Sponsored Project to Teach Manufacturing Simulation in a Multidisciplinary Environment

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Abstract

This paper describes a course that was redesigned to meet industry's need for a product life cycle management (PLM) literate workforce. The objective of this interdisciplinary course is to introduce students to manufacturing engineering theories coupled with an industry-sponsored project. Throughout the building of an assembly line simulation, students are exposed to topics including process design, process verification, and workspace ergonomics. Moreover, practices of project management along with the theory of critical chain are built into this course. The end goal is to prepare students with not only the knowledge of PLM but also the capability of problem solving, communication, self-motivated teamwork, and leadership.

Keywords: *Assembly Simulation, Project-Based Learning, Project Management, Problem Solving, Teamwork, Leadership, Communication*

Introduction

Product life cycle management (PLM) is the latest IT innovation that has caught the attention of the manufacturing industry. Different from the cost or production-centered lines that ERP, SCM, or CRM are based on, the practice of PLM, which focuses on managing a product's related data, information, and knowledge generated during its lifespan, presents a totally different business perspective (Abramovici and Sieg 2002); PLM's comprehensive approach will enhance the decision-making quality with hard evidence and provide a better estimate of a product's total cost. As preproduction activities can determine a product's overall cost up to 70% (Aberdeen Group 1999), a successful PLM deployment can significantly increase a company's competitive advantage in the marketplace.

Through its collaborative projects and strategic partnerships with software vendors and industry users, Purdue University has been engaging in PLM-related research since 1999. Being active in this field, Purdue University has many opportunities to inspect various facets of PLM realization. On the one hand, the authors' own experience strongly echoes the statement made by Stiffler and Romanow (2004) that the key to a successful PLM implementation is not the fancy software function but the change of the mind-set—the way the business should operate. On the other hand, the authors also learn from their industry contacts regarding the currently great shortage of a PLM-literate workforce—those who can put this vision into practice. One major concern the authors picked up from early PLM adopters was that the new graduates right out of school often do not have proper training to consider a problem from different angles. As reported by MacSweeney (2005), the ownership of PLM technology does not always equal PLM literacy; the new graduates might be good at using certain CAD/CAM software but are still short of the capability to see real-world problems in a holistic manner (Therani and Tanniru 2005).

Trying to resolve such a lack of training, the faculty at Purdue University has been working together to reform existing PLM-related courses. One of the efforts is the offering of a computer graphics technology (CGT) minor curriculum. Based on the original manufacturing graphics track in the Dept. of Computer Graphics Technology, this new curriculum provides an environment where participating engineering and technology majors can be exposed to different aspects of PLM. In addition to the freshman engineering graphics course, students in this minor track will take four more courses, including Solid Modeling, Surface Modeling, Manufacturing Graphics Standards, and one of the following two courses: Industrial Applications for Simulation or Manufacturing Documentation Production and Management.

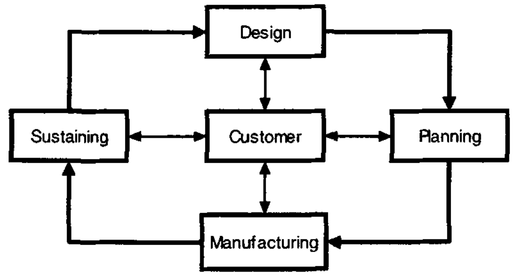
The first three courses, offered in the sophomore and junior years, intend to build a student's basic PLM knowledge and skill sets. The last two senior-level electives both provide a project-based learning environment to help the students synthesize what they have learned during the past academic years into a bigger picture. Built on the previous industry projects, different scenarios are designed for students to apply what they learn in lectures and labs to solve real-world PLM-related problems.

Of the two senior elective courses, the first one focuses on the applications of computer-based simulation in the four product life cycle stages, as shown in *Figure 1a*, such as design, planning, manufacturing, and sustaining. The design of this course stresses how computer simulation can be used to support engineering decision-making processes. Comparatively, the second course centers on the handling of product documents throughout the life cycle period. In addition to topics on data generation and control in the product design and planning stages, the necessity of product data retrieval within the second half of a product life cycle, illustrated in *Figure 1b* (manufacturing and sustaining), is presented; the information of possible interactions between PLM/PDM and ERP, SCM, or CRM is also elaborated.

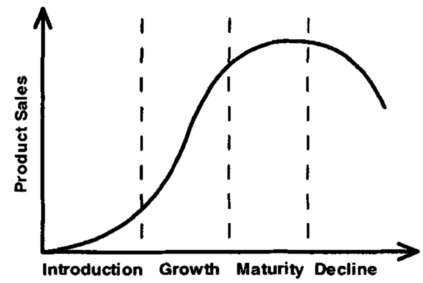
In this article, the first elective course, Industrial Applications for Simulation, is highlighted. Its structure and rationality, general information of the students, selection of themes, exercise design, tactics for lesson-plan execution, observations and interventions, and feedback from industries and job markets are discussed in detail. This article concludes with possible future improvements.

Design of a Project-Based Course

Prior to 2004, the Industrial Applications for Simulation course was designed to teach specific simulation packages and practices for design verification tasks, including kinematics, dynamics, and structure analysis. When the computer graphics technology (CGT) minor track—of which this course is a part—shifted its emphasis from CAD to PLM, it became natural for this course to include simulation applications for other life cycle activities, such as process planning, product manufacturing, and product sustainability. Moreover, as the target audience has changed from mainly CGT seniors to upper-level undergrads from various engineering and technology disciplines, the context of the course had to be adjusted so that it would not be too domain specific.



(a) Process-centered PLM



(b) Production-centered PLM

Figure 1
Product Life Cycle Stages

Course Structure and Rationale

The newly designed course is composed of two sections. The first part teaches theoretical foundations and best practices of computer-based simulation, while the second part reinforces learning from the first section by applying it to an industry project. The benefit of project-based or problem-based learning environments has been documented by many literatures (Albanese and Mitchell 1993; Leifer 1995; Barron et al. 1998). Although these two strategies are similar in terms of engaging authentic, real-world problems and being student-centered, they are not quite the same. According to Esch (1998), *project-based learning* that is often associated with K-12 instruction usually starts "with an end product or 'artifact' in mind." To the contrary, *problem-based learning* that is originated from the field of medical training usually "begins with a problem for students to solve or learn more about." To maximize the learning outcome, the authors decided to utilize both strategies from the instructional design aspect.

The goal of this course is not only to provide students a first-hand PLM experience but also shape them to meet the skill competency that industry expects from new graduates (Todd, Sorensen, and Magleby 1993; SME 2001; Todd et al. 2001). Using design principles of project-based and problem-based learning, a new course structure was developed, as shown in *Figure 2*. The students are presented first with what the end product will be (in this case, a simulation model), then for the rest of the semester they work toward this goal by learning more in order to answer problems that belong to one or more of the nine areas shown on the right side of *Figure 2*. These nine areas can be grouped into three major components of the project: problem solving, manufacturing knowledge, and project management. One thing noteworthy is that this conceptual map is used to illustrate the essence of this course; it does not mean that each topic could be taught separately.

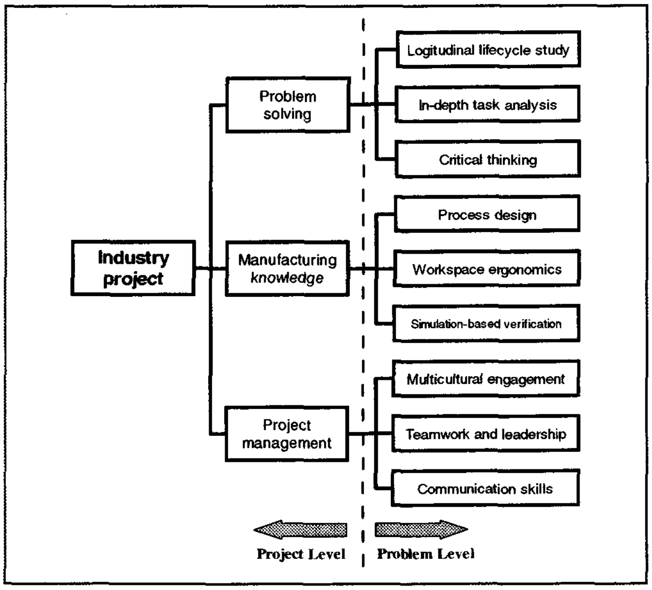


Figure 2
New Course Structure

General Information of the Students

In the fall semester of 2004, the 21 students enrolling in this redesigned course came from five engineering and technology disciplines, including aeronautics and astronautics engineering, computer graphics technology, computer-integrated manufacturing technology, mechanical engineering, and mechanical engineering technology. As this course is offered at the senior level, all students had been immersed in different engineering principles for at least two years, and all had taken the first two courses in the CGT minor track—Solid Modeling and Surface Modeling, which provide the CAD skills needed. Furthermore, more than one third of the students in this class had co-op or internship experiences at manufacturing and consulting companies such as Boeing, Honda America, John Deere, Eaton, and IBM. Their knowledge and experiences from work brought in different industry practices and ways of thinking, which enriched the course content and class discussions greatly.

Selection of Themes

While the multidisciplinary nature of the students' backgrounds more or less realistically simulated an industry work environment (Miller and Olds 1994), it brought difficulties as well in regard to topic selection. Students might not have the same background knowledge for certain subjects, and unrelated topics might affect students' retention. To overcome these issues and at the same time to provide every student the experience of a beginning-to-end product life cycle within limited class hours, an exercise was devised that could get across the great variety of PLM activities. The mechanical assembly/disassembly process was identified as the best candidate for simulation applications. This process was then further categorized into process design, workspace ergonomics, and simulation-based verification:

- *Process design:* Covering the principles of assembly process planning, including task breakdown, sequence planning, tool and fixture planning, and instruction generation.
- *Workspace ergonomics:* Covering not only the work study principles used in the production-line environment but also the human factors and job safety concerns in other PLM activities.
- *Simulation-based verification:* Covering graphical-based applications for process verification purposes at the station level, line level, and factory level.

It is apparent that these selected topics focus on activities of the planning stage in a product's life cycle. However, the actual "product" to be studied in this course is the simulation model itself than the product to be assembled virtually. With proper guidance from the instructors, the students would be able to see the transitions and interactions between phases of design, planning, manufacturing (e.g., creation), and sustaining of a simulation model.

Exercise Design

With the selected themes, lesson plans were drafted according to the principle of active learning (Felder and Brent 2003). The following four activities were designed to provide the students with course information through reading, hearing, and seeing:

- Theory lectures on simulation and process planning activities;
- Complementary readings of online reports and case studies;
- Field trips to on-campus and off-campus end-user sites; and
- Guest speakers from on campus and from industry.

To further enhance learning, the following three exercises were designed:

- Group research project on simulation applications in major industry sectors;
- Hands-on laboratory assignments on kinematics, assembly process simulation, and ergonomics; and
- Individual final project to model automated and manual assembly processes.

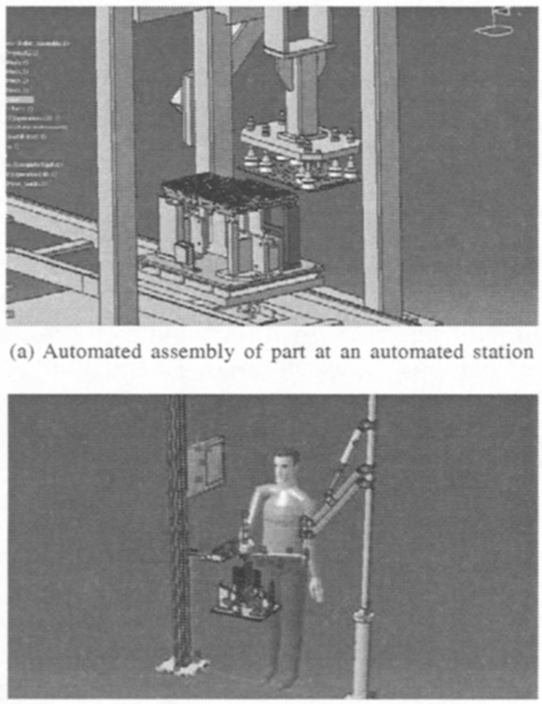
All three activities above were accompanied with written and/or oral reports.

Industry-Sponsored Project

The project governing this course was an expansion of a previous collaborative project between a U.S. automobile manufacturer and Purdue University. The optimal goal of that project was to streamline product design and assembly process planning activities, where the product to be studied was the valve body assembly of an automatic transmission used in passenger vehicles, along with an assembly line consisting of 42 automated (unmanned) and manual (assembled by human operators) stations. Example models of automated and manual stations are shown in *Figure 3*. Through the first two phases of this project, simulation models of the valve body assembly process and of assembly operations in one automated station were built. Currently the project has been put on hold due to the industry partner's budget; however, the partnership still remains as the industry contact is willing to let the authors to use existing information to train students, publish findings, or conduct further research as long as the outcomes of any of those activities can be accessed by this industry partner.

By modifying or adapting the exercises from the previous phases, the goal of this project was to increase the students' retention of knowledge and skills learned in the course by building computer simulation models of the processes occurring at automated or manual assembly stations. While simulating the movements of mechanisms on an automated station seemed to be challenging, to control the body movement of a mannequin (e.g., model of a human operator) at the manual station also presented certain levels of difficulty. With the information available covering all 42 different stations, every student had the opportunity to be in charge of the modeling of one automated and one manual station. In the meantime, several students were asked to team up with one another to tackle those automated stations with high complexity in addition to working on their own manual stations.

For each student, the information from the industry partner included (1) multiple-layered AutoCAD 2-D drawings of components and/or subassemblies



(a) Automated assembly of part at an automated station

(b) Mannequin installs screws with help of semi-automatic tool

Figure 3
Example Models of Automated and Manual Stations

of both automated and manual stations; (2) the text-based process sheet of the whole assembly line; and (3) the drawing of the assembly line layout. To save time and standardize the project deliverables, 3-D models of the valve body and its assembly fixture/pallet were provided by the instructors.

By studying the drawings of individual stations and that of the production line side-by-side with the assembly process plan, students had to first conceptualize the work in process of each station, including the incoming parts and subassemblies, the required operations, and the station's output. After identifying the necessary level of details, they then built each station piece by piece in a 3-D solid modeling program; the corresponding assembly processes can then be modeled in a simulation package.

Video clips of simulation can be generated directly from the software. Work instruction might be added to these clips to enhance the usability of simulation models. The filming and camera moving strategies were determined by each student according to his or her perception of the crucial processes on a specific station. At the end of the semester, a portfolio CD from each student, which contained 3-D models of individual stations, process simulation, video clips, and a written report, was submitted to the instructors.

Project Management

With the scope of the project that involved more than 20 people (including instructors, students, and industry contacts) and the given time constraint, the practice of project management popular in today's industry setting was introduced for better project execution. The students were first briefed on the key elements of project management, e.g., time, cost, and resources, and the foreseeable benefits of tactics. Next, a project handbook and a special presentation were used to give the students up-to-date information, such as project history, objectives, team composition, stakeholders, and the operation environment. Each student then had to conduct task analysis for her or his own stations, set up personal goals and deliverables, and articulate the outcomes in an individual project proposal. An individual timetable was also designed by the students under the guideline of major project milestones. Later during the project execution, personal work logs were kept to track individual and overall progress. Project meetings were held weekly, and project memos were delivered to the corresponding personnel if necessary.

Lesson Plan Execution

Rather than helping students develop expertise in just the subject area, this course was taught as a cross between project-based and problem-based learning. It was purposely delivered in a way that helps cultivate soft skills such as problem solving, communication, teamwork, and leadership.

Problem Solving. After discussing common practices for problem solving, the students were left to adapt these strategies to create the simulation model. Problems were given in a relatively vague form of "scenarios" or word questions than in a form with detailed and exact directions. Through such exercises, the students learned how to identify the critical issues and conduct critical thinking to find the best solutions before jumping into solving some problems that might be comparatively minor.

Communication Skills. Most lectures were given through interaction and brainstorming rather than one-way teaching. In addition to presenting her or his own ideas or opinions, the student also improved her or his communications skills through intense reading and writing. The content of reading materials was always brought to in-class discussion and examinations. Furthermore, instead of learning by following the demonstration in the lab, students learned different software modules by reading the user manual and familiarizing themselves with key functions through trial and error and specially designed assignments.

Teamwork and Leadership. At the beginning of the project, most of the students would work on the project alone. Before long, they found out that their projects shared a lot of commonalities, such as similar station equipment or processes, and that it was beneficial for them to work together. To further promote teamwork, a short talk on the critical chain theory, usually used for project management, was given in mid-semester to "enlighten" the students that they indeed belonged to a "super" project. Their personal achievements could not really be considered as a success unless they were willing to take the lead to help those "weaker links" in the chain.

Observations and Interventions

Throughout this course, several observations were made on the ordinary behaviors of engineering and technology students in the classroom, although they might not represent average college students. To influence those behaviors and create a better learning environment, tactics based on Maslow's need theory or motivation (Boeree 2004) and Skinner's shaping theory or modification (Skinner 1968) were used to help the students gain a better understanding of the optimal goal and expectation of this course.

Observation 1

What do engineers like? They like one straight answer out of a multiple-choice question.

This statement sounds like the students' preferred format of the test, but it might also be a major concerns for industry. Most of the students in this class—or perhaps for the majority of today's engineers—do not like to explain things in detail. It was not simply the issue of their willingness, but they might not have the capability to produce quality writing for course assignments, group reports, and the quizzes and exams; essay-style writing instead of a short answer was required by the instructors so that every answer was justified by a full statement. This helped perfect the students' skills on problem solving as well as writing.

The students' response to this exercise was very harsh. Rather than digging out the answer by themselves, they wanted the instructor to prepare all the directions, even giving a specific range of course content for exam preparation. An answer template had to be used to "modify" or "guide" the students' writing, and they were encouraged to bring in related internship experiences to motivate their work.

Observation 2

How do engineers think? They think in a linear and isolated way, which is not necessarily independent, though.

From time to time, the students lacked the capability to perform critical thinking. Their education training made them only look for one answer based on their gut feeling—and most of the time without any rationale. Similarly, the interpersonal and communication skills needed improvement.

To help the students see the need for knowledge exchange, specially designed assignments, projects, and lab environments were used to promote interaction. Meanwhile, the tactic of critical thinking was used in classroom discussion to stimulate the students to think things through from different angles.

Observation 3

What do engineers worship? They worship efficiency rather than effectiveness.

The majority of the students only considered how they could finish their assignments in the most efficient way. The effectiveness of whether they learned something or could further develop their knowledge based on the existing information was not important to them.

In this case, there was really no way to change their "attitude" or force them to think in this way. Only by using many real-world situations could the instructors hope to have the students realize that efficiency was not their whole life.

Feedback

The setup and atmosphere of the course were very different from the usual engineering and technology classroom, and many students initially could not clearly understand the purpose of different exercises.

Sometimes even the instructors, after hearing feedback from the students, wondered if all these problems were normal, or they were actually the by-products of this new approach. It was not until later when Purdue University held two conferences with its industry partners, where representatives from industry spelled out expectations and shortcomings in current engineering education systems, did the instructors realize that this class is exactly what industry is looking for. Such confirmation from industry directly was great encouragement to the instructors.

Although this course was not designed to teach any specific software, market demand for simulation-literate workforces is extremely high today. In fact, more than 90% of the students from this 2004 fall class had opportunities to interview and/or be hired for full-time jobs, co-ops, or summer internships as long as they put the magic word *simulation* on their resume. Also, one of the instructors continues to forward student resumes to his industry contacts who are in need of qualified employees. This elective course is in a sense a de facto "vocational" course for Purdue engineering and technology students.

Conclusion

Overall, this redesigned course was very successful. However, there are still several areas for improvement. First, as it was the first time the course was offered, everything was developed from scratch. Much of the content was experimental and must be finalized.

Second, because the majority of the assembly line now has been modeled, it has not been determined whether the same exercise on modeling individual stations could be used in coming semesters or whether a different project needs to be chosen. Because the first part of the course helps students finish the industry project in the second part, adding or removing of any course materials has to depend on the knowledge, experience, and skill level of the incoming students.

Third, while the built simulation models were based on real-world artifacts, they could still fall into the category of animation if they are used only for visual verification. Due to the tedious work of building CAD models and the extensive amount of manufacturing knowledge and software capability the students had to learn to create a meaningful simulation, the topics of using simulation to measure and optimize the performance of the product line and that of individual stations were not discussed. In the future, by reusing the existing models, exercises such as changing current process sequences, fine-tuning the timing of individual operations, or optimizing the line layout with the help of discrete event simulation packages could be added to address the dynamic aspects of manufacturing environments.

Finally, while the instructors would like to keep the vague, scenario-telling approach in projects and assignments so the students can practice problem-solving strategies or conduct necessary critical thinking, a better quantitative assessment system is needed because much of the course is customized for the needs of individual students. Other formative and summative evaluations, such as pre- and post-class attitude surveys and examinations of key concepts, should be put into place for students to receive timely feedback and for the instructors to alter lesson plans as necessary. Continual reiteration of the course objectives and expectations would be beneficial.

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References

Albanese, M.A. and Mitchell, S. (1993). "Problem-based learning: a review of literature on its outcomes and implementation issues." *Academic Medicine* (v68), pp52-81.

Aberdeen Group (1999). "Collaborative product commerce: delivering product innovations at Internet speed." Aberdeen Group Market Viewpoint (v12, n9).

Abramovici, M. and Sieg, O. (2002). "Status and development trends of product life cycle management systems." *Proc.* of IPPD 2002, Wroclaw, Poland.

Barron, B.J.S.; Schwartz, D.L.; Vye, N.J.; Moore, A.; Petrosino, A.; Zech, L.; and Bransford, J.D. (1998). "Doing with understanding: lessons from research on problem- and project-based learning." *Journal of the Learning Sciences* (v7), pp271-311.

Boeree, C.G. (2004). "Abraham Maslow." *http://www.ship.edu/~cgboeree/maslow.html.*

Esch, C. (1998). "Project-based and problem-based: the same or different?" *http://pblmm.k12.ca.us/PBLGuide/PBL&PBL.htm.*

Felder, R.M. and Brent, R. (2003). "Learning by doing." *Chemical Engg. Education* (v37, n4), pp282-283.

Leifer, L. (1995). "Evaluating product-based-learning education." *Proc.* of US-Japan Conf.: Evaluation Engg. Education Reform, Osaka, Japan.

MacSweeney, G. (2005). "Innovation mastery: Pratt & Whitney Canada." *Managing Automation* (March 2005). *http://www.managingautomation.com/maonline/magazine/read/2588694.*

McDonald, D.; Devaprasad, J.; Duesing, P.; Mahajan, A.; Qatu, M.; and Walworth, M. (1996). "Re-engineering the senior design experience with industry-sponsored multidisciplinary team projects." Frontiers in Education Conf., pp1313-1316.

Miller, R.L. and Olds, B.M. (1994). "A model curriculum for a capstone course in multidisciplinary engineering design." *Journal of Engg. Education* (v83, n4), pp1-6.

Skinner, B.F. (1968). *The Technology of Teaching.* Reprinted by the B.F. Skinner Foundation (2003).

SME (Society of Manufacturing Engineers) (2001). "Manufacturing Education Plan Phase III: 2001-2002 Critical Competency Gaps." *http://www.sme.org/downloads/foundation/Competency_Gap.pdf.*

Stiffler, D. and Romanow, K. (2004). "PLM in consumer products: which service providers have the goods?" AMR Research Report. *http://www-1.ibm.com/services/us/imc/pdf/plm-in-consumer-products.pdf.*

Therani, M. and Tanniru, M. (2005). "Knowledge partitioning: a strategic approach to product lifecycle management." *Int'l Journal of Product Development* (v2, n1/2), pp85-108.

Todd, R.H.; Sorensen, C.D.; and Magleby, S.P. (1993). "Designing a senior capstone course to satisfy industrial customers." *Journal of Engg. Education* (v82, n2), pp92-100.

Todd, R.H.; Red, W.E.; Magleby, S.P.; and Coe, S. (2001). "Manufacturing: a strategic opportunity for engineering education." *Journal of Engg. Education* (v90, n3), pp397-405.

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