

SUITE-210: A MODEL FOR GLOBAL PRODUCT-BASED-LEARNING WITH CORPORATE PARTNERS

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ABSTRACT

It is hypothesized that Product-Based-Learning (PBL) theory, methodology and technology are evolving in a manner that will make widespread PBL adoption and assessment financially feasible at all levels of Engineering education. It is asserted that student-created case material, a natural by-product of PBL curricula, effectively supports learning re-use and external validation of curriculum reform. ME210, "Team Based Product Design-Development with Corporate Partners", and the 210-web (<http://me210.stanford.edu>) will be used to benchmark the issues.

WHAT IS THE PROBLEM?

The intellectual content and social activity of engineering product development are a constant source of surprise, excitement and challenge for engineers. When our students experience product-based-learning (PBL), they experience this excitement [Brereton '95]. They also have fun and perform beyond the requirement of a simple grade. We, their teachers, experience these things too. Why, then, are so few students and faculty experiencing PBL? How can we put the excitement back in engineering education? In part, we think, this is because of four persistent mistakes in engineering education:

1. We focus almost exclusively on individual student activity and grading.
2. We over-emphasis analytic thinking and numerical technology.
3. We neglect synthesis thinking and communication technology.
4. We fail to co-develop the necessary thinking skills for engineering science and engineering practice.

WHAT IS THE SOLUTION?

Engineering Education Reform has adopted broadly constructivist learning theory without fully adopting the corresponding pedagogic practices. It is the thesis of this presentation that both reform and assessment objectives are served by moving vigorously towards product-based-learning core-curricula. The focus on "product" goes beyond "project" or "problem" based learning in focusing attention on the delivery of something of value to an outsider. It goes beyond the academic exercise. PBL curriculum objectives may be stated briefly as follows [after Bridges and Hallinger, 1995]:

1. Familiarize students with problems inherent in their future profession;
2. Assure content and process knowledge relevant to these problems;
3. Assure competence in applying this knowledge;
4. Develop problem formulation and problem solving skills;
5. Develop implementation (how to) skills;
6. Develop skills to lead and facilitate collaborative problem solving;
7. Develop skills to manage emotional aspects of leadership;
8. Develop and demonstrate proficiency in self-directed learning skills.

Those who seek to support distant learning, asynchronous design-teams and interdisciplinary collaboration must be vigilant about preserving the critical features of experiential learning. This is particularly true as one explores the utility of emerging technology to bring this pedagogic model to more people, in more places and at lower cost than has previously been possible. We are encouraged by emerging design-team performance studies. They show that diverse distributed teams,

making optimal use of electronic communication and documentation services, out-perform co-located design teams [Hong, '95].

WHAT DOES LEARNING THEORY TELL US?

Educational theorists (including Jean Piaget) have developed a model of learning by which students develop knowledge structures based on previous experience. A theory of how to teach science known as the "scientific learning cycle" is a direct outgrowth of Piaget's ideas and constructivism [Harb, Durrant, and Terry, '93]. Our experience in engineering design education supports the critical role of experience (versus information or theory) as the learning medium. It is the measure by which designers, engineers, scientists and most professionals are rewarded. One may summarize the lessons of constructivist research as declaring that learning is best done by creating something, a product, that embodies our knowledge. This is product-based-learning.

(Figure 1 to be added)

Figure 1. Leifer ['95], after Kolb's ['84] models student experiential learning as a four phase iterative loop. Kolb observed that a cycle of experiences improves understanding and builds bridges between theory and practice. This is a qualitatively satisfying view of product-based-learning as well.

Students have been observed to learn in four different ways (Figure-1). Kolb ['84] proposed that repeated cycles of experiences moving through these learning modalities improves understanding. The cycle is best started with concrete experience, proceeding to abstraction [Harb, Durrant, Terry, '93]. Beginning with a need for learning stimulated by immediate experience, the learner should reflect and question his perceptions of the learning environment before proceeding to abstraction and experimentation. The complete cycle brings understanding in depth. Prompt feedback of the intention and meaning of that experience plays an important role in the preservation of learning for future reference.

Vygotsky [as represented by Moll, '90] argues that knowledge is social before it is personal, which suggests that it must be interactively and socially constructed. This is usually observed through language usage though it can also be visualization. In this model, learning must be external and shared before it can be internalized and made personal. Much of the current work on group-based learning derives from his thinking. Once again, this model reflects our experience that engineering design is a social activity [Leifer, Koseff, Lenshow, '95]. I have observed that design team failure is almost always due to failed team dynamics. However, learning failure is usually blamed on the individual. It is increasingly clear that doing design is a learning activity and I speculate that more attention should be given to the influence of team-dynamics on individual learning.

A PBL FOCUS ON MECHATRONICS

Our curriculum technology focus is on Mechatronics systems design-development (smart products). Mechatronics is frequently defined as the integration of real-time software, electronics, and mechanical elements for imbedded systems. In our definition, we include human-computer-interaction and materials selection. Typical products in this domain include: disk drives, camcorders, flexible automation-systems, process-controllers, avionics, engine controls, appliances and smart weapons. Mechatronics is a particularly good medium for introducing PBL because of its dependence on interdisciplinary collaboration.

Implementation of this curriculum builds, in part, on recently developed internet tools and services for distributed product-development teams (virtual design teams). Such teams are common in the mechatronics field. Using the World-Wide-Web (WWW) as an informal, work-in-progress document archive and retrieval environment we electronically instrument design-team activity and knowledge sharing for project management and learning assessment purposes. Examples from our work

in the ARPA-MADE program include:

Share: the MadeFast experiment (URL <http://www.madefast.org/>), 6 universities, 6 corporations, built a virtual company, delivered a product in 6 months and documented it all on the WWW [Toye, '94];

ME210: a graduate curriculum in cross-functional-team mechatronic systems design at Stanford (URL <http://me210.stanford.edu>), 14 companies, 45 students (15 remote) built and documented 14 Mechatronic prototypes, '94'95;

NSF Synthesis Mechatronics : a multi-university(8) co-development project focused on undergraduate mechatronics (NSF Synthesis Coalition web (<http://www.synthesis.org>)).

Corporate clients of the Stanford Center for Professional Development (SCPD) are increasingly adamant about the need to give their employees a continuing, life-long, education opportunity without losing them to full time study on campus. Encouraged by this demand, Stanford's graduate level course, "Team-Based Design-Development with Corporate Partners," was offered for the first time in 1994 to SCPD students across the country and in 1996 to students around the world. The course is intensely experiential, hands-on. Distributed design teams (typically 3 members) work on different industry sponsored projects (typically 14 per year, the 1994-1995 academic year included Ford, GM, FMC, Lockheed, Pfizer, 3M, Raychem, NASA-JPL, Redwood MicroSystems, Quantum, Toshiba, Seiko and HP Medical Products). The deliverable is a functional product prototype and detailed WWW documentation of product and development activity. These teams won 11 of 2 awards in the Lincoln Foundation Graduate Design Competition in 1995.

A class information system based on the World-Wide-Web was created to meet the interactive distance education challenge. ME210 utilizes broadcast video and the Internet. The focus is on capturing and re-using informal and formal design knowledge in support of "design for re-design." Broadcast video (preferably a digital video server) is needed for high-bandwidth, real-time transmission of lectures, design reviews and demonstrations originating on and off campus. The internet is used for low-bandwidth data transmission, e-mail and knowledge capture. Electronic mail is used extensively for communication between the teaching staff, students, coaches and industry liaisons. Communication is automatically archived and organized by a HyperMail utility on the 210-web. The class syllabus, 5 years of past student reports, and each project's electronic notebook are part of the web. The 210-web functions as a cumulative curriculum memory. It facilitates informal knowledge sharing within the class and gives subsequent generations our legacy knowledge.

In addition to distance education benefits, the dynamic nature of the 210-web fundamentally changes the model of interaction between student teams, teaching staff, coaches and industry liaisons. Before the 210-Web, product development team progress was only observable at formal meetings and quarter critical-reviews. With the 210-Web, work-in-progress is available for review by all members of the 210 community, any time, any place. This option augments and strengthens traditional briefings. It facilitates feedback from the teaching team, coaches and corporate partners to the design team. Importantly, teams can share their "lessons-learned" in real-time. All of this gives our corporate partners a basis for judging the validity of our curriculum and the value of their financial investment in engineering education.

The course and the web become a model for instrumented learning. It was the author's experience with this course that led to formulation of the following PBL assessment-instrumentation model.

PBL ASSESSMENT

Product-based-learning integrates five key pedagogic themes, each central to assessment: 1) externally sponsored projects motivate student learning; 2) theory and practice are synthesized in hands-on development; 3) real-world projects demand multi-disciplinary experience; 4) project management requires problem formulation, teamwork, negotiation, oral

communication, and effective written documentation; 5), naturally occurring bi-products of project work (proposals, presentations, lab-notes, products and reports) directly support assessment.

PBL pedagogy maps closely to the activity and issues of real product development. Accordingly, the framework for our approach to learning assessment is derived from observational methodology in the design research community, especially the work of Tang [92] and Minneman [93]. These findings tell us what to instrument, when to instrument and to focus our attention on mapping inputs to outputs, theory to practice. Engineers must develop special critical thinking skills to map abstracts to hardware and back again. They must reason about the product and the process that will bring it into being. This is an extremely complex spatio-temporal-cognitive task that is best solved by cross-functional teams.

The half life of fundamentals in any field is much longer than the half life of related technology. This focuses our teaching investment on learning the fundamentals. However a large body of research in physics learning has shown that students have difficulty connecting abstract fundamental concepts to their understanding derived from experience [Kuhn, '62],[diSessa, '93]. Brereton [95] explored how theoretical concepts are used in practice. Here motivation was to help students integrate and leverage conceptual knowledge in the engineering workplace.

Figure-2. Assessment is calibrated and validated (authenticated) in Product-Based-Learning. Project outcomes are compared with industry performance standards across courses and campuses. Results obtained from assessment activity along three feedback paths support triangulation between findings, methods and assessors. Numbered nodes are assessment instrumentation opportunity. The choice of assessment methodology is goal specific [Bridges, Hallinger '95].

WHAT TO MEASURE, WHERE TO MEASURE IT

We favor an instrumentation metaphor for PBL activity assessment and evaluation. We instrument in the sense of observing both input and output variables in an automation environment (Figure-2). In each assessment situation we identify the locus for instrument insertion, the variables of interest and observation method of choice. The nature of the activity and its information structure influence these choices. From the automatic controls point of view, we know that time delays and process time-constants limit learning performance, therefore instrumentation should be done with the intent of minimizing loop time. Critical issues in learning instrumentation include the need to:

simultaneously observe teaching and learning; understand context, e.g., observe process & content; minimize learning feedback delay provide formative learning feedback to keep the course on target; provide summative teaching feedback to keep the curriculum on target; provide external validative feedback to keep the education enterprise on target; and define and engage those who must create and listen to the feedback.

WHAT IS TECHNOLOGY'S ROLE IN THE SOLUTION

Technology is part of the solution to the extent that implementation tradeoffs are informed by, and faithful to, our pedagogic objectives and the fundamentals of human learning. To date, internet performance has favored one-way broadcasting of information content with little or no attention to archiving the evolution of that information. As an example, our experience in ME210 argues for careful attention to the technical requirements for interactive information sharing and archiving for information reuse. Internet-II is a harbinger of our opportunity to control the evolution of information technology to meet pedagogic objectives linked to, but separable from, pure bandwidth considerations. This second generation Internet for the higher education and research must anticipate its own success and include the feature set needed by second generation users. The high-bandwidth backbone of Internet-II is a start (155mbps, <http://www.news.com/News/Item/0,4,4243,00.html>). What it carries and how usage is partitioned will determine its pedagogic value. PBL requirements should be high on the list.

PROVISIONAL CONCLUSION

Product-Based-Learning is both old and new. It is familiar as the classical conveyor of skills through apprenticeship. It is new as re-interpreted to be the formal activity of linking and integrating theory and practice. Through emerging communication technology it is revolutionary in given power back to the learner to structure and assess one's own performance at all levels of professional development. The ME210 experience is one benchmark for this paradigm. Amongst the lessons learned, we see that there is no practical upper limit on the networking bandwidth applicable to real-time collaborative learning in higher education and on the job.

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