Artificial Intelligence for Engineering Design, Analysis and Manufacturing (1998), *12,* 83–86. Printed in the USA.

POSITION PAPER

Reality brings excitement to engineering education

LARRY LEIFER AND SHERI SHEPPARD
Department of Mechanical Engineering, Stanford University, Stanford, CA 94305-4026, U.S.A.
(RECEIVED June 11, 1997; REVISED October 16, 1997; ACCEPTED August 8, 1997)

1. VISION: PUTTING THE EXCITEMENT BACK IN ENGINEERING EDUCATION

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 et al., 1995). They also have fun and perform beyond the limits required for simple grades. We, their teachers, experience these things too. Why, then, are so few students and faculty getting the PBL message? How, then, can we put the excitement back in engineering education? In part, we think this is because of three persistent mistakes in engineering education:

1. We focus on individual students.
2. We focus on engineering analysis versus communication between engineers.
3. We fail to integrate thinking skills in engineering science and engineering practice.

2. PBL AND ORGANIZATIONAL MATRIX DEFINED

PBL is a problem-based, project-oriented activity that produces a product for an outsider. One does PBL because it gives full expression to the strongest elements in active, constructivist learning theory. PBL is an antidote for many mistakes in engineering education.

PBL objectives include:

1. Familiarize students with problems and procedures inherent in their future profession.
2. Assure that content and process knowledge are relevant to high-impact problems.
3. Assure competence in applying this knowledge.
4. Develop problem formulation and solving skills for these problems.
5. Develop implementation (how to) skills to deliver the solutions.
6. Develop leadership, collaboration, and facilitation skills.
7. Develop management skills for emotional leadership.
8. Develop and demonstrate proficiency in self-directed learning skills.

Numerous examples of freshmen engineering courses that promote many of these PBL objectives were presented by Sheppard and Jenison (in press) and Sheppard et al. (in press). The examples were organized in terms of a 2D framework related to the type of skills and knowledge that a course is primarily trying to develop in the students, and a major element of the pedagogy that the course is founded on (individual vs. team). In the current paper a complimentary organizational matrix is presented that looks at the roles that various individuals and groups play in structuring and evaluating PBL experiences. The matrix, presented in Figure 1, was originally developed to describe problem-based learning (Bridges & Hallinger, 1995), then was expanded upon to more accurately depict PBL (Leifer, 1995). The matrix looks at *who structures* the course (the learning experience), and *who judges* the learning that has taken place (e.g., evaluates the right answer).

3. MAPPING PROJECTS TO THE MISTAKES, AND TO PBL OBJECTIVES AND MATRIX

Three projects that promote PBL objectives will be presented below. These three projects also serve to illustrate how various combinations of structure-judgement can be realized in course structure (Projects 1 and 2) and in course assessment (Project 3).

Project-1 is a freshman-sophomore level course (ME99) (Sheppard, 1993; Regan & Sheppard, 1996) focused on giving students *hands-on machine-dissection* experiences.

Reprint requests to: Larry Leifer, Director, Stanford Center for Design Research, Department of Mechanical Engineering, Stanford University, Stanford, CA 94305-4026, U.S.A. E-mail: Leifer@cdr.stanford.edu

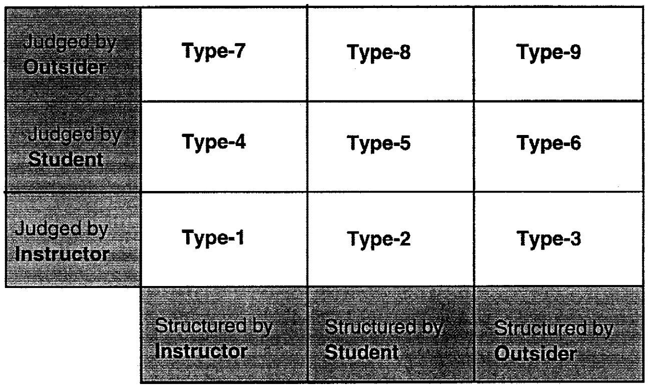

Fig. 1. Structure-Judgment (SJ) Matrix: This concept is borrowed from Bridges and Hallinger (1995) and extended to include the crucial role of "outsiders" in ME210 (Leifer, 1995). Outsiders include: coaches, corporated liaisons, technical consultants (academic and commercial), real-customer users and Design Competition Judges. The SJ-matrix reveals to students, instructors, and outsiders just where various class assignments fit in the "pedagogy space."

A major goal of the course is helping students evaluate engineering as a career option. Students produce posters, and oral and multimedia visual presentations that demonstrate their understanding of physical artifacts and principles. Our approach in creating dissection experiences is based upon learning theory that shows that most undergraduate students are inductive learners who work best starting with concrete, hands-on experience, then moving onto abstract theory. This approach provides students with the opportunity to discover the rationale for why real products are what they are. Examples of how ME99 realizes various PBL objectives are given in Table 1, and its mapping to the Structure-Judgement Matrix (Fig. 2) includes:

Type 2 Pedagogy: Each student selects, formulates, and implements final project, instructor grades.

Type 4 Pedagogy: Individual artifact presentations assigned by instructor, peer evaluated.

Type 5 Pedagogy: Each student selects, formulates, and implements final project, peers evaluate intermediate stages of project.

Additional information on Project-1 is available on http://www-adl.stanford.edu//.

Project-2 uses institutional *peer assessment* of curricula, their design and implementation, to assay pedagogic input, to observe learning output, and to institutionalize continuous education reform. The assessment approach created as part of the Peer Evaluation of Teaching Project sponsored

Table 1. *PBL Objectives Mapped to Project-1 (ME99) and Project-3 (ME210) activities. PBL objectives, as presented briefly in this document, are declarations of desired pedagogic outcomes. They are "design requirements" for PBL curricula. They do not specify the solution. ME210 and ME99 are two specific PBL models. These courses are examples of how PBL goals may be achieved at different levels of higher education (masters degree level for ME210 and freshman-sophomore level for ME99). This table maps generic PBL outcome objectives to specific PBL inputs in model courses that are the foundation for proposed projects*

PBL objective	ME210 implementation Project-3 related	ME99 implementation Project-1 related
1. Familiarize students with problems and procedures inherent in their future profession.	Use real projects from industry and teach design methodology that is expected to be industry practice in 3–5 years.	Students explore real hardware utilizing inter- and intra-university resources.
2. Assure that content and process knowledge are relevant to high-impact problems.	Use real projects from industry that are on the corporate critical path.	Lecture, the course reader and the WWW content are selected and organized as a function of the hardware being investigated.
3. Assure competence in applying this knowledge.	Build functional hardware-software solutions to these problems.	Engage students in demonstrating understanding in written, oral, and hardware forms.
4. Develop problem formulation and solving skills for these problems.	Stress redefinition of the problem through rigorous design requirement classification and modelling of the product's technical structure.	Engage students in assessing the effectiveness and quality of existing hardware and in critiquing the work of their peers.
5. Develop implementation (how to) skills.	Engage students in manufacturing the product, literally, build the real thing with their own hands.	Coach students throughout the development of their final project.
6. Develop leadership and collaboration facilitation skills.	Encourage self-managed learning teams with "flat hierarchies" and responsible peer-to-peer collaboration.	Craft many laboratory assignments to be team based.
7. Develop management skills for emotional leadership.	Recognize and actively manage the interpersonal emotional aspects of team activity, including the roles of coaches, mentors, and tutors.	Explicitly discuss time-management and negotiating issues.
8. Develop and demonstrate proficiency in self-directed (active) learning skills.	Promote, support, and finally require, peer assessment and collateral learning with self-generated agendas.	Balance class assignments between individual and team accountability.

https://doi.org/10.1017/S0890060498121182 Published online by Cambridge University Press

Judged by Outsider	Type- 7 **project-2** peer course review & student interviews	Type- 8 **project-2** peer course review & student interviews	Type- 9 **project-2-3** peer course review outsider observation
Judged by Student	Type- 4 **project-1** mechanical dissection	Type- 5 **project-1** mechanical dissection	Type- 6 **project-3** direct observation of and by outsiders
Judged by Instructor	**Type- 1** passive learning typical engineering science classes	Type- 2 **project-1** mechanical dissection	Type- 3 **project-3** direct observation of and by outsiders
	Structured by Instructor	**Structured by Student**	**Structured by Outsider**

Fig. 2. Projects mapped to the Structure-Judgment (SJ) Matrix: Each project explores an important part of the PBL pedagogy space. Project-1 deepens our experience with, and yields formal understanding of the impact on students of having responsibility for structuring and judging their own "dissection based" learning activity. Project-2 includes outsiders (in this case, faculty peers inside and outside the institution) in the judgment of learning outcomes. Project-3 takes us decisively into the space where outsiders (in this case, industry-based project sponsors) make a contribution to structuring the learning experience.

by the Hewlett Foundation and the Pew Charitable Trusts through the American Association for Higher Education (AAHE) (Sheppard et al., 1996; Sheppard, Johnson, & Leifer, in press) has proven itself as an effect means of providing formative assessment to instructors of PBL learning experiences. In addition, it creates a community for sustained faculty engagement and quality assurance, and a documented methodology for including peer and student input to course assessment. The mapping of this assessment approach to the Structure-Judgment Matrix (Fig. 2) includes:

Type 7 Pedagogy: Instructor assembles course goals statement, faculty peer synthesizes statement, and student interviews into feedback statement to instructor.

Type 8 Pedagogy: Student interviews form a major component for feedback by faculty peer to instructor.

Type 9 Pedagogy: Faculty peers set-up and facilitate small group interviews of students for feedback to instructor.

Project-3 is a masters level course (ME210: Machine Design) that has evolved based on Design Research findings by M.E. doctoral candidates who directly observed design practice and design education (Tang & Leifer, 1991; Minneman & Leifer, 1993; Brereton et al., 1995) and feedback obtained through Project-2. Examples of how ME210 realizes various PBL objectives are given in Table 1, and its mapping to the Structure-Judgment Matrix (Fig. 2) includes:

Type 3 Pedagogy: Student presentations and documentation of design work on industrial-sponsored project evaluated by course instructor.

Type 6 Pedagogy: Student presentations and documentation of design work on industrial-sponsored project evaluated by teaching assistants.

Type 9 Pedagogy: Student presentations and documentation of design work on industrial-sponsored project evaluated by industrial sponsor/representatives.

Additional information on Project-3 is available on http://me210.stanford.edu.

4. CONCLUDING REMARKS

In concert, these three projects help us understand what should be taught and how it should be learned. Two of the projects are courses that directly promote many of PBL objectives, and the other is an assessment approach that has proven effective in providing feedback in the evolution of PBL curriculum.

These projects complement one another by enabling us to gain synchronous insight into all nine of the situations depicted in Figure 1, and by providing input to one another. For example, the peer assessment technique of Project-2 is a window into the curriculum and environment developed for Project-1, machine-dissection. Likewise, insights gained from direct-observation in Project-3 will inform the design of learning situations created for Project-1 and the peer-assessment criteria used in Project-2. Over time, students passing through Project-1 (freshmen) will appear in courses assessed in Project-2 (sampling at all levels). Some will eventually enter Project-3, where they will be trained as "participant observers" to enter industry as part of our direct-observation field study.

ACKNOWLEDGMENTS

We wish to thank those who have supported this work financially: The Synthesis Coalition funded by the National Science Foundation, The Powell Foundation, the Hewlett Foundation, and the Pew Charitable Trusts. We would like to acknowledge the many individuals who have been partners in helping us develop our approaches to PBL, namely our students and our colleagues in the Design Division at Stanford University.

REFERENCES

Brereton, M.F., Sheppard, S.D., & Leifer, L.J. (1995). How students connect engineering fundamentals to hardware design. *Proc. 10th Int. Conf. Eng. Design*, 336–342.

Bridges, E.M., & Hallinger, P. (1995). *Problem based learning: In leadership development.* ERIC Clearinghouse on Education Management, Eugene, Oregon.

Leifer, L.J. (1995). Evaluating product-based-learning education. *Proc. Int. Workshop Eval. Eng. Educ.*

Minneman, S., & Leifer, L.J. (1993). Group engineering design practice: The social construction of a technical reality. *Proc. Int. Conf. Eng. Design (ICED '93)*.

Regan, M., & Sheppard, S. (1996). Interactive multimedia courseware and the hands-on learning experience: An assessment study. *J. Eng. Educ.*, 123–131.

https://doi.org/10.1017/S0890060498121182 Published online by Cambridge University Press

Sheppard, S. (1993). Mechanical dissection: An experience in how things work. *Proc. Eng. Found. Conf. Eng. Educ.: Curriculum Innovation.*

Sheppard, S.D., Leifer, L., & Carryer, J.E. (1996). Commentary on student interviews. *Innovative Higher Educ., 20(4)*, 271–276.

Sheppard, S., Johnson, M., & Leifer, L. (1997). A model for peer and student involvement in course assessment. *Journal of Engineering Education* (in press).

Sheppard, S.D., & Jenison, R. (in press). Freshmen engineering design experiences: An organizational framework. *Int. J. Eng. Educ.*

Sheppard, S., Jenison, R., Agogino, A., Brereton, M., Bucciarelli, L., Dally, J., Demel, J., Dym., C., Evans, D., Faste, R., Henderson, M., Minderman, P., Mitchell, J., Oladipupo, A., Piket-May, M., Quinn, R., Regan, T., & Wujek, J. (in press). Examples of freshman design education. *Int. J. Eng. Educ.*

Tang, J.C., & Leifer, L.J. (1991). An observational methodology for studying group design activity. *Res. Eng. Design, 2(4)*, 209–219.

Larry Leifer, a member of the Stanford faculty since 1976, teaches ME210abc, "Team-Based Product Design-Development with Corporate Partners," a masters level course and the Design Theory and Methodology Forum for Ph.D. candidates in Design Research. He is founding director of the Stanford Center for Design Research (CDR) where he does design theoretic research. Special interest projects include: (1) development of a collaborative engineering environment for geographically distributed product development teams; (2) instrumentation of that environment for design knowledge capture, assessment, and reuse; (3) development of tele-assistive robots for physically limited individuals; and (4) development of Synalysis-Exercise modules for education and learning assessment. In his most recent position as founding director of the Stanford Learning Laboratory (July 1997), he is challenged with university-wide insertion of pedagogically informed learning-technology to improve the learning experience in higher education.

Sheri D. Sheppard has been at Stanford University in the Design Division of Mechanical Engineering since 1986. She is an associate professor. Besides teaching undergraduate and graduate design-related classes, she conducts research on weld fatigue and impact failures, fracture mechanics, and applied finite element analysis. This work involves experimental and analytical efforts. She is particularly concerned with the development of effective engineering tools that enable designers to make more informed decisions regarding structural integrity. In addition, she is PI on a multi-university NSF grant that is critically looking at engineering undergraduate curriculum, and is co-director of the Stanford Learning Laboratory. Professor Sheppard is a registered Professional Engineer and is a member of the ASME Design Division Executive Committee. Before coming to Stanford, Dr. Sheppard held several positions in the automotive industry, including senior research engineer at Ford Motor Company Scientific Research Lab.

https://doi.org/10.1017/S0890060498121182 Published online by Cambridge University Press