AC 2008-1492: USING HANDS-ON SIMULATION TO TEACH LEAN PRINCIPLES: A COMPARISON AND ASSESSMENT ACROSS SETTINGS

Sharon Johnson, Worcester Polytechnic Institute

Bryan Norman, University of Pittsburgh

Jean Fullerton, Elizabethtown College

Susan Pariseau, Merrimack College

Using Hands-On Simulation to Teach Lean Principles: A Comparison and Assessment across Settings

Abstract

Lean thinking has transformed the way that processes are designed and managed, significantly improving lead times, quality and cost for many organizations. These ideas are being applied to more complex processes, involving supply chain partners, services, and product development processes. Undergraduate students in industrial and other engineering programs often encounter lean ideas in a fragmented and theoretical way, with particular tactics taught in existing courses, rather than from a holistic and applied perspective. We are using a hands-on approach to teaching lean principles based on a physical simulation called Time Wise™, developed by Time Wise Management Systems, where participants assemble clocks using a multi-stage process to get hands-on practice applying lean principles.

In this paper, we describe the use of this hands-on approach in three settings: in two different introductory courses in Industrial Engineering (IE), at different schools, and in one Introduction to Engineering course at a third school. We describe and contrast the implementation experience at each school, including specifics about how the materials were included in the courses, the support needed, and faculty preparation and observations. In addition, we present some of our assessment tools, and provide a preliminary analysis of student learning across two settings. Our assessment addresses the extent to which students are able to apply lean principles and use data to support decision-making.

Introduction

Good process design can be a cornerstone of competitive advantage, and provide an opportunity to significantly improve operational performance[6]. The techniques and issues associated with process design are a significant part of the Industrial Engineering (IE) discipline[10], yet as in other engineering fields, good design is difficult to teach. Design is a creative process that must address the complexity of real-world processes with unique constraints and competitive drivers.

In the past 20 years, diverse organizations have used lean principles to design processes that deliver significantly improved lead times, quality and cost[15]. Lean principles provide systematic guidelines for designing effective processes, focusing on eliminating waste by specifying value, simplifying flow, and pulling from customer demand[18]. Specific tactics, such as cellular layouts, are employed by designers to translate principles into practice. Because many IE courses focus on detailed design related to specific tactics, which fit naturally as subtopics within existing courses, students often encounter lean tactics in a piecemeal fashion, making it difficult for students develop an integrated understanding of the underlying philosophies. Courses dedicated to lean are generally aimed at senior-level students. Opportunities to practice process design are often the domain of senior-level capstone projects as well.

To improve the teaching of lean concepts, as well as to develop students' ability to design effective processes, several IE faculty at one university (referred to as Site 1 here) developed a lean laboratory to support an introductory IE course. Because lean thinking plays such a central role in many organizations today, we believed IE students should be given a holistic view of lean principles early in their academic careers. Another benefit is that management majors and engineers in other disciplines, who may take only one operations-focused course, can then also have exposure to these ideas.

When companies embrace a lean philosophy, they generally train employees in lean principles and associated tactics, often using classroom instruction supplemented with hands-on applications, plant floor exercises, and live simulations. We adopted one of these simulations at Site 1, called Time Wise™ and developed by Time Wise Management Systems for use in corporate training (http://www.timewisems.com), as the foundation for the laboratory. Simulations provide important opportunities for practice, which are more controlled and time-limited than mini-projects done at company sites[3]. In the course, traditional topics, such as line balancing and material management, are linked to lean concepts of value, flow, demand pull, and perfection and then also explored in related laboratory exercises. We found that incorporating the laboratory improved students' abilities to apply lean ideas, as well as their confidence in those abilities. In addition to providing students with a context for exploring lean principles, we found that one of its greatest strengths was the opportunity it offered to explore 'real-life' lessons about process improvement and design. These results are consistent with other studies that show students' design and problem-solving abilities are improved in courses that use active and collaborative learning[17].

Given the success with using the hands-on simulation at Site 1, the project was expanded to create additional learning materials and an implementation model to support use in other universities and colleges. In particular, because the application of lean principles is context dependent, the Time Wise™ simulation provides only one setting in which to practice lean design skills. Case studies, which will complement the simulation, form the core of additional learning materials. In this paper, we focus on the first use of the existing simulation in two other universities, called Site 2 and Site 3, presenting an implementation model as well as an initial evaluation of student learning.

Simulation and Supporting Materials

The Time Wise™ simulation involves participants in assembling clocks using a multi-stage process. Three versions of the simulation are available: (1) high-volume, standard products, (2) low-volume, customized products, (3) supply chain. In this paper, we describe experiences with the high-volume, standard product simulation. Each simulation is carried out in a large group of 15-20 people, with each person assigned a different role. In addition to assembly personnel, participants take on the roles of production planners, material handlers, quality inspectors, warehouse clerks, inspectors, suppliers, and customers. One round of the simulation takes approximately 15 minutes, and corresponds to a work shift. To run the simulation, a lead trainer (faculty member) and 2 assistants (undergraduate or graduate students) are needed.

The simulation is carried out in a series of rounds; after each round, participants make improvements to the process and play again to test their solutions. The first round corresponds to a facility with a poor layout, large batch sizes, a disconnect between forecasts and customer orders, confusing work instructions, unbalanced capacity, and a poor understanding of quality drivers. The number of improvement rounds, and the topics explored in each, is flexible. In the corporate training devised by Time Wise Management Systems to accompany the simulation, four rounds of the simulation are typically played. At Site 1, three rounds are played; the 'traditional operation' first round, a second round that focuses on value and improving flow, and a final round used to explore pull.

The Time Wise™ simulations have many features that make them attractive for a university setting. The materials are packaged in suitcases, with all necessary documentation and facilitator's guides. The materials were designed to be portable, so trainers could use them in different locations, yet are professional and durable. A specialized laboratory space is not required (an approximately 300 square foot room with moveable tables is preferred). Simulations take about an hour to set up. Competing simulations often require significant preparation time on the part of the trainer (for example, those with paper-based materials), or are more simplistic. The professional presentation (e.g., laminated work instructions that describe each participant role) engages students in the simulation. In addition, teaching notes and homework assignments have been developed for the rounds delivered at Site 1, which connect the simulation to traditional course topics.

The simulation scenario is rich enough to support curriculum development and links to a variety of process design topics. For example, at Site 1, the data collected in the first round of the simulation is used to teach students basic process calculations, including capacity and takt time. Teaching notes have also been developed for value-stream mapping and a kanban exercise.

Implementation Model

Relative to a corporate training environment, where a standardized approach to introductory lean training is often a goal, existing courses and faculty expertise create significant diversity among universities even within a major. Implementing material developed at another university setting often requires modifying materials to fit the setting, which limits diffusion of teaching innovations. Creating modular and flexible materials can increase the likelihood of adoption; this approach was taken to develop materials for the Time Wise simulation. Ease of use is also an important factor.

The issue is not just a function of the teaching materials. Because a hands-on simulation such as Time Wise is complex relative to typical classroom materials, and hands-on experimentation can result in unexpected (but very rich) learning experiences, faculty must typically invest additional time in teaching as well as learn new styles of teaching. Given these factors, sustaining the use of a hands-on simulation such as Time Wise can be problematic.

The implementation model and process for faculty development used in this project, and shown in the box Figure 1, has three components: workshops that introduce participants to the material, follow-up support during initial implementation provided through the Time Wise Management

System delivery network, and opportunities to work on a product team to develop case studies. Because introducing classroom innovation involves faculty learning about both the materials and new teaching strategies, this approach employs features that address important learning principles[4,16]; the sustained support offers multiple opportunities for feedback and discussion as well as opportunities to be actively engaged in creating new knowledge. The proposed model also alleviates cost issues by providing the Time Wise simulation materials to the initial participants through grant funding.

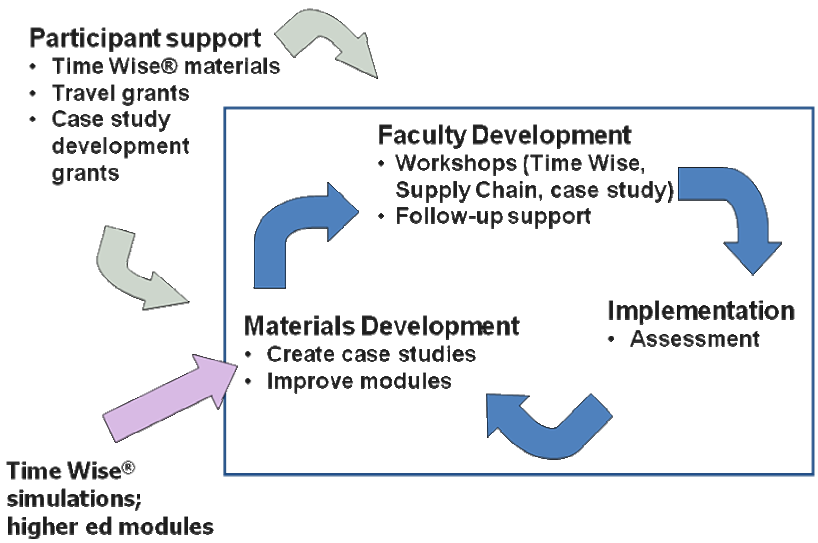

Figure 1: Implementation Model

Faculty at Sites 2 and 3 are participating in this process, starting with a 2 ½ day seminar in Summer 2007 that involved hands-on simulation sessions and planning for implementation in a course at their university. Faculty at both sites used the materials in a course in Fall 2007; the remainder of this paper reports on their experiences and examines student learning in different settings.

Description of Implementation Sites and Courses

Table 1 summarizes the courses and student characteristics at three sites where the Time Wise simulation was implemented in Fall 2007. The three sites represent significant diversity in terms of course content and student majors, as well as how simulation materials were used.

At Site 1, the Time Wise simulation has been used as part of an introductory course taken by IE majors, as part of a separate laboratory section which meets for 3 hours for 5 weeks. The course is also required for management majors, who often take it later in their academic program, and by (mostly) mechanical and manufacturing engineers as an elective. The simulation materials have been used for approximately five years. In addition to three labs that are based around the traditional manufacturing, improving flow, and pull rounds of the Time Wise simulation, a fourth lab involves process and data analysis to support improvements and the fifth explores the value of postponement and the complexity of information management in a customized product environment. The laboratory section is taught by a graduate student, and supported by 2 students

Table 1: Description of Courses and Student Characteristics

Site	Course Description	Number of Students and Sections, Student Characteristics
Site 1	**Introductory IE:** This course is an introduction to the planning, analysis and design of production systems. It is designed for students in engineering or management who may wish to assume responsibilities in the production of goods or services. Topics to be covered will include: operations strategy, project management, quality management, process analysis, capacity management, and just-in-time and lean systems	30 students 2 sections Major distribution: 40% IE, 27% management, 30% other engineering, 3 % unknown Class distribution: 24% sophomores, 45% juniors, 31% seniors
Site 2	**Introductory IE :** Introduction to Industrial Engineering concepts and thought processes including manufacturing processes; design-product and process considerations; methods engineering, standards development, predetermined time systems, computerized work measurement; motivation and incentives, and facilities design.	51 students 3 sections 100% IE majors 100% Sophomores
Site 3	**Intro to Engineering:** Introduction to the study, practice and various branches of engineering, including problem solving, teamwork, project management, design, statistics, solution of equations, and technical writing. Includes a design project, guest speakers and plant tours.	21 students 1 section Major distribution: 71% engineering, 10% science, 19% unknown 100% First Year

who have previously taken the course and have experience with the lab. The graduate student is typically trained by helping out in the course once before serving as the lead facilitator.

At Site 2, the simulation was also used in an introductory IE course, as part of a scheduled laboratory session. The class was divided into three groups that participated in the simulation in separate time slots to ensure each student could be actively involved. The sessions were run by a faculty member who had attended the summer workshop, and two graduate students. They felt comfortable delivering the simulation after attending the workshop, and elected not to have support on-site when first running the simulation.

At Site 2, three rounds of the simulation were used, spaced approximately 2 weeks apart. The first round was the original condition where nothing worked very well. After this lab, students were given an individual assignment to determine ways to make things work better. For the second lab the students got together for 30 minutes prior to the lab and discussed how to combine their ideas (written down in their lab 1 assignment) into a new line design and operation plan. Then they ran the line using their layout and operation plan. After this run they could make modifications and then ran it again. The assignment for the second lab was to discuss the effectiveness of their changes and then to suggest additional changes. In the final lab, the faculty member used the suggestions from round 3 of the Time Wise materials.

Finally, the Time Wise setting was used at Site 2 to provide a scenario for other topics covered in the course, including time study, Right Hand/Left Hand charts, muda, and process flow charts. Some were hands-on activities (e.g., examining certain operations in the clock building process as examples for LH/RH chart construction and understanding), while for others, Time Wise example were used to support lecture.

At Site 3, the simulation materials were used in the first of a two-part Introduction to Engineering course. Students major in engineering, and may concentrate in a specific engineering discipline. The simulation was used during two of the regular 3-hour class sessions, the first of which was facilitated with on-site support from a Time Wise lean trainer from a Manufacturing Extension Partnership (MEP). In the first session, the students played the traditional simulation, then made suggestions for improvement and a second round was played. In the second session, which took place approximately one week later, students played two more rounds of the simulation focused on additional flow improvements and implementing pull. Follow-up lectures explored terminology and concepts in more detail.

Project Evaluation

The goals of the project include developing an effective implementation and faculty development process, as well as materials and pedagogical approaches that support increased student learning. Our evaluation addresses each of these goals. In this preliminary analysis, we present only a few of our objectives and metrics; our full design includes more objectives and multiple indicators, both qualitative and quantitative, of outcomes to support our analysis[5]. Formative evaluation is currently underway to evaluate project progress and to provide initial feedback on success in meeting project goals.

Observations of Participating Faculty

To explore faculty development outcomes, we created a faculty journal format, which provides faculty who are implementing the simulation materials for the first time with a structure for recording feedback on the implementation. Such qualitative methods are important for uncovering and understanding human perspectives[9]. Table 2 provides a summary of responses of faculty from Sites 2 and 3 related to key dimensions.

From a faculty perspective, the Time Wise simulation was effective in meeting learning objectives related to industrial engineering and lean topics. The simulation scenario also provided a source of examples for other course topics.

As might be expected, faculty delivering material for the first time encountered some obstacles. In particular, one start up issue is finding TAs (either graduate or undergraduate student) who have enough familiarity with the simulation to provide support. At Site 1, we use students who have previously taken the course, so this obstacle may not be as significant in future years. At Site 2, where the simulation was not co-facilitated by an experienced lean trainer, both data collection/use and experimentation issues were identified. Working with a lean trainer ensures that small simulation details are not overlooked, which might have avoided the data issues encountered. On the other hand, much is learned from these types of mistakes; the second simulation at Site 2 may be smoother than at Site 3 because the faculty member has already been fully in charge of the simulation.

Use of a lean trainer, who is used to delivering the simulation a particular way, is also more likely to constrain students to particular solutions. Thus in striking a balance between letting students generate improvements and experiment, versus controlling learning content, working with a trainer creates a more structured approach that may be valuable as the faculty member

Table 2: Summary of Faculty Observations From Sites 2 and 3

Evaluation Dimensions	Site 2	Site 3
Room and Physical Materials	Easy to arrange, satisfied	Easy to arrange, satisfied
Preparation	• Demoed the labs with TAs prior to running them in class. • Faculty member held weekly meetings with TAs to discuss lab	• Support from MEP from first round was effective
Delivery	• Difficult to work with students in TA roles who have not seen the simulation • Need to find better balance what students can change and explore with keeping enough control to make key points • Support students doing a better job of data collection, including process times, quality, and WIP	• Energy level of students was high • Energy level required of faculty member is high • Difficult to work with students in TA roles who have not seen the simulation • In addition to training, TAs should have assigned roles (e.g., disassembling, quality) during the simulation.
Success in Meeting Learning Objectives	Yes, overall providing students with an introduction to what IEs do, including • Line balancing • Good process flow • Correct poor layout • Process analysis: eliminate wasted and inefficient motions	Yes, including • Understand lean terms • Understand factory assembly steps • Understand what an IE does • Ability to apply 5S to different situations • Identify process wastes and generate ideas for eliminating them • Apply lean techniques

gains experience with the simulation. From a learning perspective, student experimentation is a key enabler associated with hands-on pedagogy, and the balance may shift to greater experimentation over time. Another critical factor affecting the balance is the time available within the course. Allowing more experimentation takes more time, and may be more appropriate for IE courses that seek to develop students' abilities as process designers, rather than managers and engineers who are knowledgeable about processes.

Student Learning

Our assessment plan calls for experimental studies that evaluate how both behavioral and content outcomes of student learning are affected by the new curriculum materials. Behavioral outcomes include increased self-efficacy, i.e. a personal judgment of one's capability to perform a particular activity. This is a particularly important affective measure for tasks perceived to be difficult, because it is highly correlated with the amount of effort individuals are willing to expend and their determination to complete tasks[1,2]. Self-efficacy has been positively associated with greater motivation, higher levels of interest, and better academic performance[2, 7, 14]. We developed a pre- and post-course survey that asked students to evaluate their proficiency in specific knowledge areas related to lean and process design. The survey was used at all three sites, but data for Site 2 has not yet been analyzed.

Results for Sites 1 and 3 are shown in Table 3, where knowledge areas in some cases represent responses averaged across several questions. At both sites, the results support the expected hypothesis, that students rate their proficiency more highly after taking the course. The somewhat higher responses at Site 1 also seem consistent with the fact that this course is taken by sophomores, juniors and seniors, while the students at Site 3 were all in their first year. The Time Wise materials are also used more extensively at Site 1, where 15 hours of laboratory time are used, versus five hours at Site 3.

Student learning content outcomes are also being evaluated using students' work across standardized assignments and/or test questions, although these have not yet been fully analyzed. We are interested in topical knowledge as well as the level of mastery, as defined by Bloom's taxonomy[8]. Standardized problems have been completed by students at all three sites, and rubrics and coding standards are being developed to ensure reliable assessment[12,13].

As an example, students were asked to "define lean in the context of process design". Answers were scored according to the rubric in shown in Table 4, which also reports the results for Sites 1 and 3. At both sites, the 'pre' responses were collected as part of a questionnaire given at the beginning of the course, which also asked students to evaluate their proficiency. At Site 1, a similar post-survey was given during a class session at the end of the course. At Site 3, the open-ended questions were included on an end-of-term exam. As shown in Table 4, students' ability to define lean improved at both sites, and the scores are consistent with students' rating of their own proficiency (Table 3) in relative terms.

Future analysis will examine scores on additional questions, as well as compare them to student work prior to the implementation of the simulation. The other questions used in the standard assessment ask students to provide examples of how lean principles can be applied in practice, to calculate capacity and determine the bottleneck, and to calculate takt time and suggest improvements to meet it. Rubrics specific to each question have been developed. In addition to these standard survey questions, we are also setting up controls to compare results with and without simulation use. These controls are setting-specific. For example, at some sites, where multiple sessions of the course are taught, the simulation can be implemented in some sections and not in others to permit comparison.

Table 3: Students' Evaluation of Their Proficiency, Pre- and Post Course, at Sites 1 and 3

Knowledge Areas	Site 1 N=29		Site 3 N=18	
	Pre*	Post*	Pre*	Post*
Lean Principles	1.5	4.4	1	3.7
Process Analysis	1.7	4.2	1.2	3.5
Lean Tactics	1.3	4.3	1.0	3.6
Data Analysis	2.9	4.2	1.9	3.7
Problem Solving	1.3	4.4	1.7	3.1
Overall	1.6	4.3	1.2	3.6

* The scale is:

- **Level 1: Have no exposure to or knowledge of**
  (have never heard of the topic, or only in casual conversation)
- **Level 2: Have experienced or been exposed to**
  (have had some organized introduction to the topic, have had someone explain it to me)
- **Level 3: Can participate in and contribute to**
  (can participate in and contribute to a discussion about the topic, or have participated in an event where the topic was used)
- **Level 4: Can understand and explain**
  (have explained the topic to someone else, prepared a presentation about the topic, or written a paper about the topic)
- **Level 5: Am skilled in the practice or implementation of**
  (have applied my knowledge in the topic by developing solutions to a case study or other academic exercise, solving a problem in an organization, or leading an activity)

Conclusions and Future Work

This paper describes the implementation of a hands-on simulation to teach lean principles at three universities, which is part of an ongoing project to study effective processes for implementing and sustaining such active learning approaches in a variety of courses at different schools. The project also seeks to generate greater understanding about what students learn, and how such simulations might impact the ability to design effective processes and use data efficiently. The cross-site comparison also allows exploration of the correlation between the time spent on the simulation and student learning.

Table 4: Students' Ability to 'Define Lean', Sites 1 and 3

Define Lean (in the context of process design)	Site 1		Site 3	
	Pre* N=29	Post* N=25	Pre* N=19	Post* N=19
Average	0.6	2.0	0	1.6
Standard Dev.	0.9	0.6	0	0.7
Rubric:*				
0	No answer, incorrect (in the context of rubric below)			
1	Related to improvement generally			
2	Include both (1) improving a process (could state cost, quality, etc. as types of improvement) (2) understanding value or eliminating waste (can give examples of eliminating waste, rather than stating directly)			
3	Include responses above, and also describe how they are accomplished; improving flow, pull.			

The use of hands-on simulation to teach lean principles, and more generally process analysis and design concepts, has been very effective at Site 1, where a simulation has been used for five years. In this project, each site has implemented the Time Wise simulation, but use of other lean simulations (such as the Lean Enterprise Value simulation, where team of 6 students compete to build a Lego aircraft) is likely to yield similar results[11]. For Sites 2 and 3, where a simulation was used for the first time in Fall 2007, the assessment analysis so far indicates that it has been successful in helping students learn lean principles. These results demonstrate the effectiveness of the approach across different implementations, faculty, and students.

As we collect more data, we are also seeking to understand more specifically the benefits related to this learning approach over others, such as improving students' ability to apply what they have learned in other settings. This more detailed understanding is being driven in part by the quantitative outcomes assessment, but also by the qualitative observations of the faculty implementing the model. For example, relative to application, the faculty member who ran the simulation at Site 3 noted:

> "I was surprised at how much freshman got from this simulation. They had fun doing it, but all of them were able to evaluate past jobs and give very specific lean changes that would have increased their efficiency. I think this training will open up internship opportunities as well. My students would never have learned as much from a lecture format."

Another goal of the project is to create an implementation model that supports sustained use of the learning methods. Because simulation logistics require preparation on the part of faculty members, and experimentation can require additional class time, it is easier to lecture. Demonstrating learning benefits is critical for generating faculty enthusiasm. At both Sites 2 and 3, the faculty leading the simulation felt it was worthwhile. They are not only excited about using it again, but in expanding its use to explore additional topics. Initially, it is also important that faculty feel comfortable leading the simulation; the'Train-the-Trainer' workshop, on-site support during the first run of the simulation, and the simulation documentation all contributed to the success at Sites 2 and 3. Longer term, we are evaluating the importance of ongoing support, reflective activities such as writing articles, and opportunities to participate in case development as ways of keeping faculty engaged to sustain changes.

The results from these initial implementations are being used to refine assessment tools, as well as to inform the process for future implementations. Several additional universities will be using the materials for the first time in Spring 2008, and a second workshop is planned for June 2008 to support implementations at additional schools in 2008/2009.

Bibliographic Information

(1) Bandura, A., *Social Foundations of Thought and Action: A Social Cognitive Theory*, Englewood Cliffs, NJ: Prentice-Hall, 1986.

(2) Bandura, A., *Self-Efficacy: The Exercise of Control*, New York, NY: W.H. Freeman and Company, 1997.

(3) Bradley, J. R., and J. Willett, “Cornell Students Participate in Lord Corporation’s Kaizen Projects”, *Interfaces*, 34(6), 451-459.

(4) Donovan, M. S., and J. D. Bradford, “Pulling Threads”, *How Students Learn: History, Mathematics, and Science in the Classroom*, Washington, D.C.: Nataional Academy Press, 2005.

(5) Frechtling, J. and L. Sharp (Ed.), *User-Friendly Handbook for Mixed Method Evaluations*, NSF Directorate for Education and Human Resources, Division of Research, Evaluation, and Communication, 1997.

(6) Hayes, R. and D. Upton, “Operations-Based Strategy”, *California Management Review*, 40(4), 1998, 8-25.

(7) Hackett, G., N. E. Getz, J. M. Casas, I.A. Rocha-Singh, “Gender, Ethnicity, and Social Cognitive Factors Predicting the Academic Achievement of Students in Engineering”, *Journal of Counseling Psychology*, 39(4), 527-538, 1992.

(8) Krathwohl, D. R., “A Revision of Bloom’s Taxonomy: An Overview”, *Theory into Practice*, 41(4), 212-218, 2002.

(9) Leydens, J. A., B. M. Moskal, and M. J. Pavelich, “Qualitative Methods Used in the Assessment of Engineering Education”, *Journal of Engineering Education,* 93(1), 65-72, 2004.

(10) McGinniss, L., “A Brave New Education”, *IIE Solutions*, 34(12), 27-31, 2002.

(11) McManus, H. L., E. Rebentisch, E. M. Murman, A. Stanke, “Teaching Lean Thinking Principles through Hands-on Simulations”, *Proceedings of the 3rd International CDIO Conference, MIT, Cambridge, MA, June 11-14, 2007.*

(12) Moskal, B. M., “Scoring Rubrics: What, When and How?”, *Practical Assessment, Research & Evaluation,* 7(3), 2000a.

(13) Moskal, B. M., “Scoring Rubric Development: Validity and Reliability”, *Practical Assessment, Research & Evaluation,* 7(10), 2000b.

(14) Multon, K.D., Brown, S.D., and R. W. Lent., "Relation of Self-Efficacy Beliefs to Academic Outcomes: A Meta-Analytic Investigation", *Journal of Counseling Psychology*, 38(1), 30-38, 1991.

(15) Nakamura, M.S., S. Sakakibara, R. Schroeder, "Adoption of Just-in-Time Manufacturing Methods at US- and Japanese-Owned Plants", *Transactions on Engineering Management*, 45, 230-240, 1998.

(16) National Research Council (NRC), *How People Learn: Brain, Mind, Experience, and School*, Washington, D.C.: Nataional Academy Press, 2000.

(17) Terenzini, P. T., A. F. Cabrera, C.L. Colbeck, J. M. Parente, S. A. Bjorklund, "Collaborative Learning vs. Lecture/Discussion: Students' Reported Learning Gains", *Journal of Engineering Education*, 90(1), 143-150, 2001.

(18) Womack, J. P. and D. T. Jones, *Lean Thinking*: Banish Waste and Create Wealth in Your Corporation, Revised and Updated, Free Press, New York, NY, 2003.

.