SYSTEMATIC DEVELOPMENT OF AN EXPERIENTIAL-BASED LEARNING ENVIRONMENT IN ENGINEERING

Andres L. Carrano, John K. Kaemmerlen, Jacqueline R. Mozrall

Department of Industrial and Systems Engineering,
Rochester Institute of Technology, Rochester, New York 14623. USA
alceie@rit.edu, jxkpdm@rit.edu, jrmeie@rit.edu

Abstract

This paper describes the systematic development and evolution of an experiential-based learning environment developed at RIT that facilitates active and collaborative learning of principles related to contemporary production systems, problem solving, continuous improvement, and systemic thinking. Centered around the unique Toyota Production Systems (TPS) Lab, and based on active and collaborative learning, this environment targets a broad range of audiences, including K-12, undergraduate, and graduate students. Cognitive skills for different audiences are taught and reinforced via an innovative instructional delivery framework. In this paper, the laboratory facilities and instructional approach are described. In addition, the assessment, evaluation and continuous improvement methods being applied in the TPS Lab are presented.

Keywords: Active and collaborative learning, production systems, laboratory environment.

1 INTRODUCTION

In industry, there is a growing need for engineers that can contribute immediately upon graduation and who are well versed on problem solving, continuous improvement and systemic thinking skills [1]. Meeting this need requires different and more innovative ways to impart knowledge. Traditional lecturing is an excellent mechanism for delivering large amounts of information but it also encourages passivity in students and compromises their interaction in class. This also dulls student creativity since the instructor is expected to provide all the necessary material and ideas. The aim of this paper is to present a unique approach to experiential learning. The development in this paper is soundly rooted in proven learning approaches including: active learning, collaborative learning and curriculum integration [2-6]. This paper describes the systematic development and evolution of an experientially-based learning environment (facilities, curricula, teaching content, instructional approach, and corporate relations) that facilitates active and collaborative learning around the skills of problem solving, continuous improvement and systemic thinking.

2 TARGETTED LEARNERS

Because of the applicability and relevance of problem solving and continuous improvement concepts to a wide range of disciplines, the audience targeted by this effort is quite broad. The material developed in the laboratory has traditionally been imparted within a course in the Department of Industrial and Systems Engineering. This course was delivered in the fourth year of a five-year undergraduate curriculum. Subsequent adaptation allowed for delivery of this material in the introductory class at the freshman level. In the last couple of years, new instructional material has been developed in the lab and is being imparted to the following audiences: pre-college students (K-12), freshmen and upper-level undergraduates, as well as graduate students from several engineering disciplines, including international programs. Currently, some 160 students from the mentioned groups participate in credit-bearing lab exercises, and more than 600 students are exposed to the lab by means of outreach activities every year. With respect to Industrial Engineering, this approach is used in two mandatory undergraduate courses, Fundamentals of IE (first-year) and Design and Analysis of Production Systems (fourth-year). There are also two graduate courses, Contemporary Production Systems and Production Systems Management, which undergraduate students can also take as electives (fifth-year). Additionally, there are efforts underway to develop and deliver this type of content to students from other disciplines. These disciplines include engineering technology, packaging science, and business. Finally, an audience that is now being targeted for future work is the large hard-of hearing and deaf population that resides in the National Institute for the Deaf (NTID), a college within RIT. NTID is the only institution in the U.S. that focuses on preparing and educating deaf students for technology-related careers. NTID students typically pursue either an Associate or a Bachelor's degree and obtain jobs in a technical field. According to industry feedback, further exposure to the material and experiences in the lab by this student population, especially in the form of problem solving, continuous improvement and systemic thinking skills, will provide them with tools and techniques that are valued by prospective employers. It is expected that the current delivery format, which heavily relies on active/collaborative learning, will be particularly attractive to hard-of-hearing students.

3 DESCRIPTION OF THE ENVIRONMENT AND INSTRUCTIONAL APPROACH

The Toyota Production Systems Laboratory currently resides in a 1600 sq. ft. facility in the Kate Gleason College of Engineering. It contains two modular assembly lines and a storage area that contains parts, assemblies and structural components. The facility can be reconfigured to stage assembly, kitting, storage, and warehousing scenarios. Some combinations of these operations are also possible. Within each scenario, it is possible to represent larger systems (e.g. an assembly operation line fed by a supplier and that delivers to customers) or to isolate specific parts of the operation to focus on a certain aspect of interest (e.g. the ergonomics of a workstation, the conveyance from a supplier, the heijunka-based leveling of the line, etc). The lab is surrounded by white boards and "A3" poster display areas for both student work and documents related to the management of the lab. An area for displaying problem-solving approaches is also provided. A section of the lab reserved for teamwork contains tables and mobile white boards. The audiovisuals include a ceiling-mounted projector that swivels for displays on different walls. This is used for both lecturing and for displaying line status and production run time. Figure 1 depicts a view of the overall layout of the lab.

Figure 1: Overall Layout of the laboratory

The majority of the parts being assembled in the lab are actual components from existing products. Most of the parts and components have been provided by either Toyota or first-tier automotive suppliers. The lab keeps an inventory of dozens of parts and components for academic assembly case development. Currently, there are two fully developed assembly cases: a radiator fan assembly and an ABS brake module assembly. The parts flow in pallets that were designed to nest with each other to allow for batch sizes of 1, 2, and 4 assemblies.

The academic content for the environment has been developed around the idea of providing the student with "lab experiences" on specific topics. Every experience contains several elements (a teaching component, an assembly case study, a script for the physical simulation, a description of the participant's roles, the facilities prep sheet, a list of resources needed for the experience, an off-line assignment, and the corresponding instructional/delivery approach), which can be modified for customized delivery to the wide range of audiences, from K-12 through graduate students. For example, the same assembly experience (e.g. a physical production run that highlights queueing, bottlenecks and workstation utilization) can be delivered to either elementary school students or graduate engineering students on the same platform. However, the educational objectives and the cognitive skills targeted for each audience are different, thus every lab experience has been developed at three levels: *observational*, *operational*, and *designer*. These levels are the basis for a framework for delivery (Table 1) and are used throughout several courses with varied audiences (Table 2).

Table 1: Framework for instructional delivery

Instructional Level	**Bloom's Taxonomy levels (Cognitive Domain) [7]**						**Experience duration**
	Knowledge	**Comprehension**	**Application**	**Analysis**	**Synthesis**	**Evaluation**	
Observational	•	•					15-45 min
Operational			•	•			1-2 hours
Designer				•	•	•	2-4 weeks

Observational Level: In this level of instructional delivery, a previously designed production scenario is staged in the facility and run by the lab staff. The participants observe the dynamics of the production system and engage in facilitated, highly structured, discussions around it. This "show and tell" approach is appropriate for audiences that do not possess the technical background and/or that can only participate for a very limited amount of time, or whenever safety reasons preclude direct participation. This is typically delivered to elementary school students and visitors through some of the camps, festivals and short events that take place in the lab. Depending on the type of scenario and existing time constraints, the entire experience for this level can be delivered within 15-45 minutes. This type of instructional delivery targets the first two levels of cognitive domains in Bloom's taxonomy [7]: knowledge and comprehension.

Operational Level: In this level of instructional delivery, a previously designed production scenario is staged in the facility. An initial assignment for the participants typically requires modeling the given system and predicting the behavior of the production line. The complexity of the modeling tools depend on the background and skill level of the audience. Afterwards, the participants, acting as line workers, interact in a physical simulation that emulates the production system (e.g. an assembly line, a part conveyance process, a warehouse, etc) for an established period of time. Sometimes more than one production run (or shift) is staged so everyone is allowed to participate in different capacities. During the production run, the participants collect data on performance parameters (e.g. queue size, workstation utilization, process times, etc.). After the production run is over, further analysis and open discussions allow for a better understanding of the system's behavior. In particular, discussions on the discrepancies between theoretical predictions and actual performance are always fruitful. Finally, unstructured problem solving and continuous improvement are introduced at this level. Without providing an in-depth treatment, and usually within the facilitated discussion, students are asked to improve the performance of some characteristic (e.g. throughput, process time variability, etc.) of the system. The entire experience at this level is usually contained within one lab session (1-2 hours depending on the class). This approach is suitable for middle school students, freshman/sophomore engineering and technology students, as well as business students. Senior and graduate engineering students often participate at this level as a preliminary step before engaging on the designer level. This type of instructional delivery targets the third and fourth levels of cognitive domains in Bloom's taxonomy: application and analysis.

Designer level: in this level of instructional delivery, a team of students is tasked with designing a production system that meets specific performance criteria. Afterwards, the students are engaged in an iterative problem solving and improvement process that challenges them to achieve more aggressive performance targets. Typically, the students would have participated in an experience at the operational level before engaging at this level. In one scenario, with a given assembly case, the students are tasked with designing a system capable of achieving certain throughput and quality levels without exceeding a pre-specified operational budget. Some restrictions are imposed to reflect the operational conditions of real assembly lines. The student teams are encouraged to use all the tools and methods learned in their current and previous courses: e.g. line balancing, simulation, jig and fixture design, etc. After the design is complete, the students have to stage their design and act as line operators while engaging in a production run over several shifts. After they collect performance data, a small discussion and brainstorming are facilitated by the instructor. The student teams are then asked to engage in a structured problem solving process, based on their line performance, focusing on specific Key Performance Indicators (KPIs), and by following a PDCA (Plan-Do-Check-Act) based methodology. They are typically asked to report their problem solving approach in an "A3 format", which should contain a clear problem definition, key performance indicators, current and target state, the problem breakdown, a root cause analysis, countermeasures and an implementation plan, all in a sheet of paper of A3 size. In subsequent iterations, the teams are asked to implement their countermeasures and to improve the system to meet more aggressive performance targets. This experience usually lasts 2-4 weeks, with significant "off-line" brainstorming and design time spent by each of the teams. This type of activity is usually delivered to upper level undergraduate and graduate engineering students. This type of instructional delivery targets the upper three levels of cognitive domains in Bloom's taxonomy: analysis, synthesis, and evaluation.

Table 2: Instructional delivery by audience

Audience	Background	Instructional Level		
		Observational	Operational	Designer
Visitors	Variable	•		
Camps	K-12	•	•	
Business *	UG/G	•	•	
Engineering Technology *	UG/G	•	•	
Freshman Engineering	UG	•	•	
Upper Level Engineering	UG		•	•
Graduate Engineering	G		•	•

(* currently under development, UG – undergraduates, G - graduate)

4 EXPERIENCE ASSESSMENT AND IMPROVEMENT

In an effort to provide students with experiences that are both relevant and close to real world applications, the laboratory personnel is constantly developing, and adapting, instructional material based on the continuous feedback received from students, alumni and industry. Support from Toyota allows for faculty to learn their methods through internal training, focused group discussions (e.g. with their production control department) or through plant and supplier visits. They also provide parts and components for the assembly lines. A flexible and dynamic curricular environment has allowed for an iterative improvement process in which the courses continuously evolve. The overall effectiveness of the environment is measured with a composite indicator that contains five key performance indicators (KPI). The five KPIs are:

1. Number of students exposed to the environment (KPI_1)
2. Variety of populations served (KPI_2).
3. Number of lab experiences (KPI_3).
4. Depth of lab experiences (KPI_4)
5. Percentage of positive reviews in course evaluations (KPI_5)

- Number of students exposed to the environment (KPI_1): The first KPI measures the cumulative number of students who participate in a planned experience in the lab during a period, usually an academic year. This includes undergraduate and graduate classes as well as K-12 camps. Since one of the goals of the lab is to augment the exposure and visibility of the environment, as well as to expose young audiences to engineering applications, this KPI does not discriminate between credit-bearing and non credit-bearing experiences. It does not include, however, tours and visitors to the lab even if they participate in a small activity. The current baseline for this indicator, that is the number of students exposed to the environment during the 2008-2009 academic year, is 311 (up from 280 a year ago).
- Variety of populations served (KPI_2): This measures the diversity of the audiences who are exposed to the environment. For the purposes of this indicator, the audiences have been classified into six categories: pre-college, engineering freshman, engineering upper level

undergraduates, engineering graduate level, engineering advanced graduate, and other (non-engineering) programs. The current baseline for this indicator is 5 different populations (up from 3 the year before).

- The number of lab experiences (KPI_3): This indicator measures how many different experiences have been developed and are being offered through the environment, regardless of their instructional level. There are currently 24 distinct experiences (up from 11 a year ago) across all courses and activities in this environment.
- Depth of the lab experiences (KPI_4): This indicator measures the depth of each lab experience, as it relates to Bloom's taxonomy. Each experience is scored according to its targeted cognitive skills (i.e. knowledge/comprehension = 1, application = 2, analysis = 3, synthesis and evaluation = 4). The current state of the depth chart is shown in Table 3.
- Percentage of positive reviews in course evaluations (KPI_5): this KPI captures the feedback from students and other participants. Every camp activity uses one assessment instrument while credit-bearing courses use two assessments: the college of engineering course evaluations and one instrument specifically designed for this environment. Due to the courses being offered at different times during the academic year, the state of this indicator is constantly being updated. At the time of writing, the courses that had been assessed (2 out of 4) reported 83% positive reviews.

The improvement framework used to manage the environment is based on the Plan-Do-Check-Act (PDCA) process. Each one of the aforementioned indicators is revisited once a year and discussed among the instructors, lab staff and liaison personnel from Toyota. These meetings are used to set new goals and define the future (desired) state of each indicator. Typically, a gap is identified on a particular indicator and a plan (target, countermeasure, and implementation) subsequently defined. A past example of a current/future state exercise for the KPI_3 and KPI_4 for the lab environment is shown in Table 3. The future state reflected in Table 3 now represents the current state for academic year 2009-2010.

Table 3: Depth charts with current/future state of KPI_3 and KPI_4

	Current state						Future state					
	Pre College	**Eng. Fresh.**	**Eng. Upper**	**Other**	**Eng. graduate**	**Eng adv. grad.**	**Pre College**	**Eng. Fresh.**	**Eng. Upper**	**Other**	**Eng. Grad.**	**Eng. adv. grad.**
Value and waste	0	4	1	N/A	3	N/A	0	4	3	3	3	3
Kanbans	2	2	3	N/A	3	N/A	2	2	4	4	4	4
Takt – shojinka	0	3	2	N/A	3	N/A	0	3	4	4	4	4
Value stream map	0	1	1	N/A	4	N/A	0	1	2	4	4	4
Kaizen	2	2	0	N/A	4	N/A	2	2	2	4	4	4
Standard work	2	3	2	N/A	3	N/A	2	3	2	3	3	4
5S and visual mgmt	2	3	1	N/A	2	N/A	2	3	2	2	2	2
PDCA - Gemba	0	0	0	N/A	2	N/A	0	0	3	2	2	3
Line balance	2	3	4	N/A	4	N/A	2	3	4	4	4	4
Jidoka	0	1	1	N/A	2	N/A	0	1	2	2	2	4
Heijunka	0	1	1	N/A	2	N/A	0	1	2	2	2	4
Poka Yoke	0	1	1	N/A	1	N/A	0	1	2	1	1	1
Setup reduction	0	1	4	N/A	1	N/A	0	1	4	1	1	1
A3 Hoshin planning	0	0	0	N/A	2	N/A	0	0	2	2	2	3
Lean supply chain	0	0	0	N/A	2	N/A	0	0	0	1	1	3

(shaded) Indicates a hands-on experience in the lab.

As an example, an actual gap analysis from previous years on KPI_2 and KPI_4 is shown in Figure 3.

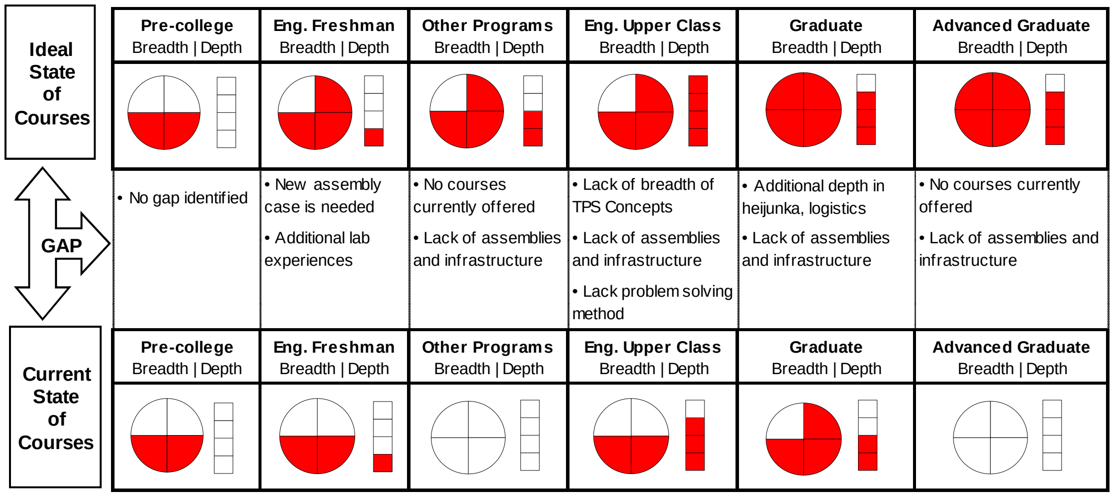

Figure 2: Gap analysis exercise

Each one of the KPIs is then normalized and the *Overall Lab Effectiveness* indicator is calculated by averaging all five normalized indicators:

$$Overall\ Lab\ Effectiveness = \frac{(KPI_1 + KPI_2 + KPI_3 + KPI_4 + KPI_5)}{5}$$

This indicator is revisited once a year when goals for the following academic period are established and documented in an A3 format. Since the inception of this performance assessment approach two years ago, significant improvements have been realized across all key performance indicators. However, and consistent with continuous improvement philosophies, the lab staff strives to make incremental improvements in every academic term.

The assessment of student learning for the IE courses is addressed via two evaluation instruments: the traditional course evaluations administered by the college (Table 4) and a questionnaire that focuses on the lab activities (Table 5). Because of the timing of the courses and the evolution of the lab evaluation process, the data presented below is not consistent across all courses. Also, the two evaluations may be administered at different times hence the discrepancies in the sample sizes. All evaluations are on a (1-5) scale, with 5 being the highest/best.

Table 4: Traditional course evaluations (ISE courses)

	Fundamentals of IE		**D/A Production Systems**		**Contemporary Production Systems**		**Production Systems Management**	
Academic Year / # of Students	***07-08 N=35***	***08-09 N=37***	***07-08 N=47***	***08-09 N=57***	***07-08 N=24***	***08-09 N=22***	***08-09 (W) N=23***	***08-09 (Sp) N=21***
Course objectives	4.30	4.06	4.10	4.08	4.84	4.90	4.82	4.62
How much did you learn?	4.48	3.87	4.40	4.26	4.92	5.00	4.92	4.80
Out of class assignments	4.63	4.51	4.34	4.56	4.84	5.00	4.91	4.95
Overall rating of course	4.04	3.90	4.11	4.10	4.71	4.82	4.65	4.61
Overall rating of instructor	4.19	4.11	4.38	4.11	4.79	4.86	4.78	4.86

Table 5: Lab experience student evaluation (ISE courses)

	Fundamentals of IE	D/A Production Systems		Contemporary Production Systems	Production Systems Management	
Academic Year / # of Students	***09-10 N=40***	***07-08 N=51***	***08-09 N=17***	***09-10 N=28***	***08-09 (W) N=24***	***08-09 (Sp) N=25***
"Which rating best describes the impact of the exercises you did in the TPS lab on your confidence and ability to apply the material taught in class?"	4.20	4.41	3.70	4.30	3.85	4.33
"Which rating best describes the VALUE of the exercises you did in the Toyota Production Systems Lab?"	4.26	4.49	3.94	4.40	4.20	4.67
"Which rating best describes the QUALITY of the exercises you did in the Toyota Production Systems Lab?"	4.23	4.42	4.12	4.30	3.80	4.00
"Which rating best describes the performance of the instructor in conducting the lab exercises?"	4.36	4.38	4.17	4.70	4.35	4.50

5 RELATIONSHIP WITH TOYOTA MOTOR ENGINEERING AND MANUFACTURING NORTH AMERICA

The cornerstone of the relationship between RIT and Toyota was initially built by students engaging with Toyota through RIT's cooperative education ("co-op") program. RIT has one of the oldest and largest cooperative education programs in the world, where all engineering students complete at least one year of co-op. The first RIT cooperative education student was hired by Toyota in 1998. Since then, a large number of RIT co-op students have been placed at Toyota. Because of the integrated structure of the engineering curriculum and cooperative education at RIT, students alternate academic terms with co-op work experiences, thus RIT students are placed at Toyota throughout the entire year. Today, in any given academic quarter, over a dozen RIT coop students are working at Toyota facilities throughout the country. Over the years, more than 75 RIT graduates have been hired by Toyota. Many of these participated in some of experiences under the environment described in this paper prior to their employment.

Additionally, the strong flow of students between RIT and Toyota has created opportunities for exchanges and interactions between the RIT faculty and Toyota personnel. This relationship continues to evolve, as both institutions strive to strengthen the experiential learning opportunities for students. This relationship has grown to include RIT faculty and staff visits to Toyota plants (Georgetown, Kentucky (TMMK), and Evansville, Indiana (TMMI), RIT faculty and staff training at Toyota Engineering and Manufacturing North America headquarters (TEMA), as well as frequent Toyota staff visits to RIT to review and support lab development. This relationship has also fostered plant visits to facilities in Toyota City (Tsutsumi, Japan) as well as discussions with Toyota managers, designers and engineers. Today, RIT is considered one of the top "suppliers" of engineers to Toyota Engineering and Manufacturing North America.

Finally, it should be noted that, although the Toyota Production System (TPS) is recognized as the leading production philosophy in the world (thus widely adopted), and in spite of the generous support given by the Toyota Engineering and Manufacturing North America to the lab, the instructors associated with the environment do not convey the TPS philosophy as the unique approach to production systems. Rather, the motivation lies in the fact that the skills taught and reinforced through the environment (i.e. problem solving, continuous improvement and systemic thinking) are invaluable commodity skills that can be applied in any production system, whether it is an automotive assembly plant, a hospital, a theme park or any other. Numerous feedback from industry and advisory boards continues to confirm the value of these skills.

6 CONCLUSIONS AND FUTURE DIRECTIONS

The approach presented in this paper has proven to be very successful and effective, as captured by student, alumni and industry feedback. Nonetheless, this learning environment and its supporting laboratory are constantly evolving. The ultimate goal of this effort is to become the leading provider of experiential education in the field of production systems engineering. With this goal in mind, future efforts will focus on as dissemination of existing material as well as development of new material.

Dissemination of the approach and the materials developed under this effort will be an area of focus in the upcoming years. It is anticipated that the Toyota Production Systems Lab will start produce teaching modules for academic dissemination at other institutions in the near future. These modules will be a “ready-for-delivery” package containing: instructional materials (lectures, presentations, assignments, etc.), infrastructure components (both for an in-classroom setup as well as for a larger facility), blue-prints for fabrication of supporting materials, directions for running a physical simulation, and suggestions for an assembly case. Also, new experiences are being developed in other areas of the supply chain (supplier conveyance, warehousing, etc.), waste identification, as well as in fundamental assembly skills.

Additional information on the laboratory, as well as additional pictures, can be obtained at the following URL: http://www.rit.edu/kgcoe/ise/facilities/ToyotaLab/ .

REFERENCES

[1] Wulff, W.A. (2004). An urgent need for change. The Bent of Tau Beta. Spring 2004, pp. 31-33.

[2] Dale, E. (1972). Audio-Visual Methods in Teaching. 3rd Edition. Holt, Rinehart, and Winston, Austin, Texas, p. 235.

[3] Felder, R.M., and R. Brent (1994). Cooperative learning in technical courses: Procedures, pitfalls, and payoffs. Report to the National Science Foundation (ERIC Doc. Reproduction Serv. No. ED 377038).

[4] Johnson, D.W., R.T. Johnson and K.A. Smith (1991) Active Learning: Cooperation in the College Classroom, 2nd Edition, Interaction Book Co., Edina, MN.

[5] Felder R.M., G.N. Felder, and E.J. Dietz (1988). A longitudinal study of engineering student performance and retention. V. Comparisons with traditionally taught students. Journal of Engineering Education. Vol. 87, No. 4, pp. 469-480.

[6] Lamancusa, J.S., J.E. Jorgensen and J.L. Zayas-Castro (1997) The learning factory: A new approach to integrating design and manufacturing into the engineering curriculum. Journal of Engineering Education. April. pp. 103-112.

[7] Bloom, B.S. and D.R. Krathwohl (1956) Taxonomy of Educational Objectives, Handbook 1, Cognitive Domain, Longmans, New York.