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Can lean principles be applied to course design in engineering education?

Daniela Pusca & Derek O. Northwood

University of Windsor
Windsor, Canada

ABSTRACT: Since lean principles have been successfully applied in industry with the benefits of improved quality and customer satisfaction, it would seem appropriate to learn from these experiences and apply them to academia. However, it must be recognised that the academic environment is very different from industry since the authors are not dealing with inanimate objects, but students, who represent both the product, a valuable employee for industry and the customer. This article will demonstrate how lean principles were employed to improve an engineering design course in terms of content, methods of instruction and assessment methods. Lean tools like value stream mapping, root cause analysis and kaizen were used to understand the problems, and identify solutions for course improvement.

Keywords: Engineering design course, lean principles; value stream mapping, kaizen, 5Why, quality function deployment

INTRODUCTION

The main goal in the process of teaching and learning is to produce satisfied customers - our students, and their future employers. With this in mind, the questions that need to be addressed are: are we teaching the right topics? How efficient is the process of teaching and learning? The reality is that industry is sometimes dissatisfied with the graduates' quality of knowledge in engineering design. If this is the case, a root-cause analysis will probably indicate an outdated course design in all three aspects: content design, delivery methods and assessment methods. The content of engineering design education should be continuously revised to accommodate the changes in technology and manufacturing methods, and also the changes regarding how students learn, to ensure that the graduates will possess the required knowledge, skills and capabilities. This is a collaborative endeavour including instructors, graduate assistants, laboratory technicians and the students [1]. The gap that exists between what design engineers do and what faculties teach must be continuously reduced, so that students will be able to compete in a demanding market.

In the same manner as industry made radical changes in the way it conducts business and understands customer needs with tools and techniques, such as lean manufacturing, six sigma, total quality management and concurrent engineering, faculty (academic staff) can learn from these experiences and apply them to academia. For example, lean principles have been applied in manufacturing with the benefits of improved quality, waste elimination, reduced costs and improved customer satisfaction. Applying lean principles to course design in engineering education is not about teaching lean principles, which is best done using an interdisciplinary problem-solving learning approach [2].

This article is a case study to demonstrate how the application of lean principles can assist in improving the quality of an engineering design course in all three aspects: course content, methods of instruction and assessment methods. For this purpose, engineering design education is considered as a process, and the instructors can apply value stream mapping, root cause analysis and kaizen to improve the quality of teaching and learning, and students' satisfaction.

LEAN PHILOSOPHY AND THE PROCESS OF EDUCATION

The academic environment is unique and different from industry in many respects, but the lessons learned from industry can help faculty to better understand their customers' needs, to select and organise course content and activities, and also to change their teaching methods, and to consider realistic assessments of student learning. Lean is a customer focused philosophy, a system that provides value to the customer [3]. The lean transformation is based on five principles, as shown in Figure 1.

Figure 1: Lean principles.

Value is defined by the customer, and it is the end result the customer is willing to pay for. The value stream is the chain of processes that consists of all actions (both value added and non-value added) currently required to create value. Processes are the key enabler to both effectiveness and efficiency. Value stream mapping (VSM) helps to quickly visualise the entire process, identifying bottlenecks or inefficiencies, and where the processes can be streamlined or improved. An example of VSM for a manufacturing system is shown in Figure 2. VSM increases understanding of value-adding and nonvalue-adding activities, as well as how inputs are transformed into outputs. Flow in the value stream is created by removing obstacles (e.g. clutter and bottlenecks). The intent is to improve the system, by converting it from a *push* to a *pull* system that is driven by customer demand. To achieve this, a kaizen blitz is employed. A kaizen blitz is defined by Laraia et al as:

> *…experienced practitioners sharing knowledge and skills in learn-by-doing …projects that change the way people do their work* [4].

It is a way for teams including engineers, technicians, operators, supervisors and *lean* specialists to carry out structured, but creative problem-solving and process improvement. The result will be a future VSM that will indicate potential improvements, such as reduced lead time, reduced inventory, reduced space utilisation and increased process efficiency.

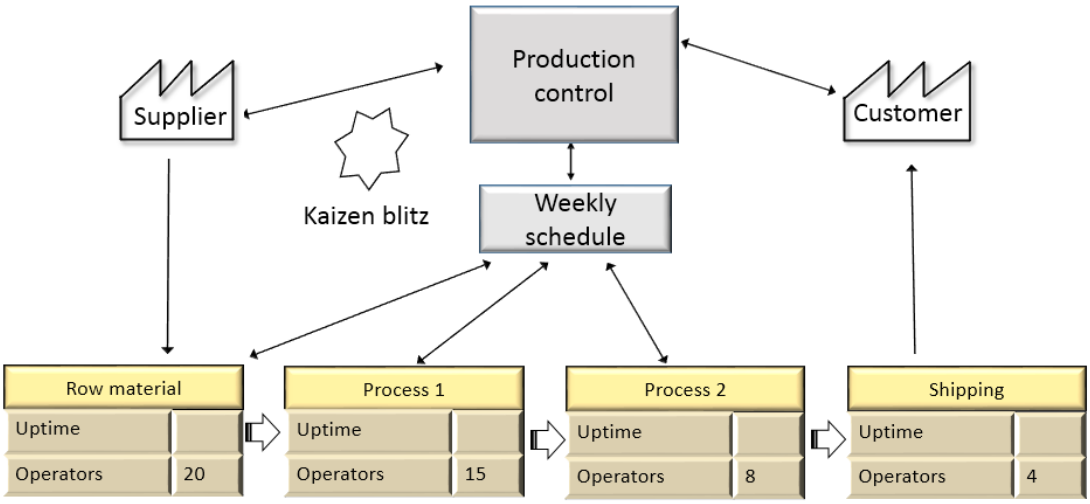

Figure 2: An example of value stream mapping for a manufacturing system.

Lean principles can also be applied to educational processes [5][6]. Flow is created by removing the potential obstacles in the process, and streamlining the content and delivery methods. A team including instructors, graduate assistants, laboratory technicians and the students in an engineering design class work to identify areas of improvement and indicate the corrective actions to be implemented. As a result, the course design will include more value-adding activities, and the content will be better organised, meanwhile reducing waste associated with the teaching and learning process - as will be further explained. The VSM for an engineering design course prior to application of lean principles is shown in Figure 3.

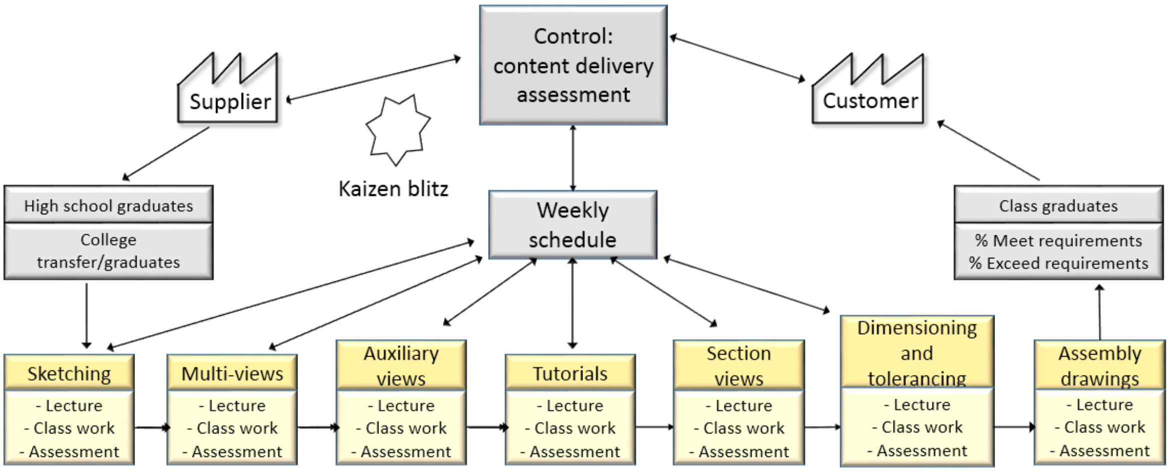

Figure 3: Value stream mapping for an engineering design course prior to application of lean principles.

The improvement process should be viewed as an iterative process, triggered not only by rapid changes in technology, but also by the need of changes regarding the content, methods of delivery, changes in the way students learn and, as a consequence, the role of the instructor and the student. The new model must centre on the active role of students, and the importance of acquisition, application and integration of knowledge, critical thinking and problem-solving skills, communication skills, creativity, ability and desire for lifelong learning. The ways faculty select and implement these features in their courses significantly impact what students learn and the quality of the end product. Just as engineers design products according to their perceptions of what customers need, faculty should make decisions regarding the course design based on their expectations of what students need to learn and perform.

COURSE DESIGN AND FUTURE VALUE STREAM MAPPING

As part of the continuous improvement process, a kaizen blitz project was initiated by the course instructor at the end of the semester. The team consisted of the instructor and the graduate assistants that were assigned to support the teaching and learning activities as shown in Figure 3.

To create a future VSM requires an understanding of the problem. In a similar manner as in manufacturing industry, an Ishikawa diagram, commonly known as the cause and effect diagram, is used as a tool to identify major causes of quality problems. Causes can be traced back to root causes with the 5Why's technique [4][7]. The causes are derived from brainstorming sessions and are categorised in groups, as shown in Figure 4.

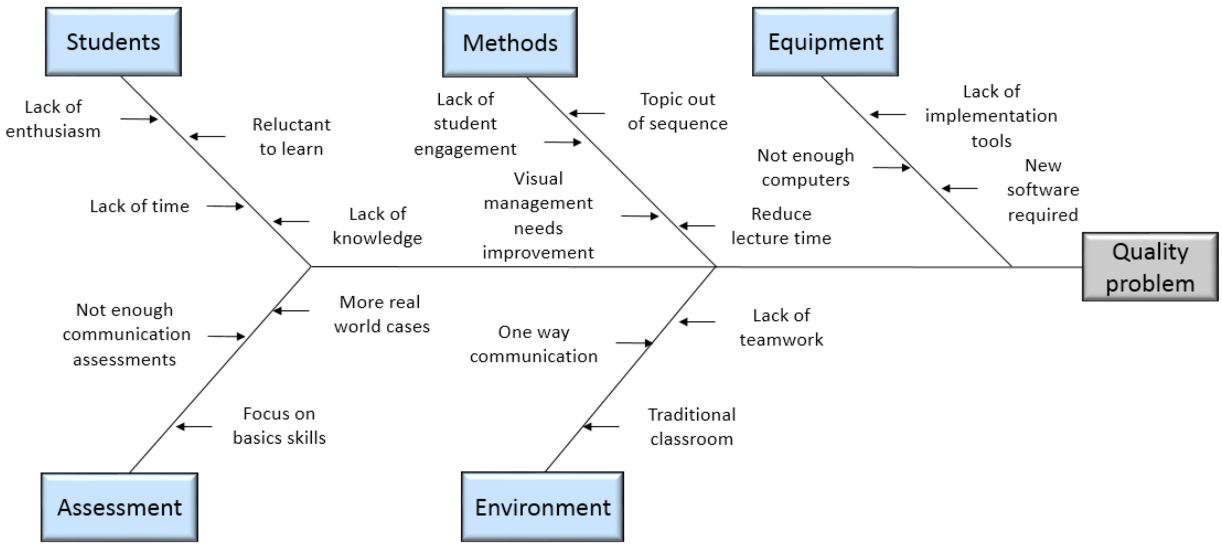

Figure 4: Cause-and-effect diagram.

Typical categories shown are similar with the 5 M's used in the manufacturing industry [7]:

- Machine (equipment);
- Method (process);
- Material (students' knowledge);
- Man power (physical work)/mind power (brain work): kaizen, suggestions;
- Measurement (assessment).

While not all causes are controllable, instructors can exercise substantial control over what to teach, how to teach and how to assess student learning. The future VSM is intended to contribute in solving practical problems, regarding methods of instruction and assessment in relation with learning outcomes. The new design will need to consider not only the demand for students' early exposure to the engineering profession, but also the development of their problem-solving and critical thinking skills. In this new approach, the main priority was student engagement through active learning [8][9].

The team used the initial VSM and the feedback collected from the students to rapidly develop and refine solutions to the identified problems, and to re-design an improved course. The non-value added activities were identified and eliminated, since time constraints often limit the number of topics and the activities that the faculty would like to include in a course. For example, it was decided to use the concept of flipped teaching [8][9]. In this new context, the lecture content and other related resources, such as indicated video tutorials and Internet sources are made available to the students before the class, using the university learning management system (LMS). From this *supermarket* [10] that is designed by the instructor, students *withdraw* the information they need on the topic of interest, as shown in Figure 5.

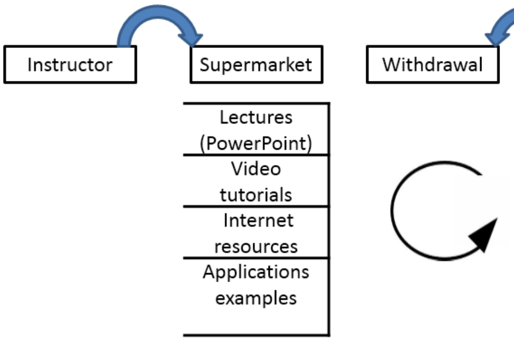

Figure 5: The *supermarket* content for the Engineering Design course.

By eliminating waste, instructors can free up many hours. Waste is any activity that adds cost, but provides no value to the customer. Toyota Motor Company defined seven most common forms of waste as (TIMWOOD) [7]:

1. **T**ransportation, e.g. moving materials from one work centre to another;
2. **I**nventory (more than needed);
3. **M**ovement (unnecessary movement);
4. **W**aiting, e.g. waiting for a machine to be repaired;
5. **O**verproduction, when producing items that are not ordered;
6. **O**ver- processing; for example, adding unnecessary functions and features to a product;
7. **D**efects.

Waste in education occurs when time and effort are expended, but the quality of final results is not as expected according to the key performance indicators: students do not gain enough new knowledge or skills. Some examples of waste are: excessive review of prerequisite course materials, unnecessary and redundant introductions, spoon-feeding, and waiting for unprepared students to catch up. The emphasis should be placed on designing value-adding activities.

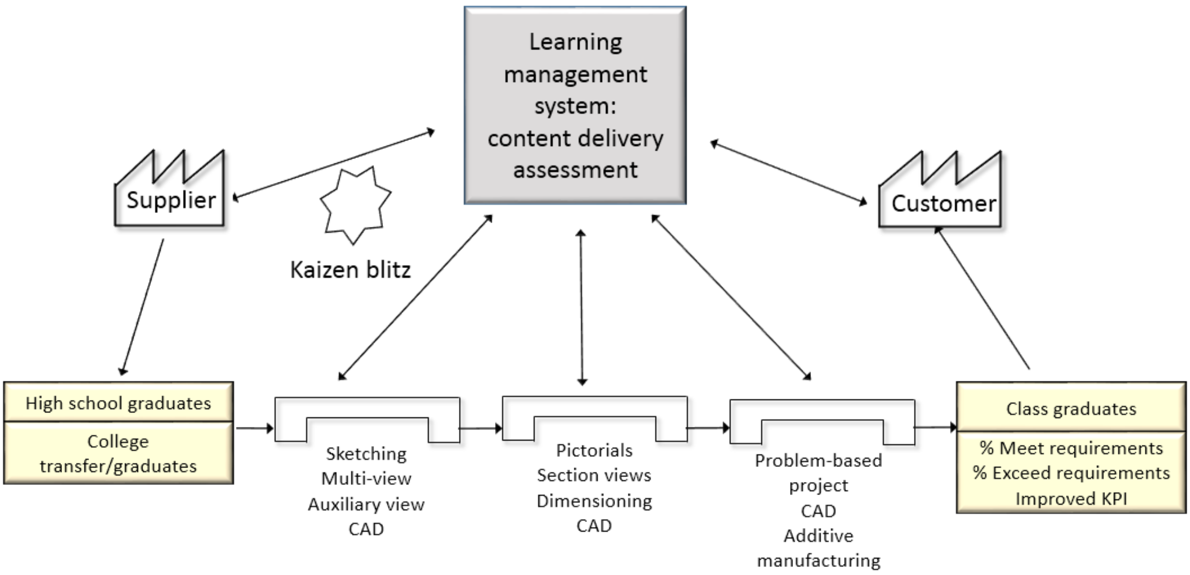

Figure 6: Future value stream mapping.

The future VSM resulting from the brainstorming sessions is shown in Figure 6. In the same manner as in manufacturing settings where improvement is achieved by grouping machines in cells to reduce cycle time, similar efficiencies can be gained by grouping topics in *families*. Within each *family*, material can be organised in a series of incremental steps, with each step building on the previous ones. This approach allows for concurrent teaching and learning.

The desired student engagement was achieved because the following changes were implemented:

- Flipped teaching, so that more time is available for practical examples and group work [8];
- New content design allows for more active learning and hands-on experiences [9];
- Classroom design facilitates group work to encourage and develop personal, teamwork and leadership skills [8].

COURSE CONTENT AND THE QUALITY FUNCTION DEPLOYMENT

Using quality function deployment (QFD), faculty can identify and select course activities as enablers to enhance students' knowledge and skills, and also to eliminate non value-adding activities [1][11][12]. A QFD matrix is created by first selecting a set of course specifications, including topics, assessment and the methods that would best enable students to acquire the required knowledge and skills. Finally, these specifications are ranked by how well they relate to the expectations, as shown in Table 1. The relationship matrix was developed between five identified groups for graduate attributes and nine enablers (course activities in Table 1).

Some enablers show a strong relationship with the graduate attributes; for example, problem-based project shows a very strong relationship with creativity. Lectures do not show any relationship with problem-solving skills. CAD applications show a strong relationship with integration of knowledge and a moderate relationship with teamwork. The current course design needs to be further improved to ensure students' satisfaction and success in areas, such as problem-solving skills, teamwork and creativity, as identified in Table 1.

Table 1: Quality function deployment for course design.

Course activities / Students' graduate attributes (knowledge and skills)	Lectures	Class applications	Written assignments	Problem-based projects	CAD applications	Additive manufacturing	Progress tests	Class presentations	Feedback	Course design ranking* *(Likert scale 1-5)		
										Improved design	Initial design	Areas of improvement
Integration of knowledge	▶	●	⌗	●	●	●	●	●	●	5	3	
Problem-solving skills		●		●			⌗	▶	●	4	3	x
Communication skills		⌗	●	●	●	⌗	⌗	●	●	5	2	
Teamwork		⌗		●	⌗	⌗		●		4	2	x
Creativity		⌗	⌗	●				⌗		4	3	x

● Strong relationship; ⌗ Moderate relationship; ▶ Weak relationship.

IMPLEMENTATION ISSUES AND CONCLUSIONS

As with any new approach, there will be implementation problems associated with the proposed changes. These must be overcome, and the faculty should not be reluctant in trying new approaches to teaching and learning. This article demonstrates that the lean principles used in industry can be implemented not only to help the faculty to better understand students' needs, but also to solve issues concerning course design, delivery and assessment methods.

At the heart of *lean* is *continuous improvement*. *Lean* is a *continuous improvement process* toolkit that can be used in both the improvement efforts and in the analysis of any resulting improvements [13]. The other important aspect of *lean*, at least in the management sense, is *respect for people* [14] and *lean must do not harm* [15]. The application of lean principles should result in a *win-win* situation for both the students and the faculty. *The Toyota Way* [7] of lean manufacturing was inspired by the principles of Frederick Taylor [16], the original efficiency expert, who put forward the idea that there is one best way to do every task. In terms of management, this meant that managers must ensure that no worker should deviate from this *system*. *Taylorism* requires the *system* to be first, not *man* [17]. Experience with *medical Taylorism*, which *…began with good intentions, to improve patients' safety and care* [17], has shown that its blanket application is not appropriate. To quote Hartzband and Groopman:

…We need to recognize where efficiency and standardization efforts are appropriate and where they are not. Good medical care takes time, and there is no one best way to treat many disorders. When it comes to medicine, Taylor was wrong: man *must be the first, not the system* [17].

The same argument can be made for engineering education. Any application of lean principles should be *student centred*. Any change in course delivery should be *student centred* not *faculty centred* [5]. Any *value added* should not just be in terms of test scores. As eloquently argued by Johnson:

…In lean schools, value is specified as test scores. In lean schools, teachers are managers who supervise the flow of value through their students, whose job is to produce test scores as efficiently as possible. Unless they contribute to the production or flow of value, abstract values like emotional and social development, safety, comfort, and joy are all considered waste [18].

In conclusion, a certain degree of flexibility must be considered in all aspects of the teaching and learning process, and the lean principles and tools mentioned in this article should be selected and applied considering the human aspect of the relationship between all involved; namely: students, teaching assistants and faculty.

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BIOGRAPHIES

Daniela Pusca, PhD, is a Learning Specialist in Engineering Education in the Department of Mechanical, Automotive and Materials Engineering (MAME) at the University of Windsor, Windsor, Ontario, Canada, and is teaching engineering design courses. She has earned her doctorate in Technological Equipment Design from Cluj Napoca University in Cluj Napoca, Romania, and a BSc in Mechanical Engineering from *Lucian Blaga* University of Sibiu (Romania). She is a licensed Professional Engineer in Ontario (PEng). Her educational background is mechanical engineering and engineering education. From 1986 until 1999, she was a lecturer at *Lucian Blaga* University of Sibiu, where she was teaching machine design courses and was involved in research projects on a wide range of topics. In 2000, she became part of the MAME Department at the University of Windsor. She has written research papers on innovative educational practices. She has published over 50 papers in refereed international journals and conference proceedings in the field of engineering design, engineering technology and engineering education.

Professor Derek O. Northwood is a Distinguished University Professor and Professor of Engineering Materials in the Department of Mechanical, Automotive and Materials Engineering at the University of Windsor, Windsor, Ontario, Canada. Professor Northwood has earned his doctorate in Crystallography from the University of Surrey (UK) and a BSc (Eng) in Engineering Metallurgy from the Imperial College of the University of London (England). He is a licensed Professional Engineer in Ontario (PEng) and is a Chartered Professional Engineer (CP Eng; NER) in Australia. In the 40+ years as an academic, Professor Northwood has held various administrative positions including Department Head, Dean, Associate Dean of Research, Director of the Office of Research Services, President of the Industrial Research Institute and Research Leadership Chair, both at the University of Windsor and Ryerson University, Toronto, Canada. Professor Northwood has taught, researched and facilitated joint research and educational programmes at 14 universities worldwide, including the UK, Australia, Taiwan, China, Singapore, Canada and the USA. He has published over 650 papers in refereed international journals and conference proceedings on a wide range of topics including materials and their applications, and engineering and technology education. He has been elected Fellow of four international professional societies in Australia, the UK and the USA, namely: Fellow of the Institution of Engineers Australia (FIEAust); Fellow of the World Institute of Engineering and Technology Education (FWIETE); Fellow of the Institute of Materials, Minerals and Mining (FIMMM); and Fellow of ASM International (FASM).