

Enhancing Engineering Education Using Thematic Case-Based Learning*

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This paper describes a learning architecture for developing a series of case-based studies that are linked by a common thematic basis. The proposed architecture takes into account 'four forces' that influence the development of the thematic cases: namely, Bloom's learning levels, industry cases to add realism to the engineering curriculum, the plug and learn approach, and incorporation of business and management issues in the context of engineering problem-solving. We developed a set of three industry case studies using the lean manufacturing/continuous improvement theme and cover various topics such as total productive maintenance (TPM), reduction of energy waste, process mapping, quality improvement, and various business and managerial issues. This series of cases is intended to immerse students in situations that they could expect to encounter while working in an industrial setting by emphasizing the usage of engineering and business tools and methodologies in the context of a real-life project. We believe that our approach, of developing theme-oriented case studies as opposed to isolated case studies, will help the students to internalize learning. Students are often taught various tools and techniques, but they may not necessarily see if and how these complement each other. We believe that presenting the tools and techniques around a thematic basis will help the students to understand 'how, when, and which' tools and techniques need to be applied in a given context. We also conducted preliminary experiments to ascertain the value of the case studies to the students.

INTRODUCTION

ENGINEERING IS AN applied field in which problem-solving techniques play an important role and hands-on experience is a desirable skill. In the engineering curriculum, there still exists a gap between theory and practice—a gap that can be partially filled through deployment of thematic case studies in the classroom. An engineering case study is an account of an engineering activity or event, or a problem that has been actually encountered by professional engineers in the workplace [1, 2]. Herreid [3] discussed the use of case studies in science education. Traditionally, the case study method of learning is widely used in the business curriculum. For example, the Harvard Business Publishing website (www.hbsp.harvard.edu) has a pay-per-use case repository site containing over 5,000 cases, with topics ranging from finance, to general management, entrepreneurship, negotiations, and marketing, among others. In contrast, engineering education primarily focuses on imparting discipline-specific problem-solving skills to the students. The use of case-study-based learning in the engineering field is quite limited. Although case studies have been used in the engineering curriculum since the 1970s, there are only a few that are readily available to the instructors that can be used in the classroom. Chau [4] described a problem-based learning (PBL)

approach for teaching undergraduate civil engineering students using real-life civil infrastructure problems. The potential benefits of case studies are consistent with an educational approach that emphasizes the need to support a variety of learning styles. Various student learning styles have been discussed by Felder [5].

Thematic-based case studies can be used by instructors as a complementary method for addressing non-traditional learning styles. The thematic basis and some amount of open-endedness in the cases can help students to grasp knowledge in a holistic fashion in an active learning educational setting. Speich *et al.* [6] have described how the Experiential Engineering Library provides hands-on learning experience beyond the traditional mechanical engineering curriculum in the areas of micro-electromechanical systems (MEMS), bioengineering, and nanotechnology at the Virginia Commonwealth University. There is a need to teach students 'how' various tools and techniques can possibly relate to one another. Quite often, students are taught various tools and techniques and they may not necessarily see if and how these tools and techniques complement each other. Ellis *et al.* [7] described the use of concept maps for learning in the sophomore level Continuum Mechanics course. Students in this course used concept maps to see the relationships among concepts, to solve problems, and to support their project work. We believe that presenting the tools and techniques around a thematic basis will help the students to understand 'how, when, and

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which' tools and techniques need to be applied in a given context.

In this paper, we describe our approach to addressing some of the points mentioned above. Specifically, we present a theme-based, case-based learning framework to increase the educational value of case studies. The rest of the paper is organized as follows: the next section describes the architecture of our proposed work, the section that follows describes the application of the proposed framework to developing a series of case studies around the lean manufacturing/continuous improvement theme, and the final section presents our conclusions and areas of future work.

CASE-BASED LEARNING ARCHITECTURE

Figure 1 depicts the proposed case-based learning architecture. This approach relies on the development of a series of cases (each focusing on a specific topic) that are linked by a common thematic basis. There are 'four forces' that influence the development of these thematic cases: namely, Bloom's learning levels, industry cases that add realism to the engineering curriculum, the plug and learn approach, and incorporation of business and management issues in the context of engineering problem-solving.

The desired output is internalization of learning by students (i.e. achieving a deep connection between concepts and practice). The framework proposed in this study relies heavily on the thematic basis, which is essentially selected by the case developers. Once the thematic basis is selected, the developers can then proceed to specify the type of cases that will be sought from the industry. This framework also provides the flexibility to add new types of cases (that can be linked to the thematic basis) at a future point in time. The new cases that may be added later are indicated by the dotted circle in Fig. 1. We describe the thematic basis concept and the 'four' forces in the following sections.

Thematic basis

Traditionally, case studies have been used to illustrate real-life situations or problems, but the major drawback of many case studies is the lack of interconnectedness between them. In a sense, each case is developed in an isolated way, which often prevents students from achieving higher levels of learning. As mentioned before, in this paper we attempt to develop a series of case studies that are linked by a common thematic basis.

We use a concept map for defining the issues around a thematic basis. A concept map works like a spider-web, where each node on the web is a piece of knowledge or information [8]. Each node

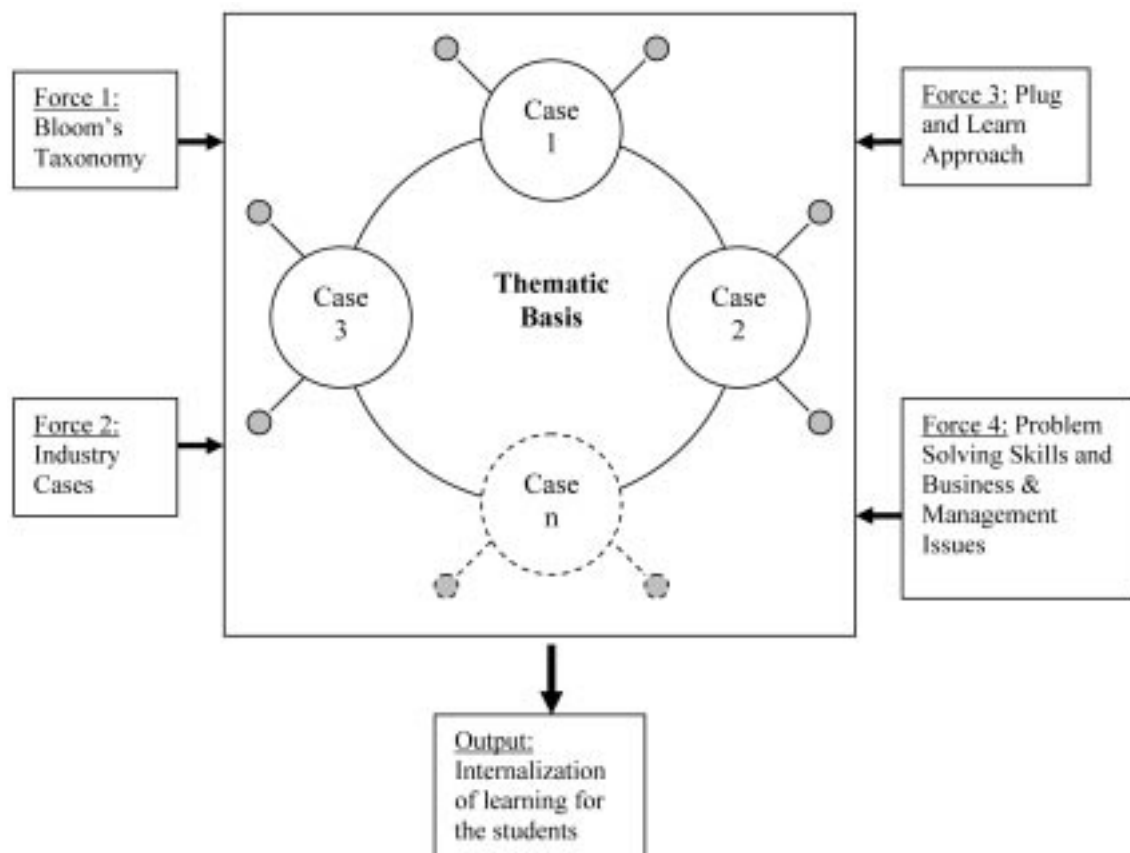


Fig. 1. Case-based learning architecture.

is connected to all the other nodes by direct paths or indirect paths through nearby nodes. The concept map shows how the various pieces of information relate to one another and to the thematic basis. Using this concept map, the case developers can then approach industry to solicit cases and define what information will be covered in various cases. The concept map will be discussed below.

Bloom's taxonomy

In 1956, Benjamin Bloom intended to capture the intellectual behavior that is most important in the learning process. The levels of learning identified on the cognitive domain are listed below [9]:

- Knowledge: Recognition or recall of information by students.
- Comprehension: Understanding the material without necessarily relating it to other material.
- Application: The ability to use previously learned material in new situations.
- Analysis: Decomposition of the material into its constituent parts and studying the relationship between the constituent parts and the way they are configured.
- Synthesis: The creative behavior of putting together a number of parts to form a whole, just like a Lego game.
- Evaluation: Making judgments about the value of ideas, work, methods, and solutions.

In this study, we use Bloom's learning taxonomy to develop various modules relating to each of the cases. Each of the modules is designed to cater to one or more of the six learning levels described above. The application of Bloom's taxonomy will be presented below.

Industry cases

The decision about the types of cases to be solicited from the industry is made based on the concept map of the thematic area topics. Typically, most companies have case histories that indicate

the nature of the problem and how the problem was solved. The solution to the problem may not necessarily be the best one. We recommend that the case developers focus on getting the case histories from the company and then, if necessary, attempt to bring other tools and methodologies to solve the problem. The case history, along with the set of other tools and models, represents the case study (Fig. 2).

It should be noted that the case study material is deconstructed into several small modules and mapped against Bloom's taxonomy (described below). The modules of a case study provide the flexibility to 'plug and learn' in the engineering curriculum.

Plug and learn approach

As mentioned above, the various modules of the case study provide the flexibility to 'plug and learn'. This would mean that one or more modules of the case or cases can be used in some of the existing courses of the engineering curriculum, at the discretion of the course instructor. As mentioned in the first section, many universities are under pressure to reduce the credit hours required for graduation so that most students can graduate in a four-year time frame. At the same time, there is a need to accommodate new teaching material in the classroom. In some instances, we anticipate that the gridlock between introducing new teaching material and time constraints can be solved by designing modules that can be plugged into related existing courses.

The implementation of the 'plug and learn' approach entails expansion of an apparently narrow-focused company case history into a case study by adding 'learning modules' that are related to the case history and that have been identified in the concept map. The aim is to introduce students to new methodologies and techniques that are applicable to the case study, but not necessarily developed within the company case story.

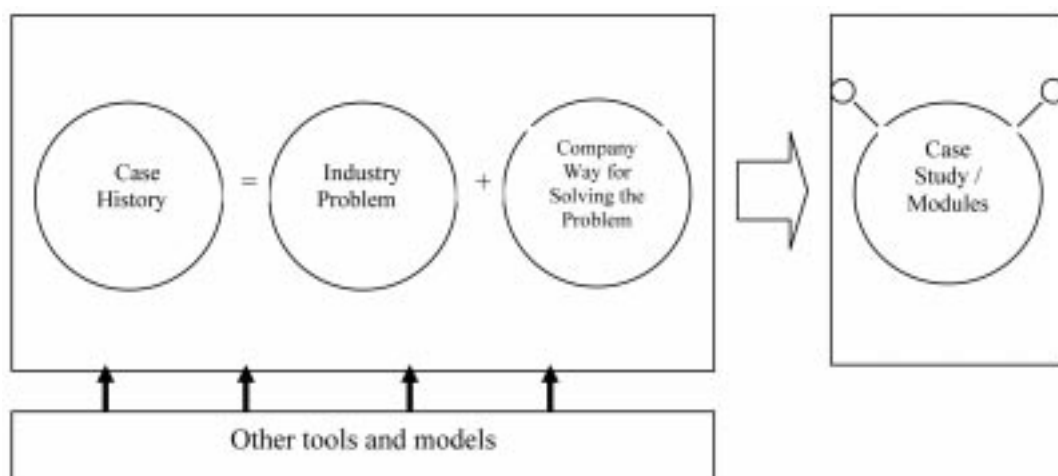


Fig. 2. Approach for developing industry cases.

Problem-solving skills and business and management issues

The engineering case studies developed in this paper seek to integrate numerical problem-solving skills in the context of an actual business project. It is our hope that the students not only experience the 'plug and solve' number-crunching aspects of engineering tools, but also gain a deeper understanding of the engineering tools in the context of a real-life project.

The current reality is that industry perceives a shortfall in the way graduating engineers are prepared for entering the workforce. An industry study by the Society of Manufacturing Engineers (SME) [10] revealed that the vast majority of managers believed that freshly graduated engineers were not well prepared for 'real world engineering applications'. Gaps in competencies were identified in areas including communication skills and teamwork, application of scientific first principles to specific real-life engineering problems, deep and detailed understanding of the principles, tools and processes of modern manufacturing, appreciation for business and economic factors in engineering, and skills for managing change and continuous learning. While this study was specific to the discipline of manufacturing engineering, it can be argued that a similar critique is applicable to other fields of engineering [11]. Including business and management issues within the case studies is key for connecting students with some of the real-life

non-engineering issues surrounding an engineering project. These case studies are designed to train students to link the theories to solving practical problems that may occur in real life [12].

LEARNING FRAMEWORK IMPLEMENTATION

This section focuses on the development of a series of case studies using the architecture presented in Fig. 1. It is to be noted that, even though we discuss only three cases relevant to the 'lean manufacturing/continuous improvement' theme, more cases are needed to fully cover this thematic area. We do not claim that the three case studies presented here provide a comprehensive view of the lean manufacturing theme. They were selected according to the perceived gaps at our university—especially how various continuous improvement tools and methodologies may fit into the lean manufacturing philosophy. For instance, we did not attempt to include topics such as 5S, pull system, value stream mapping, etc., since these topics are already covered in a fully fledged lean manufacturing course at our university.

Thematic concept map

We chose the thematic area to be the integration of various continuous improvement tools and

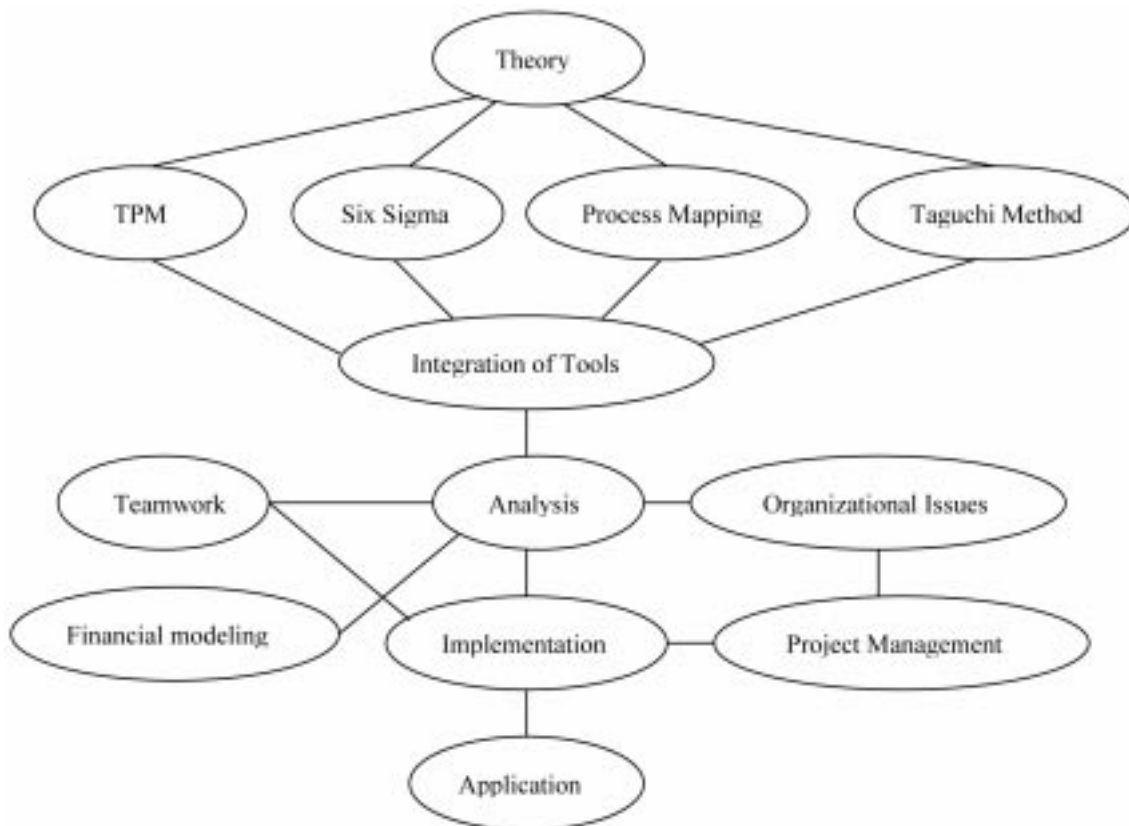


Fig. 3. Concept map for the thematic basis.

methodologies in the context of lean manufacturing for the development of a series of cases. For this thematic basis, we developed a concept map (shown in Fig. 3) to delineate the important issues and topics that we wanted to cover in the case studies.

Soliciting case histories from companies

We visited three companies in Colombia (South America) that agreed to give the information required for case development. Several interviews with people that participated on the projects (including top management, middle managers, field engineers and operators) were conducted. The interviews, along with the company project reports, were used to develop the case history.

Developing case studies and learning modules

Using the company case histories, we proceeded to develop case studies by adding other related learning material to the case history. The three case studies we developed are:

1. Process capability improvement at a laundry detergent manufacturing plant.
2. Manufacturing cost reduction through the efficient use of energy at a citric acid plant.
3. Total productive maintenance (TPM) study at a notebook production facility.

The general objectives of this series of case studies include the following:

- To develop a modular 'plug and learn' exercise that can be used in a variety of manufacturing and quality-related courses or to educate industry professionals.
- To provide the student with opportunities to discuss and learn various soft issues, such as managerial decision-making, basic financial model development, organizational structure, project management, and people skills.
- To expose students to the company work culture and related information from various industries as a case study by-product [13].
- To provide the student with opportunities to internalize learning.

We briefly describe here the three cases that were developed under the lean manufacturing/continuous improvement theme.

Case 1: Process capability improvement at a laundry detergent manufacturing plant. This case describes a project involving the improvement of process capability indicators at a powder laundry detergent plant. It narrates the case of a multinational company involved in standardizing quality procedures at all its subsidiaries worldwide. The standard set of policies for the company covered various issues, such as technology transfer, process capability, documentation, change control, utilities, recall of products, and process control. The subsidiaries received the standard set of policies and it was the responsibility of the Vice-President-

Operations for each subsidiary to implement these policies within approximately one year. Teams of international auditors (employees of the parent company at different subsidiaries and experts in the relevant fields) were formed to audit the implementation of the quality standards. This case describes the work that was pursued in one of the subsidiaries for implementing process capability standards. The process capability standards of the company state that 'each manufacturing facility has to have appropriate statistical measures to ensure that the processes are capable of consistently producing products that conform to all specifications and then implement procedures to monitor and control variation during ongoing manufacturing.' The case describes in detail the work done by the company to identify key variables of manufacturing variability within the laundry detergent process and how process capability standards were achieved.

For case study 1, we developed the following four modules:

Module 1: General discussion about the project to help students understand how the project was conducted, what are the lessons learned and what could have been done differently.

Module 2: The objective of this module is to make students understand the meaning of process capability indicators (C_p and C_{pk}), and gain proficiency in the calculation of those indices.

Module 3: This module aims to expose students to six sigma concepts through the application of the Define, Measure, Analyze, Improve, Control (DMAIC) model to the project described in the narrative.

Module 4: This module introduces the application of Taguchi concepts for quality improvement to the project described in the case study.

It is to be noted that case study 1 describes a project regarding the implementation of a quality standard (process capability) and the work done by a group of engineers to eliminate sources of variability within the process. This project work was done at the company using common sense, empirical approaches, and good process knowledge. We thought that other tools such as the six sigma and Taguchi methods are valid tools as well, hence it was decided to include those tools as part of learning modules 3 and 4, respectively. Some of the details of the case study narrative and the teaching notes for the above-mentioned four modules are depicted in Table 1.

Case 2: Manufacturing cost reduction through the efficient use of energy at a citric acid plant. This case describes how a company facing a sharp decrease in the market price of its prime product (citric acid), due to global competition, used an energy conservation program to substantially reduce its manufacturing costs. The entrance of overseas companies into the citric acid business

Table 1. Topics covered by the case-based exercise 1

Case study	Teaching notes
<ul style="list-style-type: none"> • Company's background • Implementation of quality policies among subsidiaries worldwide • Description of the manufacturing process • Steps done to implement the process capability standard • Sources of process variability found in the detergent's spray-drying process • Actions taken to reduce or eliminate sources of variability • Conclusions and results 	<ul style="list-style-type: none"> • Module 1. Base Case Review <ul style="list-style-type: none"> – Approach taken to execute the project – Importance and minimum requirements for a quality system – Organizational issues – Importance of soft & technical skills – Process attributes selection – Process control measures • Module 2. Process Capability <ul style="list-style-type: none"> – Process capability calculations – Evaluate the results obtained • Module 3. Six Sigma <ul style="list-style-type: none"> – Formulation of the project using the DMAIC model – Distinguish the characters' plot in the case in terms of the six sigma players. • Module 4. Taguchi Method <ul style="list-style-type: none"> – Quality loss function (QLF) calculation – Relationship between QLF and Cp – Justify potential investment in process capability improvement – Construct a P-diagram

converted this product from a chemical specialty into a commodity product. The case describes how the company, initially with the help of an outside consultant and later through a corporate program, substantially decreased its electricity and thermal energy costs over a period of four years. This accounted for a reduction of more than 10% in its manufacturing costs. The case illustrates the approach used by the company to reduce energy usage. The project describes the use of energy audits and process mapping tools for spotting savings opportunities.

For case study 2, we developed three modules:

Module 1: General discussion about the managerial approaches required to execute the project, and the relationship between energy conservation and lean manufacturing.

Module 2: Integration of cash flow analysis and financial performance measures as key aspects of project design and evaluation.

Module 3: Introduction to the basic formulae for estimating energy savings, using examples and exercises from the actual energy-saving policies implemented by the company.

Table 2 shows a detailed summary of this case study.

Case 3: Total productive maintenance (TPM) study at a notebook production facility. This case reports on the implementation of TPM at a school notebook production facility. The case starts by introducing the concern of upper management about the low efficiency of their production lines. After some years of hesitation, the company finally committed itself to TPM implementation and motivated its plant staff and operators toward the same goal. The work done and the results obtained by the company are described in a step-wise procedure. The company has been so successful in its TPM efforts that it won the 'Excellence in

TPM Award', awarded by the Japan Institute of Plant Maintenance (JIPM). TPM has been incorporated as a tool for achieving the company's mid-term strategic objectives. The case ends with a note about the company's efforts to push TPM to the next level and its pursuit of an integrative continuous improvement game plan.

For case study 3, we developed two modules:

Module 1: Managerial discussion points are elaborated regarding the strengths and weaknesses of the TPM efforts undertaken by the company. Students are asked to identify strategies for the current issues faced by the company.

Module 2: The objective of this module is to introduce students to line and equipment efficiency productivity metrics.

Table 2 also shows a detailed summary of this case.

We used a master design chart (MDC) to 'map' the contents of the case modules to the different learning levels, as shown in Fig. 4. The MDC represents mapping of the learning contents and the learning outcomes in a two-dimensional matrix [14, 15]. The number contained in each cell refers to the relative emphasis that the case modules place on that particular content (3 for heavy emphasis, 2 for major emphasis, and 1 for minor emphasis).

Video footage is very useful for immersing students in the case and is divided into three sections: a brief description of the production process; interviews with the company personnel who participated in the project; and a description of other related projects executed by the company. The thoughts expressed by the company personnel in the video, along with the video images, can also be used for case discussion or for bringing up other case issues. A sample video screenshot of the citric acid production process is depicted in Fig. 6.

Table 2. Topics covered by case studies 2 and 3

Case study	Teaching notes
Case 2. Manufacturing cost reduction through the efficient use of energy at a citric acid plant <ul style="list-style-type: none"> • Company's background. • Citric acid market situation in late 90s • Methodology provided by an external consultant for the implementation of the energy conservation program • Methodology provided by an international energy team conformed by the parent company • Description of most important projects undertaken to increase energy efficiency • Results 	Module 1. Base Case Review <ul style="list-style-type: none"> • Steps taken by the company to implement an energy conservation program • Importance of an efficient program for measuring and collecting information • Importance of energy audits • Arguments for obtaining project approval • Key aspects of an energy conservation program • Energy-saving techniques • Relationship between lean manufacturing and the energy conservation program Module 2. Financial Analysis <ul style="list-style-type: none"> • Calculation of before and after tax cash flows for a project • Calculation of Net Present Value, Internal Rate of Return and payback time for a project Module 3. Energy Savings <ul style="list-style-type: none"> • Calculation of project savings through basic heat exchange formulas • Calculation of different energy-type savings
Case 3. Total productive maintenance (TPM) study at a notebook production facility <ul style="list-style-type: none"> • Company's background • Need for TPM within the company • 12 steps of TPM implementation • Main activities done to deploy TPM at the shop floor level • Results achieved under the TPM program • TPM awards 	Module 1. Base Case Review <ul style="list-style-type: none"> • Importance of TPM • Integration of TPM, lean manufacturing and six sigma • Positive and negative aspects of TPM implementation at this company • Define a strategy to deploy TPM through the holding company • Suggestions for integrating three manufacturing sites and still retaining the TPM excellence Module 2. Overall Equipment Efficiency (OEE) <ul style="list-style-type: none"> • OEE/asset effectiveness calculations • Interpretation of results • Purchase of a production line • Calculation of savings due to OEE & asset effectiveness improvement

It is very important at this stage to design the module contents and module questions according to what was mapped on the MDC. The case developers have to write appropriate questions for the different levels of learning. Table 3 shows how some of the questions prepared for the laundry detergent case fit into each of the learning levels.

Evaluation

Case study 1, the process capability study, was discussed in the Engineering Management graduate course, EMGT 472: Lean Manufacturing Systems, during the winter and fall 2003 semesters. This case study was covered in one week. The authors then evaluated the effectiveness of the case study for classroom use by asking the students to complete a questionnaire (presented in Table 4). A scale of 1–5 (1 = Poor and 5 = Excellent) was used to measure the student responses for each of the ten questions. Hypothesis testing (test concerning means) using the mean response μ for each question (with its known variance) versus a specified value μ_0 of 3.5 was performed at a 0.05 significance level. The authors assumed that, if the mean response for a given question was greater

than 3.5, then that particular task was accomplished satisfactorily.

The survey was given to 23 students (15 from the winter 2003 session and 8 from the fall 2003 session). Out of these 23 students, 11 were on-campus students with limited or no company experience and 12 were students who had substantial industry experience. The 23 students were graduate students from the Manufacturing Engineering, Engineering Management, Mechanical Engineering, and Systems Engineering programs.

T-tests were run to test the hypothesis whether the means were significantly greater than 3.5 at a level of 0.05, suggesting that the students perceived that the case-based exercise was effective. The results are presented in Table 4.

A second t-test (paired t-test) was performed to evaluate if the mean response of each question was consistent between the students enrolled in the two sessions (fall 2003 and winter 2003). We wanted to determine if there was a statistical difference between the average responses given by the students of the two sessions at a 95% confidence level. The interval found was $[-0.13, 0.25]$. We plan to conduct an evaluation of the other two cases in the near future.

			Knowledge			Comprehension			Application		Analysis		Synthesis		Evaluation				
Cases	Modules	Content	Know	Describe	Identify	Discuss	Summarize	Differentiate	Interpret	Calculate	Classify	Analyze	Explain	Arrange	Formulate	Integrate	Asses	Select	Recommend
Case 1. Process Capability Improvement in a Laundry-detergent plant	Case issues		3	1	1	3	1	2	-	-	-	-	-	-	-	-	-	-	-
	Process Capability	Cp / Cpk / Calculations	3	-	-	3	-	3	2	2	-	3	3	-	-	-	3	-	-
	Six Sigma	Six Sigma overview	3	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-
		DMAIC Model	3	1	-	-	-	2	2	-	-	2	-	-	-	3	3	-	-
		Six Sigma players	3	1	-	-	-	2	2	-	2	-	-	-	-	-	-	-	-
	Taguchi Method	Taguchi Method overview	3	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-
		Quality loss function / Calculations	3	-	-	-	-	-	2	-	-	3	3	-	-	-	3	-	3
Parameter diagram		3	1	-	-	-	2	2	-	3	2	-	-	-	3	3	-	-	
Case 2. Cost reduction through the efficient use of energy	Case issues		3	1	1	3	1	2	2	-	-	-	-	-	-	-	3	-	3
	Energy issues	Heat transfer basics / calculations	3	-	-	3	-	2	-	2	-	3	3	-	-	-	3	-	3
		Energy Savings calculations	3	-	-	-	-	2	2	2	-	3	3	-	-	-	-	-	-
	Industrial equipment	Boilers	3	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-
		Cooling Towers	3	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-
		Heat exchangers	3	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-
	Evaluation of projects	Net present value / Calculations	3	-	-	-	-	2	2	2	-	2	2	-	-	3	3	1	3
		Payback time / Calculations	3	-	-	-	-	2	2	2	-	2	2	-	-	3	3	1	3
Internal rate of return / Calculations		3	-	-	-	-	2	2	2	-	2	2	-	-	3	3	1	3	
Case 3. How TPM works in a production line	Case issues		3	1	1	3	1	-	-	-	-	-	-	-	-	-	-	-	-
	TPM	TPM overview	3	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-
		Overall equipment efficiency / Calculations	3	-	2	2	-	2	-	2	-	3	3	-	-	3	3	-	-
		Physical-Mechanical analysis	3	-	2	-	-	2	-	-	-	3	-	-	-	3	3	-	-

Fig. 4. Mapping contents of the case modules.

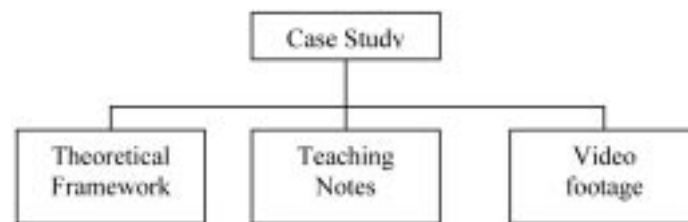


Fig. 5. Supplementary case material.

DISCUSSION OF RESULTS

Case study 1 rated very well on questions 1–4, 6, and 9–10. Before its introduction, most of the students were not very familiar with concepts such as six sigma and the Taguchi method. After going through the case study, they reported that the tools covered in the case study were useful and felt motivated to learn such concepts.

Only students with previous work experience were asked to answer question 7. The rating given by those students to this question was the lowest for the entire survey. We feel that the case

study 1 modules may require some adaptation to be scalable to lifelong learning modules. However, the high rating for question 4 (the usefulness of the case for real-industry problem-solving) certainly confirms two things: the case-based exercise approach is suitable for lifelong learning; and students benefit from an exercise that shows, in detail, the actual problems faced by engineers, and the application of tools and calculations within the context of a real-life project.

The rating for question 8 is also important, since the students gave a high rating to this type of case study when compared to the traditional approach



Fig. 6. Citric acid filter (video snapshot).

Table 3. Levels of learning for case study 1

Levels of learning (cognitive)	How case study 1 satisfies learning levels
Knowledge	<ul style="list-style-type: none"> • Identify the attributes chosen to measure Cp and Cpk
Comprehension	<ul style="list-style-type: none"> • Describe steps taken to improve Cp and Cpk
Application	<ul style="list-style-type: none"> • Summarize in a step-wise fashion the approach taken by the people involved in the implementation of the standard and improvement of the process capability • Discuss the importance of process mapping, described in the case • Calculate the capability index and quality-loss function • Calculate savings obtained for improving Cp • Classify the roles played by the people involved in this project in terms of the six sigma players
Analysis	<ul style="list-style-type: none"> • Arrange the actions taken to improve process capability in terms of a cause-effect diagram
Synthesis	<ul style="list-style-type: none"> • Formulate in terms of the DMAIC model all the aspects and actions related in the case study
Evaluation	<ul style="list-style-type: none"> • Formulate a P-diagram for powder detergent density control • Assess and evaluate the Cp and Cpk indices calculated • Assess and evaluate the quality loss calculated • Recommend the maximum capital expenditure that can be spent in the project

Table 4. Means and standard deviations of EMGT 472 student responses (case study 1)

Questions	Winter session		Fall session		Total		Result (t-test)
	Mean	Std.	Mean	Std.	Mean	Std.	
1. Do you find the presentation of the embedded material (Process capability, Six sigma, Taguchi method) in this study useful?	4	0.7	4	0.8	4	0.7	>3.5
2. The exercise (case study, questions, theoretical frame) helped and motivated me to learn more of concepts such as process capability, six sigma and Taguchi method.	3.9	0.8	3.9	1	3.9	0.8	>3.5
3. Rate the additional information provided along with the case (exhibits, theoretical frame, case study presentation).	3.7	0.7	4.4	0.5	4	0.7	>3.5
4. Rate the usefulness of this exercise to real life industry problem solving.	4.1	0.8	4	0.9	4.1	0.8	>3.5
5. I found the exercise intellectually stimulating.	3.8	0.8	3.9	0.6	3.8	0.7	>3.5
6. How do you rate this exercise type-case study compared with traditional case studies (Please answer if you have used case studies in past)?	3.9	0.9	4	0.8	3.9	0.8	>3.5
7. Rate the usefulness of this case study for life-long learning (please answer only if you have had previous working experience).	3.5	1.1	3.6	0.5	3.5	0.9	Inconclusive
8. Do you feel that after solving this exercise you are familiar and know how to apply the process capability concept?	3.7	1.1	3.9	0.8	3.8	1	Inconclusive
9. Do you feel that after solving this exercise you have learned the basic concepts of Six Sigma and the Taguchi method?	4.1	1	3.6	1.1	3.9	1	>3.5
10. Overall, how do you rate this exercise case-study (presentation, theoretical frame-work, questions, case-study)?	4	0.8	4.1	0.6	4	0.7	>3.5

of case studies. Students rated the overall case and its approach very well (question 10), with a score of 4.0. Also, since the interval found for the paired t-test contains zero, we can conclude that there is no statistical difference between the mean responses of the students of both sessions, so we can assume that students' opinions regarding this case-based exercise were consistent.

A few examples of the students' comments are listed here:

'I think the case study shows the steps of the DMAIC in a context of industry that is useful.'

'I did enjoy learning about the Quality Loss Function via the case study questions. Perhaps the concept could be incorporated into the story.'

'The points made in the case, I have seen similar conditions happen in my work experience. This is good for students with little or no experience.'

'I liked the mathematical calculation problems. It was interesting to actually perform the calculations instead of just reading about them.'

CONCLUSIONS

The gap between theory and practice can be bridged to a certain extent through the deployment of thematic case studies. We believe that the integration of theme-oriented case studies with a balanced view of the engineering activity implications on the business decisions will enhance the learning value for students.

The knowledge of an average engineer becomes obsolete in two to five years [10]. The rapidly changing technological world forces engineers to update their skills and methods continuously [16]. The learning needed can be furnished from many sources, including short courses, seminars, and professional conferences and courses [17]. Our untested belief is that the case studies discussed in this paper have the potential to be adapted for life-long learning, after making necessary modifications. The adaptation process could possibly consider life-long learning guidelines such as those presented by the Commission of the European Communities [18], including how to devise participation and outcomes particularly for informal learning, and how to effectively transfer the knowledge in an Internet-enabled environment while reaching geographically isolated and scattered students.

The thematic basis for the series of case studies can provide students with a broader and integrative view of concepts and tools. Even though we have developed just three case studies, more cases and modules revolving around the thematic basis can be developed to increase the usage of the case studies in several courses. We are in the process of creating teaching notes for the overall discussion of the thematic basis of these series of cases. It is to be noted that we have not conducted any experiments to make any claims about the usefulness of the thematic case studies over traditional isolated case studies.

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