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Why and How to Develop a Meaningful Quality Assurance System in Engineering Schools*

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National accreditation of engineering undergraduate programs is probably the most common quality assurance scheme used in universities today. However, calls are increasingly being made to expand the scope of formal quality assurance systems into graduate education and research, and to provide an international accreditation framework. The new ISO 9000 (2000) standards have the capability to address these issues. This paper discusses the reasons for the implementation of the flagship standard in the series, namely ISO 9001 (2000), as well as methods for the development of a quality system in engineering education and research. In addition, approaches to monitoring the quality of teaching and learning outcomes are presented.

INTRODUCTION

SINCE THEY WERE introduced in 1987 to alleviate pressures for formalized quality assurance, ISO 9000 standards have caused a business revolution. Today, more than 350,000 organizations worldwide are registered to these standards. Often cited for increasing competitiveness by providing an independent 'stamp of approval' of an organization's quality management practices, ISO 9000 quality systems are nevertheless criticized for their lack of emphasis on continuous improvement and their inability to ensure a quality output. The newest edition of the standards, ISO 9000 (2000), is expected to address most of such criticisms. Because of their generic applicability, manufacturing, service and even non-profit firms have developed ISO 9000 compliant systems.

However, comparatively few higher education institutions, and even fewer universities, are registered. This is largely due to the lack of immediate pressure from the stakeholders, including industry and government. In countries where such external forces exist, it seems that the number of ISO 9000 registered universities is directly proportional to the fostering efforts of national higher education ministries. A good example is Taiwan, where almost all colleges are registered [1]. In the United Kingdom and Australia, where governments also place a high emphasis on quality assurance, several universities (for instance Wolverhampton and the Royal Melbourne Institute of Technology) have been operating for five or more years with ISO 9000 quality systems. On the other side of the spectrum is North America, where the number of registered engineering educational institutions can be counted on the fingers of one hand, and any concerns about quality assurance are promptly set aside under the banner of program accreditation. For instance, the Canadian Engineering Accreditation Board (CEAB) approves engineering programs across the country by visiting and examining each school every six years. Accredited engineering schools (virtually all in Canada) can then claim that they provide 'quality education', since they are accredited. The situation is similar in the United States, where accreditation is performed by the Accreditation Board for Engineering and Technology (ABET). While it is clear that such accreditation schemes provide some degree of confidence in the quality of education, the looming question becomes: 'Is this enough?' In other words, do we need to employ additional methods and efforts to assure interested parties that our students will have adequate knowledge when they graduate, that they will be able to find good jobs and excel in their careers?

Presently, the university is a turbulent environment, similar to that of the business world. Competition for excellent students, staff and money is rapidly growing, and, due to distance learning technologies, the delivery of engineering education is becoming truly global. Pressures for the continuous improvement of engineering education and its processes and outcomes are evident in the revisions of national accreditation criteria, for example ABET 2000 in the United States, and in the claims of many universities that they practise Total Quality Management (TQM). This paper attempts to answer the question of whether engineering schools should 'jump on the ISO bandwagon' to address the imminent quality assurance (QA) issues. The advantages and possible pitfalls

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of such a development are addressed, followed by a discussion on the models for ISO 9000 (2000) implementation in education, research and administration of engineering programs. Compared to the 1987 and 1994 versions, the latest revision of the ISO 9000 standards has been much improved, especially in the realm of continuous quality measurement and analysis. This development is expected to provide a very efficient solution to the requirement of some accreditation programs (such as ABET) for the monitoring and improvement of teaching and learning outcomes. Therefore, a model for continuous tracking of educational processes in the classroom is also illustrated here. The main contention of this paper is that the development of quality management schemes in engineering schools is desirable, possible and useful.

THE QA QUESTION

Quality assurance in engineering education is a multifaceted problem, further augmented by the number of parties interested in it and the multitude of their respective concerns. Students and their families are rightfully questioning the quality of the curriculum, the instructional delivery, the learning environment, accessibility to leading technologies and equipment, employability after graduation, as well as the possibilities for lifelong learning and improvement of knowledge. Employers in the industrial and government sectors require students to be adequately prepared to enter the workforce, having not only the requisite knowledge and understanding of their specific area of study, but also interpersonal and communication skills, as well as adaptability to changing environments and job requirements. As members of the general public, we are interested in having competitive engineering schools that will ensure continuous generation of able engineers. All these concerns basically boil down to a single question: 'How can engineering schools provide confidence to customers that their requirements for quality education and research are continuously met?' [2].

Engineering faculties the world over are trying to answer this question in a myriad of different ways. Many have embarked on TQM programs, with various degrees of success in improving their performance. Recently, such efforts have increasingly focused on quality improvement through self-assessment, using well-established quality awards criteria. Examples include the Malcolm Baldrige National and European Quality Awards, which have specially designed criteria for improvement in education. The literature [3–6] provides reviews and case studies of implementing TQM in higher education. Some have followed the manufacturing and service sector and developed ISO 9000 quality systems for assurance purposes. The scope of application ranges from relatively small laboratories (e.g. the Laboratory for Machine Tools and Production Engineering in Aachen, Germany [7], and the Software Engineering Applications Laboratory in Johannesburg, South Africa [8]) to whole universities (e.g. the Ngee Ann Polytechnic in Singapore [9], University of Wolverhampton in the UK [10] and the National Kao-Hsiung University of Technology in Taiwan [1]). In some countries, the United States for instance, some engineering schools have formed coalitions with the objective of designing, implementing and assessing new approaches to undergraduate engineering education, as well as improving the overall quality of the educational experience [11].

Although the above-mentioned approaches appear diverse, there seems to exist a relative agreement on at least two issues. Firstly, it is evident that systematic changes are needed for engineering schools to survive in the changing environment. Secondly, the current engineering accreditation schemes (for example, CEAB and ABET) represent a good basis for the development of sound quality assurance systems, but are not sufficient for continuous quality improvement in their present form. Analyses of the comparative features of accreditation schemes versus ISO 9000 have been performed by Karapetrovic *et al.* [12, 13] and, more recently, by Peters [14]. In the following section, ISO 9000 standards will be briefly described, followed by a discussion of some of the advantages and possible concerns that would be incurred with ISO 9000 application in engineering schools.

BENEFITS AND PITFALLS

As a result of the worldwide trend to ensure consistent and standardized processes that will yield products meeting and/or surpassing customer needs, the International Organization for Standardization developed a series of quality assurance standards named ISO 9000 in the late 1980s. These standards stipulate a number of minimum requirements on which an organization's quality system can be assessed and subsequently verified as compliant to a quality system model. Verification of compliance with the requirements is performed by an external and independent body called the 'registrar'. ISO 9000 standards underwent two major revisions, in 1994 and 2000. The latest change decreased the number of available quality system models from three (ISO 9001, 9002 and 9003) to only one (ISO 9001), and the number of major requirements from twenty to the following four:

- management responsibility
- resource management
- product realization
- measurement, analysis and improvement

However, the scope of organizational activities covered by the ISO 9001 (2000) has not changed, and includes virtually all processes that have an impact on product quality.

Therefore, engineering faculties and departments wishing to implement an ISO 9001, 2000-compliant quality system would have to address issues such as the identification of the need for undergraduate and graduate programs to be offered, program design to meet such stated or implied needs, adequate program delivery, and maintenance and improvement. A significant difference from the older versions of the standard is reflected in the new requirement for objective evidence of quality improvement. As a consequence, claiming that a TQM program is in place becomes insufficient for obtaining registration. A university must now show that actual improvement took place in the form of concrete results and trends.

But what would engineering schools gain by ISO 9000 application? After all, it may cost a lot of money and effort. Some of the most apparent benefits include:

- ISO 9001 quality system documentation will guide teaching, learning and research in a convenient, predictable and generally acceptable way [2].
- The documentation also improves understanding among the faculty and staff, and can be used to train newly hired staff [15].
- University operations can be streamlined, quality problems can be identified, corrected and prevented, and improvement results can be accomplished in a systematic manner [16].
- Work and paper trails are not added where general and individual faculty benefits cannot be identified [2]. This reduction of bureaucracy is especially important in academia, which continuously suffers from an over-abundance of red tape.
- Internal quality auditing, a built-in system element, allows each faculty and staff member to raise and resolve practical problems, ranging from faulty overhead projectors to department and faculty management issues [2]. In addition, students and other stakeholders can realize this benefit through a more formalized suggestion and comment process.
- The quality system provides for a clearer articulation of the rights and responsibilities of students, faculty and staff [17].
- An external and independent registrar provides an outsider's point of view, which is often advantageous for quality improvement. Strengths and weaknesses are identified, and potential improvement s are uncovered.
- Marketing and government accreditation benefits are generated [17]. A lot of effort put into ISO 9000 implementation will pay dividends in marketing brochures (e.g. 'We are the only engineering school in Canada that is ISO 9001, 2000 registered') and accreditation documents (most documentation will be created only once and can be used for both purposes).
- An adequately implemented ISO 9000 system will focus on the reduction of quality problems, including student and research project failures, and foster an environment of continuous improvement.
- A registered and well-maintained quality system may serve as a solid basis for compliance with the related standards for environmental management (ISO 14000), occupational health and safety (BS 8800), and even social accountability (SA 8000).

Despite all the stated advantages, there are also pitfalls that could stop any attempts toward the development of an ISO 9001 quality system in a university setting. Probably the most important potential obstacle is the perception by faculty that a formalized quality system will restrict their academic freedom and that they will be blamed for identified quality problems. This opinion can be epitomized in the following five words: 'ISO 9000: No Good Here'. To help alleviate such perceptions, it is crucial to dispel any fears about tenure and academic freedoms before an ISO 9000 project has even begun. Emphasizing individual benefits with examples is a good start in encouraging faculty to buy into the idea. Having the faculty and staff union on board will also help.

Other possible disadvantages include:

- Fears of increased bureaucracy and paperwork [2].
- Project cost, particularly with shrinking university budgets and in cases where there is a lack of financial support by the government. Nevertheless, the latter should not be a major issue, since most governments provide some kind of support, or at least tax breaks, for ISO 9000 implementation.
- The amount of faculty and staff time and effort spent on the project can be significant [17]. If the short-term benefits are not realized, the project may lose steam and ultimately be abandoned.
- Lack of staff initiative. Committed top management (dean, head of school, department chair) and several quality champions may facilitate motivation.
- Spreading the initiative beyond the unit that first achieved registration may prove to be extremely hard [8]. However, if the implementation is successful and its advantages are evident, it can be expected that other departments will follow suit.
- ISO 9000 standards were originally drafted with a large manufacturing organization in mind, though they have been applied across industries, including production, service and non-profit organizations. In spite of the fact that the standards were made more generic in the last revision, they still require interpretation for use in engineering education.

In any case, it is argued that the benefits of an ISO 9000 implementation outweigh the perceived concerns, particularly since the majority of obstacles can be avoided with a systematic interpretation and perspective on quality assurance in a university setting. Therefore, an understanding of what the ISO 9000 standards are all about and a proper interpretation of the standard requirements should assist engineering faculties if they decide to embark on the ISO 9000 effort. The following section illustrates an interpretation of the ISO 9001 (2000) standard for application in engineering education and research.

ISO 9001 (2000) INTERPRETATION

Before attempting to incorporate a standard-based quality system, we need to understand its implications for any institution of higher learning and, more specifically, for engineering schools. Several national standardization bodies, including the British Standards Institute (BSI) and the French AFNOR, have produced handbooks for the application of ISO 9000 in education and training. These handbooks, however, have limited use in engineering education, since they conceptualize courses and undergraduate programs as the sole products of an educational institution. As such, these guidelines can be applied in community colleges (polytechnics), as well as in continuing and distance-education programs. In a university setting, the two essential products are a student's knowledge and competence, as well as research (i.e. the creation of new theories and practices). Interestingly, most available interpretations have focused on either courses or research, but not both. In order to address this deficiency in literature, Karapetrovic *et al.* have interpreted the ISO 9001 (1994) standard for use in engineering education and research [18], while conceptualizing three main products of an engineering school: student knowledge, courses and research. An abbreviated and updated version (to incorporate changes in the standard that occurred last year) of this interpretation is provided here. Table I represents the terms used in ISO 9001 (2000) and their respective analogies for engineering schools.

Table 1. ISO 9000 terms applied to engineering education and research.

	EXPLANATION(ISO 9001)	
TERM (ISO 9001)	EDUCATION	RESEARCH
Product	Student knowledge, abilities and competencies	New knowledge, theories and practice
Customers	Industry, community, alumni, professional organizations, accreditation boards, students	Industry, research sponsors, other universities, research community
Organization	University/faculty/department	
Supplier	High schools, community colleges, other universities	Researchers, industry sponsors, literature sources (journals and conference proceedings)
Top management	Dean/Head of School/Department Chair	
Quality policy	The overall quality intentions and direction of the faculty (department), as formally expressed by the dean (department chair)	
Quality objectives	Measurable goals relating to courses, programs and student education, stemming from the overall quality policy	Measurable goals relating to research projects and activities, stemming from the overall quality policy
Design plan	Undergraduate, M.Sc. and Ph.D. programs	Research objectives
Designer	Academic staff (professors and instructors)	
Process plan	Individual student curriculum	Research project plan
Raw material	Student knowledge of basic arts and sciences before entering the university	Existing practical and theoretical knowledge
Value adding to material	Value adding to students' knowledge and abilities	Value adding to existing knowledge of theory and practice
Realization process	Learning–teaching	Researching
Product part	Student knowledge accumulated on a course	A phase in a research project
Part specification	Course and program specification	Specification of deliverables in a research contract or research goals
Operation/tool	'Learning opportunity' in laboratories, lectures, tutorials and seminars	Work on a phase of a research project
Machine/technology	'Learning opportunity'	'Research opportunity'
Operator	Professor, teaching assistant, student	Researcher, research assistant
Nonconforming product	Student failure to pass a course; course and program failure to achieve objectives	Research project failure to achieve objectives

It is important to recognize that, while this interpretation is meant to be universally applicable to any academic institution, each engineering faculty may fine-tune it, depending on its perceived customers, suppliers, objectives, processes and resources, as well as the intended scope of the quality system. Much debate and contention has been generated about the issue of who the real customer in a university setting is [19–21]. Whereas this related discussion is outside the scope of this paper, it may be postulated that an engineering school always has multiple customers, and different schools can adjust their focus on each customer depending on their core objectives and competencies. For instance, a primarily undergraduate university may consider its students and their employers as the most important customers, while a research-intensive university would perhaps consider industry and funding agencies as their crucial customer. Therefore, research activities can be excluded from the planned scope of the ISO 9001 (2000) application, leaving only undergraduate education to be dealt with. An opposite case is also possible, where only research and postgraduate education are included (for example, see [7] and [8]). The following paragraphs address the four main requirements of the ISO 9001 (2000) standard [22] in education and research.

ISO 9001 (2000) REQUIREMENTS

If an engineering school decides to develop a quality system based on the newest version of the ISO 9000 standards, it must identify all the processes that have an impact on the quality of its products, including student education, courses and programs, as well as research. It is also necessary to determine how these processes interact, which resources are required to effectively and efficiently conduct them, and what objectives they are supposed to accomplish. In other words, a quality system in a university environment is a set of processes that function harmoniously, using various faculty, staff, material and information resources to achieve set educational and research goals.

Take the delivery of an introductory engineering economics course as an example. A professor sets course objectives in terms of the material to be covered, the components of student performance evaluation, as well as a detailed plan of lectures and laboratories in order to achieve the stated course objectives. During the term, teaching assistants (TA) are required to conduct seminars and mark assignments, while the administrative staff assists in establishing class lists and schedules. All these activities need to be planned and coordinated to ensure that students understand the material and are able to, for example, use the principles learned in practice. Impacts of the unavailability of a certain resource or a process on the quality of course delivery (for example, not providing adequate feedback to students on their performance) must also be assessed. Throughout the term, actual results should be evaluated against planned objectives, and any corrective and preventive actions should be taken for improvement.

As a part of the ISO 9001 requirements and to provide objective evidence of the quality system existence, an engineering school or a unit thereof must draft a statement of a quality policy and objectives, a quality manual in which the system is described, and any procedures needed to ensure adequate operation of its processes. Quality records, such as student report cards, student evaluation of courses and instructors, and course outlines, must also be kept and tracked. The standard also demands that a separate procedure for the approval, review and maintenance of documents and quality records be implemented. Although this requirement may appear to foster bureaucracy, it can actually be used to streamline much of the documentation that is unnecessarily created in academia. Sections five to eight of the standard represent the main elements of the ISO 9001 (2000) quality system (QS) model. These sections are illustrated below.

Section five requires that the school's top management (e.g. dean, head or the executive committee) prove its commitment to the development of a QS by drafting and communicating the most important quality goals, as well as by ensuring that adequate resources are available to realize stated goals. Examples of quality objectives related to education would be to reduce student failure rates, increase the number of national undergraduate student awards, improve teaching evaluations or optimize the number of graduate students. In research, such objectives may include an increase in external grant support or the number and quality of research projects conducted. Such quality objectives can be translated into a set of targets (i.e. quantifiable measures of performance). For example, an engineering department can set a goal of increasing the number of funded graduate students from three to five students per faculty member within three years. Top management is also responsible for conducting reviews of the school's QS performance, and appointing a quality management representative who liaises between the top management and other parties, including students, faculty, staff and external organizations. It is particularly useful if this representative is a faculty member, since the philosophy and methodology of continuous improvement must be primarily focused on teaching, learning and research as the main university processes, and not on administration and support activities.

The very short section six of the standard demands that adequate resources, including the infrastructure and work environment, are identified and provided to implement the QS and 'enhance customer satisfaction'. For example, an environment conducive to learning and research should be established and regulated. Again, the exact definition of such an environment is left to each individual organization, but in the context of academia may relate to safety and health of students and staff, provision of classrooms, laboratories and study rooms, as well as libraries with a sufficient supply of books, material, computers and internet connections. Another set of requirements relating to human resources attempts to ensure the competence of faculty and staff in performing their tasks, provision of necessary training and professional development, as well as the awareness of individual contributions to the achievement of quality objectives.

The topic of the seventh (and most detailed) section of ISO 9001 (2000) is 'product realization', or the processes ranging from the identification and review of customer needs and specifications, product design and development, acquisition and deployment of resources, product and service delivery, to the assessment of whether customer requirements have been met. Using Table 1 and additional interpretations from Karapetrovic *et al.* [18], it is possible to translate these requirements into the engineering education and research setting without much effort. For example, in terms of education, 'purchasing' (of raw material) relates to the enrollment of students into a program or course. Students come from high schools or the common first year of the university ('suppliers' in ISO 9000 terminology), and their previous academic performance ('purchased product quality') must conform to the requirements specified by the engineering school to which they are applying. This 'raw material quality' is normally inspected through a student's Grade Point Average (GPA) or sometimes even through an entrance exam. It is not uncommon for universities to keep lists of 'approved' high schools or other universities, which is one of the ISO requirements. In terms of research, the purchasing requirement relates to the acquisition of necessary resources to conduct a research project, for example laboratory equipment and research associates. Another example is element 7.6 of ISO 9001 (2000), 'control of monitoring and measuring devices', which is merely the establishment of marking and grading schemes to evaluate student performance (but which also includes student evaluation of courses and professors, for example). Similar analogies can be drawn in research.

Finally, section eight requires the school to continuously measure, monitor, analyze and improve its performance. It must, for instance, measure and improve the overall satisfaction of students with course and program delivery, as well as meet or exceed the expectations of student employers, granting agencies and other identified customers. The quality of products (student knowledge and abilities, courses and research) must also be continuously monitored and improved. As an example of how this may be accomplished, a method for tracking learning outcomes in a classroom setting, adapted from Karapetrovic and Rajamani [23], follows. A case study of an introductory engineering economics course, taught in the winter term of 2001 at a western Canadian university, is presented to illustrate the method.

MONITORING CLASSROOM LEARNING

Professors assume that students learn the course material during lectures, laboratories, seminars and tutorials, as well as through self- or team-learning. But how much they actually learn during a particular lecture, and whether they leave the lecture with a good understanding of the main issues taught, are largely open questions. As illustrated in Karapetrovic *et al.* [12], a student's learning is not necessarily directly proportional to the professor's teaching performance. Even if the professor performed at 100% of his/her ability in a lecture, this still would not mean that the students learned everything that was taught that day. An exam in another course, the time of day and a myriad of other reasons may influence the students to learn less or worse than the professor planned. On the other hand, students may actually learn more or better than planned, if, for example, they are interested in the subject or have studied beforehand at home. Therefore, it would be very useful both for quality assurance and improvement of educational processes if a professor could measure his/her impact on student learning, as well as the quantity and quality of the material learned, in each lecture, laboratory experiment or tutorial. The following method may help in this endeavor.

At the beginning of each lecture, the students should be given a list of three to five questions with multiple choice or true/false answers. One possible answer should always be 'I don't know'. The questions should relate to the most important topics or issues that will be covered during the lecture. Allowing several minutes for the answer period, the students should be instructed to answer these questions to the best of their abilities, and to then put the question sheet aside. This will provide information on the students' previous knowledge of the subjects to be covered, as well as focusing the class on the crucial parts of the lecture.

At the very end of the lecture, the students should be asked to answer the same questions. Treating the answers to each question as a sample of student knowledge, the following two statistics should be calculated:

- The proportion of the class that had an incorrect (or 'I don't know') answer (let us call this statistic p_C) to each question after the lecture.
- The proportion of students who, for each question, had the correct answer after the lecture and an incorrect (or 'I don't know') answer before the lecture (we can call this statistic p_L).

The p_C statistic tells us how many students actually knew the material immediately following the lecture. Despite a common belief that such a statistic will always have a 0% value, meaning that all students will have a correct answer, this is almost never the case. Historical data from several engineering courses places the average value of the p_C statistic at about 10–20% [21, 24], which can lead us to conclude that at least one in ten students may have left the lecture without learning or understanding the main points. The p_L statistic provides an indication of the actual effect that the lecture had on students' learning, because these students did not know the answer before but knew the correct answer after the lecture. Once again, although one may think that a natural p_L value would be at 100%, meaning that all students learned the material solely during the lecture, historical values that we obtained hover around 50–60% [23, 24].

These two statistics should be monitored over several lectures. To establish statistically meaningful inferences about student learning outcomes, a total of twenty to thirty questions (equivalent to about four to ten lecture blocks of 50 minutes each) should be posed. While trends and averages may be followed by a simple graph showing the p_C or p_L statistics versus the question number, it is also useful to establish a statistical control chart with the purpose of identifying and removing elements that may cause problems. General spreadsheet software (e.g. Excel) or specialized statistical packages (e.g. Minitab) can greatly assist in drafting a variety of control charts. The upper and lower limits of the chart applied in this method (called the proportion or 'p' chart) can be calculated as:

$$\bar{p} \pm 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

where $\bar{p}$ is the average of p_C or p_L and n is the number of students.

Because the number of students attending each lecture may vary, control limits will change from lecture to lecture. The central line of the chart is equal to $\bar{p}$ (i.e. the average value of the p_C or p_L statistics taken over the number of questions posed). If a point falls above the upper control limit for the p_C statistic, or below the lower control limit for the p_L statistic, this may be an indication of a problem, and should be investigated in detail for possible causes. In cases where such a point was caused by an unusual event, for example a question that had not been not covered in class and consequently had a very large percentage of incorrect answers, that point should be removed from the chart. Once such special causes are removed, the professor obtains very useful feedback on how the class is doing over the monitored period. For example, if a particular question had a large proportion of incorrect answers, the topic related to it may be repeated or additional examples may be provided. In this manner, the professor may also improve the overall average of correct answers and the learning effect due to the lecture, as well as reducing the variation in p_C and p_L statistics from question to question and from lecture to lecture.

Figures 1 and 2 represent examples of control

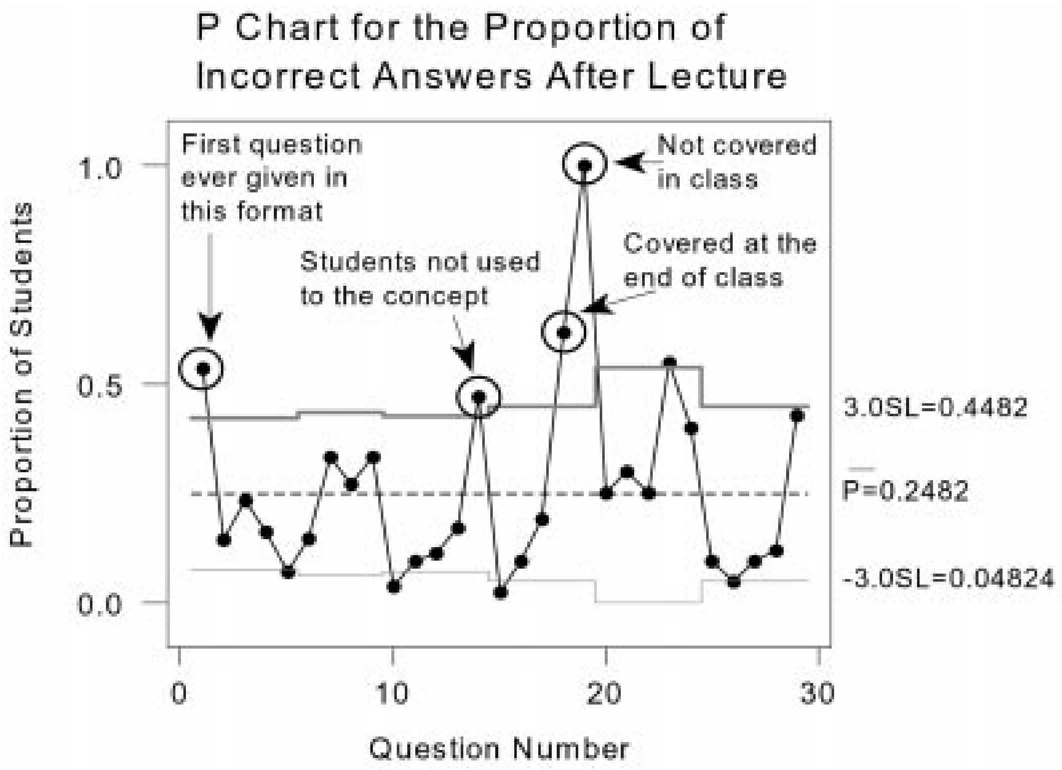

Fig. 1. Monitoring the p_C statistic in an engineering economics course.

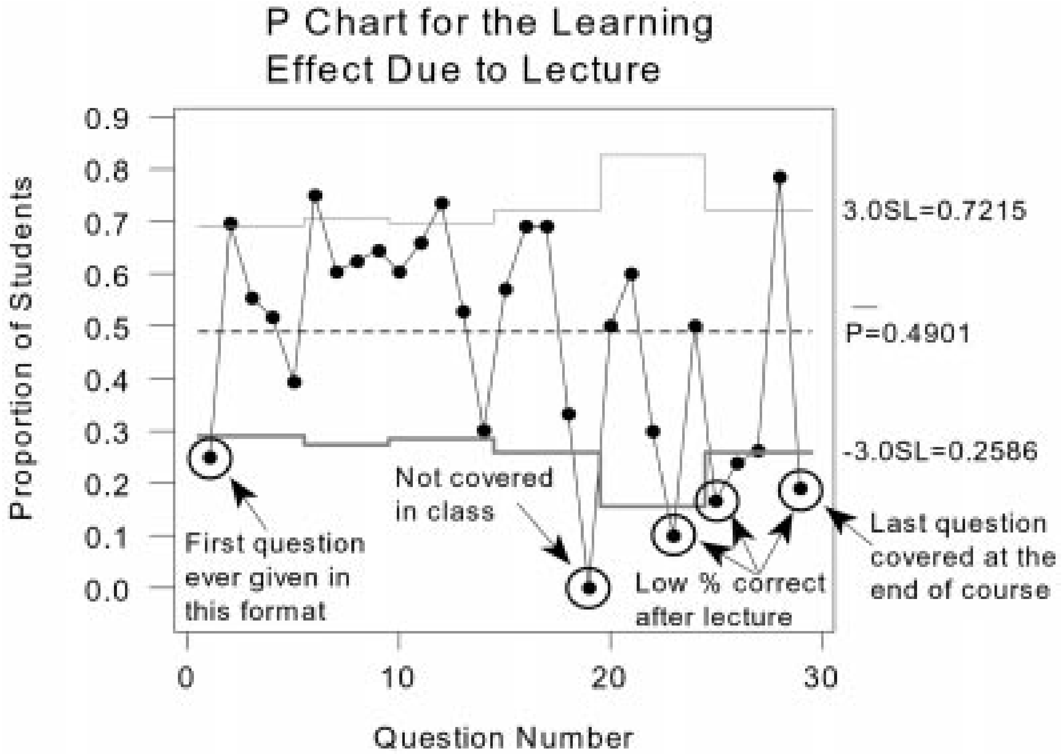

Fig. 2. Monitoring the p_L statistic in an engineering economics course.

charts for the p_C and p_L statistics, respectively. The data points were obtained from six lectures over a period of three months in a third-year engineering economics class, with an average attendance of about 45–50 students during these lectures. A total of 29 questions were posed.

It can be observed from Fig. 1 that several points occur above the upper control limit (namely, questions 1, 14, 18 and 19), indicating a larger than usual proportion of incorrect answers. Upon further investigation, the reasons for such results were uncovered. For example, question 14 concerned a new concept that the majority of students found difficult, while the material evaluated by question 19 was not covered during the lecture because of insufficient time. Interestingly, not a single student answered this question correctly! Also, the value of the old rule-of-thumb to use the last five minutes of a lecture for summary or examples only, without teaching any new material, can be seen in question 18. The topic covered by this question was only briefly mentioned at the end of class and, as a result, had a very high percentage of incorrect answers. Because they represent the so-called 'special' causes of variation in student responses, these questions can be removed from the 'revised' control chart and the teaching–learning process can then be further monitored [23]. This brings the revised average percentage of incorrect answers to 13.5%.

Figure 2 illustrates how much the students actually learned in lectures. Of concern are the points below the lower control limit, since they may indicate little or no real absorption of material. Note that the p_L and p_C statistics are related, since a high percentage of incorrect answers after the lecture (high p_C) causes the p_L percentage to be very low. Therefore, question 19 had the p_C value of 1 and consequently the p_L value of 0. After such questions are removed from the chart, an average of 60% was obtained for p_L, meaning that a relatively good percentage of students benefited from the lecture. The highest score was obtained for question 28 (related to the ways in which a company can raise capital), when 33 out of 42 students (79%) did not know the correct answer before and knew it after the lecture. For more information on this and other methods of quality control and improvement in engineering courses, the interested reader is referred to Karapetrovic and Rajamani [23] and Karapetrovic [24].

ISO 9001 (2000) IMPLEMENTATION

As can be seen from the above explanations, most of the ISO 9001 (2000) requirements are a matter of common sense, as already established in accreditation criteria or accepted as a minimum practice. This low level of required effort is an additional reason why engineering schools should consider ISO 9000 implementation. A possible approach to registration, summarized from Karapetrovic and Willborn [16] in the form of a seven-step roadmap that may be used in the development, maintenance and improvement of an ISO 9001 quality system in an engineering school, follows.

- Establish top management commitment. Appoint a quality champion from the faculty ranks. Organize an ISO 9000 project committee that will lead and coordinate the project. The committee should include faculty, staff and student members.
- Decide on the scope of the quality system (administration, teaching–learning and research activities). Perform an initial gap analysis between the requirements of the standard and the existing quality system. Address possible synergies between accreditation and ISO 9000 documentation.
- Structure the quality system from more to less comprehensive elements (i.e. from the overall undergraduate, graduate and research programs, through individual courses and projects to lectures, laboratories and seminars). Map and document the teaching, learning and research processes. Identify their mutual interactions and synergies.
- Organize the quality system documentation in several levels, starting from the school and departmental quality manual, through procedures and course and research project quality plans, to instructions (e.g. for teaching and research assistants) and quality records.
- Develop objective measures of the quality system performance, including the teaching, learning and research quality indicators. Measure and monitor selected indicators. Perform internal quality audits.
- Undertake corrective and preventive actions to improve performance. Record and track the progression.
- Register the quality system through an external audit.

CONCLUSION

With increasing concerns about the quality of engineering education came calls for the development and implementation of more formal assurance schemes. While it is widely accepted that accreditation of engineering programs by independent national bodies provides at least partial quality assurance, other methods of quality management in the academic environment can be explored. The establishment of ISO 9000 compliant quality systems represents one such methodology. This paper addresses the issues of why and how engineering schools could implement the ISO 9001 (2000) standard. After a brief discussion of various approaches to the question of quality assurance in engineering education and research, the benefits and pitfalls of implementating the standard were illustrated. Subsequently, ISO 9001 was interpreted for application in a university setting, followed by an analysis of the main requirements of the standard. A model for continuous monitoring, controlling and improvement of teaching and learning outcomes in an engineering classroom was also briefly illustrated. Finally, a short outline of a seven-step approach to implementation was presented.

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