ISO 9000 QUALITY SYSTEM DEVELOPMENT FOR ENGINEERING SCHOOLS: WHY AND HOW SHOULD WE DO IT?

Stanislav Karapetrovic[1]

Abstract — *Engineering schools are publicly accountable for their work in education and research, and thus most of them already have a more or less formal quality assurance system in place. For example, engineering faculties across North America are accredited by national boards, and have documentation available to illustrate compliance of their performance with the accreditation criteria. The main purpose of quality assurance in engineering education is to provide confidence to the profession, students and their parents, employers and various other stakeholders that the requirements for quality education and research are continuously met. To accomplish the same goal in manufacturing and service industries, ISO 9000 standards have been introduced to more than 350,000 companies worldwide. Increasingly, calls are being made to expand the applicability of these standards into higher education. This paper addresses the issue of incorporating the flagship standard in the series, namely ISO 9001: 2000, into the framework of engineering education and research.*

Index Terms ¾*ISO 9000, Quality Assurance, Standards*

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 inability to ensure a quality output. The newest edition of the standards, ISO 9000: 2000, is expected to address most 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 polytechnics are registered. 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 with the fingers of a single 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 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, engineering schools face 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 practice 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. Advantages and possible pitfalls of such a development are addressed, followed by the discussion on the models for ISO 9000: 2000 implementation in education, research and administration of engineering programs. The main contention is that the development of quality management schemes in engineering schools is desirable, possible and useful.

[1] Stanislav Karapetrovic, University of Alberta, 5-8B Mechanical Engineering, Edmonton, AB T6G 2G8 Canada, Phone: 780-492-9734, Fax: 780-492-2200 S.Karapetrovic@ualberta.ca

THE QA QUESTION

Quality assurance in engineering education is a multi-faceted problem, further augmented by the shear 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, instructional delivery, the learning environment, accessibility to leading technologies and equipment, employability after graduation, as well as possibilities for life-long learning and improvement of knowledge. Employers in the industrial and government sectors require students with adequate preparation to enter the workforce, including not only the knowledge and understanding of their specific area of study, but also interpersonal and communication skills, as well as the 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?" [1].

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 been 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. References [2-5] provide reviews and case studies of implementing TQM in higher education. Others 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 [6] and the Software Engineering Applications Laboratory in Johannesburg, South Africa [7]) to whole universities (e.g. the Ngee Ann Polytechnic in Singapore [8] and the University of Wolverhampton in the U.K. [9]). In some countries, the United States for instance, 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 educational experiences.

Although the above-mentioned approaches appear diverse, there seems to exist a relative agreement on at least two issues. First, it is evident that systematic changes are needed for engineering schools to survive in the changing environment. Second, 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. [10, 11], and more recently by Peters [12] and Sarin [13]. 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 the 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. The 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: 2000), 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 having 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 being offered, program design to meet such stated or implied needs, adequate program delivery, 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 [1].

- The documentation also improves understanding among the faculty and staff, and can be used to train newly hired staff [14].
- University operations can be streamlined, quality problems can be identified, corrected and prevented, and improvement results can be accomplished in a systematic manner [15].
- Work and paper trails are not added where general and individual faculty benefits cannot be identified [1]. This reduction of bureaucracy is especially important in academia, which continuously suffers from "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 [1]. 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 [16].
- 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 for improvement uncovered.
- Marketing and government accreditation benefits are generated [16]. A lot of effort put in ISO 9000 implementation will pay its dividends in marketing brochures (e.g. 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 obstacle is the perception of 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 making faculty 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 [1].
- 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.
- Amount of faculty and staff time and effort spent on the project can be significant [16]. 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 [7]. However, if the implementation is successful and 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 an 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.

INTERPRETATION

Before attempting to incorporate a standard-based quality system, we need to understand its implications on any institution of higher learning, and more specifically, on 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 continuing and distance education programs. In a university setting, the two essential products are the 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 [17], 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. 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. Whereas a related discussion is outside of the scope of this paper, it may be postulated that an engineering school always has multiple customers, and different schools can balance 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 [6] and [7]). The following paragraphs address the four main requirements of the ISO 9001: 2000 standard [18] in education and research.

TABLE I
PRODUCTION ANALOGIES IN ENGINEERING EDUCATION AND RESEARCH

TERM (ISO 9001)	**EXPLANATION**	
	EDUCATION	**RESEARCH**
Product	Student knowledge, abilities & 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 and stemming from the overall quality policy	Measurable goals relating to research projects and activities and 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 student's knowledge and abilities	Value adding to existing knowledge of theory and practice
Realization Process	Learning / Teaching	Researching
Product Part	Student knowledge accumulated in 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

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 adequate material to be covered, 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 the planned objectives, and any corrective and preventive actions 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. 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. Top management is also responsible for conducting reviews of the school's QS performance, and appointing a quality management representative who acts as a liaison between the top management and other parties, including students, faculty, staff and external organizations.

A very short section six 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 and internet connections. Another set of requirements relating to human resources attempts to ensure 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 I and additional interpretations from [17], 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 an engineering school they are applying to. This "raw material quality" is normally inspected through a student's Grade Point Average or sometimes even entrance exams. It is not uncommon for universities to keep lists of "approved" high schools or other universities, which is one of the ISO requirements. Another example is "control of monitoring and measuring devices" (element 7.6 of ISO 9001: 2000), which is nothing but the establishment of marking and grading schemes to evaluate student performance (but 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 monitored and improved.

As we can see, most of the ISO 9000 requirements represent common sense, already established in accreditation criteria or accepted as a minimum practice. This fairly low required level of effort is one of the additional reasons why engineering schools should consider ISO 9001 implementation. A possible approach to registration, summarized from [15], is provided next.

IMPLEMENTATION

The following seven-step roadmap may be used toward the development, maintenance and improvement of an ISO 9001 quality system in an engineering school.

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

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