Quality Assurance in Engineering Education and Applied Research

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Abstract

Total Quality Management (TQM) is recognized as an important management philosophy and is widely used in industry. Over the last few years, TQM principles, or other quality procedures, ISO 9001 for example, have also found application in the education system. Most of the applications have been in the administrative side of the institutions, although some engineering departments have attempted to apply TQM to curriculum development. A number of issues must be addressed in this respect, in order to establish a framework for successful documentation and implementation of a quality system in applied research as it is carried out in an Engineering Department or Academic Institute. The systems approach to quality assurance and the concept of a university production system could furnish the basis for a consistent interpretation of well established TQM principles to the Academic Environment, following the example of other researchers in the field. Successful application of these principles in the University environment meets significant constraints and it is necessary to define a more compact and systematic approach. In this work though, we shift our focus to a particular aspect of the academic research activity, namely, the interaction between industry and engineering departments, that can be used as a strong factor for the introduction of TQM principles in the academic environment. In this framework we discuss the merits of following quality management schemes in the interaction between academia and R&D departments of industrial partners. Listing these requirements as a starting point, quality assurance in the curricula may be systematically applied, and as we argue here, find the desired support by the academic faculty and students, due to its direct acknowledgement by the associated industrial partners. Specific examples are cited drawing from the authors' involvement in quality assurance in engineering education and applied engineering processes and research.

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1 INTRODUCTION

Quality in the academic environment is a fundamental principle embedded in the roots of the educational process and the multi-dimensional relationship between students and academic staff. Without oversimplifying the academic structure, managing successfully the quality of different aspects of the education system from administration to research and teaching, may prove vital in an era of international cooperation, continuous evolution and competition for limited resources.

It is generally accepted, that development of an engineering faculty must focus on quality and strategic research orientation. In this context, the faculty needs to produce specialized staff to support its applied research and strive towards an interactive synergy between research projects and the students' education. At a practical level, say that of the supply of R&D services by Engineering Laboratories to specialized development firms or industrial partners, need to be carried out in conformance with quality assurance schemes, in order to enable a reliable and efficient interfacing. In Europe, this necessity has become apparent during the long (over twenty years) involvement of our University Laboratories in the so-called European Commission RD&D projects. These are multinational research projects carried out by consortia of Industrial firms and Universities from collaborating countries.

In Greece, Universities are public-funded institutions that do not charge tuition fees to their students. Some faculties though, especially engineering faculties, can attract private-sector funding through their R&D services to industrial partners or private/public organizations. They may also be capable of taking advantage of significant European Commission funding allocated for the support of Research and Innovation among the member states. Thus, establishing a high level of R&D services by fully utilizing the faculty members' experience and the the graduate students/ researchers' potential, may decrease the reliance on the limited public funding and lead to a systematic organization of Departments and Research Laboratories capable of international recognition in their field of expertise.

Previous efforts to promote establishment of TQM principles in the curricula, seem to face reluctance from some faculty members, since it implies additional re-organization effort and the results will not reflect immediately on increased enrollment or public funding. A possibly efficient way to bring to the foreground the advantages of TQM would be to first apply its most important principles to R&D activities of the engineering department. The projected fast increase in industrial and other funding is expected to persuade the faculty members and the post-graduate students of the advantages of TQM application, and also dictate the required improvements in the classroom, the laboratory and the computer room to support quality in research. In the following, we present a point of view and an invitation to discuss these and related issues.

Total Quality Management (TQM) was first espoused by Dr. W. Edwards Deming in the late 1950's. Although his ideas were not initially accepted by US industry, they were heartily endorsed by Japan in their recovery from World War II, with results that attracted global praise and financial success[1]. It was only during the eighties that US and European industrial units began to exploit the advantages of a TQM approach, and profit especially in their interfacing with their daughter-companies in developing countries[1]. Universities have been slower to see the value of using TQM in their business, although several schools are now using TQM to improve their administration. In 1990 for example, Oregon State University successfully endorsed TQM as its management philosophy[2]. In 1988, the US Air Force Academy began an attempt at applying TQM to curriculum development and, in 1990, offered a course that was designed and conducted using the principles of TQM [3,4,5]).

Also, Universities that present a number of programs in different countries have a particular interest in providing quality assurance in their teaching. The advent of internet courses and video-conferencing lectures, makes inevitable the comparison of the education provided by any small regional engineering department to the top quality education provided by the best engineering schools of the world. On the other hand, internationalization of the world economy pushes engineering graduates to be employed in distant places across their country's borders, and thus engineering departments must now provide an adequate quality of education, in order to satisfy their future employers. In an analogous manner, it is necessary to assure industrial partners of the quality of the conducted applied research in the department's research units.
Industry has already faced similar problems during the past two decades, and efficiently solved them by introducing standards from the ISO 9000 family. In [3], Karapetrovic et al. argue that engineering faculties in particular should follow their industrial counterparts in this respect, and develop quality assurance systems based on ISO 9001. This would provide confidence to employers, students and the general public that their requirements for quality education and research are met, and would make systematic quality efforts visible. They offer a particularly useful model for the interpretation and translation of the ISO 9001 terminology to the so-called University Production System. However, according to their discussion, application of the ISO 9001 quality assurance system to the whole University environment seems to face difficult-to-solve problems. It seems to require the keeping of a lot of records and paperwork, in the traditionally liberal academic environment, which is known to produce high quality products in a more-or-less uncontrolled unrestricted way. For this reason, other researchers restrict the scope of the quality system in the University Environment to only the most essential elements[4,5]. Although research is an integral part of university processes and one of the distinguishing characteristics of academic staff, existing interpretations focus on the 'learning opportunity' and courses as a primary product of educational institutions [6,7]. In our approach, we focus on research and experienced engineers and Ph.D.'s as the first target in quality assurance. This interpretation, with the underlying production and quality system concepts will be used in this paper to develop a priority-based structure in our approach.

In the following sections, our discussion will examine the important role of University cooperation in industrial research, and address the application of important quality assurance criteria, starting from the Deming's 14 points and related ISO 9001 elements as interpreted in the University Production System[8].

2 WHY UNIVERSITY RESEARCH IS NEEDED BY INDUSTRY

Industrial partners in their interaction with the University R&D system expect benefits in a number of areas that include the ones listed in the following Table, where also the related industry wishes are drafted:

Table 1: Expected industry benefits from interaction with University R&D, with the associated wishes for each category of cooperation

Expected benefits from University R&D	Industry wishes in this respect
On-going fundamental or applied research in specific research areas	High level, in terms of quality, but also sense of reality (pragmatic approach)
Links for recruiting competent engineers	Quality assurance of curricula and graduates
Consulting services	Fast response, partial restriction of particular aspects of academic freedom, confidentiality, punctuality
Regular cooperation	Mutual understanding and respect of exclusive rights and intellectual property issues, quality assurance
Keep up-to-date with more recent developments	High level of knowledge in specialized areas, good understanding of industry needs
Contractual research in multinational projects that requires also academic participation	Find good partners, willing to cooperate constructively
Non-routine laboratory work	Quality assurance, customization
Independent testing of products/ independent verification of results – compliance with regulations	Quality assurance
Software development/ use/ specification of products or process components	Quality assurance, customization, good interfacing, understanding procedures
Training of industry's employees in specialized courses offered by the University.	Good mixture of basic scientific knowledge, applied engineering approaches and practices

In the following, we discuss in more detail the entries to the table above that address a number of different aspects of cooperation between University and Industrial R&D units:

- Cooperation in fundamental research, on-going for a number of years is particularly important for the industrial partners if they lack their own research in specific areas. This cooperation is usually strengthened by exchange of researchers (for example, Ph.D. students of affiliated Universities that do their work in research departments, say those of European Automotive manufacturers). High level of competency is required by the University research unit in this case, but also sense of reality (pragmatic approach), to produce useful results.

- Usually, the above mentioned relationship along with the active involvement of academic staff in cooperative R&D projects, produces also the necessary links for recruiting by the industrial partner, of competent engineering graduates from the affiliated departments. *Quality assurance* of curricula and graduate studies is obviously a key factor here.

- Another important form of University – Industry cooperation is the supply of consulting services by faculty members and researchers to industrial partners. In this case, a fast response and punctuality in the supply of services, the willingness to sacrifice a part of their academic freedom to engage in a fruitful exchange of information is important, as well as the adherence to confidentiality requirements (also extending to the laboratory staff involved in such projects), are important characteristics of the research unit required by the industrial partner.

- Successful cooperation of the above types usually results in a regular cooperation between the research unit and the industrial partner, which may proceed to a compilation of a list or database of affiliated Universities and their respective skills, that may be used whenever necessary to find a partner for a particular R&D activity. Good knowledge of each other's capabilities and interests, mutual understanding and respect of exclusive rights and intellectual property issues is necessary to develop such a long-lasting close and confidential cooperation, along with punctuality, non-disclosure of critical results and *quality assurance* in the work carried out by the University.

- Keeping up-to-date with more recent developments is essential to industrial R&D. However, the ever-increasing volume of scientific / technical literature always requires a significant part of the time of industry R&D staff. A viable alternative to this is to partly rely upon affiliated University research units, which regularly search specialized literature as part of their academic role, and occasionally (or regularly) consult with the industrial partners. Naturally, this is a very demanding task requiring from the University researchers a high level of knowledge in specialized areas, along with a good assessment of industry needs.

- Contractual research in multinational projects is now becoming more and more usual in Europe. A starting point to drop barriers between different countries were the so-called European Research projects, that always require academic institutions' participation in cooperation with industry. Nowadays, as an outcome of the long-lasting support from the European Commission, this from of cooperation is well established to the European Union, and also extended (and not limited to) most of the European countries. Being a good partner in this type of cooperation requires from the department to be willing to cooperate constructively with industry, following a *research quality assurance* policy.

- The performance of non-routine laboratory work by specialized University Laboratory Units is another well established category of University / Industry cooperation. In this case, the University research unit must strictly adhere to *quality assurance*, being regularly audited by external auditors, including the industry clients to conform to international standards. Also it should be willing to adopt a degree of customization to the specific needs of its industrial clients.

- Another related category of cooperation is the independent testing of products, or independent verification of results by University Laboratories. This requirement happens many times due to an occasional overload of industrial testing units, or due to the need of independent testing to spot possible deficiencies of the testing units. Proof of compliance of the University Laboratory with international regulations in this respect is essential to the successful involvement in this type of cooperation. Usually, the industrial partner is willing to share a part of the increased cost of this *quality assurance*, whenever the specific type of testing is important for its production.

- Software development, specification and use is another broad category of interest for University – Industry cooperation. The University research unit usually produces novel software that could be customized to industry needs and afterwards be transferred to a specialized company and become a valuable and well established industry design and optimization tool. Most of the popular industry software evolved in this way. However, in order to be really successful, this type of development must follow well established *quality assurance* criteria for software development, and also take into account the real world application requirements and input. This requires a good interfacing with the industrial partner, and a good understanding of its processes and procedures.

- Another important category of cooperation is the training of industry's employees in specialized courses offered by the University. This leads to a cooperating scheme where Industrial partners also offer a number of courses with mixed teaching personnel from industry and academia. Fees are charged for attending these courses, and also Industry employees are subsidized to attend University classes (part time undergraduate or post-graduate students. Thus, feedback for curriculum modifications / improvements is always available to address the ever expanding or changing industry needs. For this type of cooperation to be successful, a good mixture of basic scientific knowledge and applied engineering approaches is required. This must be reflected to the composition of the instructors' body in these courses.

As a general observation, it may be stated that the industrial partners have a much faster response to changes in directions of R&D, due to their strategic choices. For this reason, they are very fast in allocating human resources to different directions. This means that if a project is discontinued, the company would be refrained to know that intermediate results and accumulated knowledge to-date will be staying in the brain of an associated faculty member or even Ph.D., for at least five more years (naturally, with some risk for the knowledge to be available to a competitor that could hire the researcher's services, but this is how business goes as usual). So, if necessary, this material may be re-invoked at a later stage and, thus the company does not suffer a big loss (when companies discontinue internal research projects, usually the material is lost between some internal research reports- publications). This is a good explanation of one of the roles of University in industrial research. Also, it is well understood that *quality assurance* in the University services is vital to the successful involvement of all types of cooperation listed in the above Table's entries, and this could be taken as an axiom in the way top management of the most successful companies do.

The above could be considered as a starting point in the discussion of the extremely important role of University groups in industrial research. Of course, the fundamental research is always an activity mainly motivated by the researchers as units, and will always reside in the Universities and Research Centers. Many brilliant researchers are very keen on following directions in their fundamental research, even with minor or no funding at all. This academic liberty is essential to the advancement of Engineering Sciences. However, it must be clear that industry all over the world needs also from engineering schools to produce engineers who can solve open ended problems and produce quality design work[9]. And efficient teaching of this ability requires the participation of a good part of the faculty, staff and students to design and development projects that are really important for the industrial partners. And to succeed in fulfilling this important requirement, a significant, gradual restructuring of the Engineering Department will be required, that is described in the following.

3 PRIORITIES OF QUALITY ASSURANCE IN UNIVERSITY RESEARCH

The 14 points of Dr. W. Edwards Deming form a framework for the implementation of TQM [1]. In the following sections we further discuss the implementation of these points in an academic environment, making sure that they effectively address the industry requirements discussed in Section 2. Priority is given to the applied research and development activities, and the *quality assurance* for the curricula and the graduates' quality is considered to stem as a consequence of the research quality assurance. The Deming's 14 points are very general, therefore, when TQM is successfully applied, it is a result of a careful study of each point and a clear determination of how each applies to the situation at hand. As a consequence, the form that this particular implementation takes is dependent on many factors such as the size of the institution, the public character of the institution and the strengths of the people involved, but the most important variables are the maturity of the students and the involvement of the employer. In conducting applied research in partnership or in a direct-funding relationship with an industrial partner, the primary customer is the partner itself, or the European Commission, if it supplied the funding. Regardless who the primary customer is, it is essential that the undergraduate and postgraduate students be included in the list of customers.

Table 2. Interpretation of ISO 9001 in University Research activities (adapted from[8])

TERM	EXPLANATION in University R&D
Product	New knowledge and knowhow. Student and post-docs' knowledge, abilities & competencies
Customers	Industry, research sponsors, government, students
Supplier	Department / research unit
Subcontractor	Researchers
Executive Management	Head and Laboratories' directors
Design plan	Research objectives
Designer	Academic/ research staff
Process Plan	Research project plan, Program plan
Raw Material	Student knowledge and comprehension of basic arts and sciences. Existing practical and theoretical knowledge
Value Adding to Material	Value adding to researchers' knowledge and abilities as well as value adding to existing knowledge
Manufacturing Process	Researching
Lead Time	Time from contract to Delivery
Part	A phase in a research project
Operation/Tool	Work on a phase of a research project
Machine/Technology	'Research Opportunity'
Operator	Researcher, research assistant
Part Specification	Specification of deliverables in a research contract, (or individual research contributions from other partners / subcontractors to the common project)
Quality Policy	The overall quality intentions and direction of the department, as formally expressed by the department head
Quality Control	The operational techniques and activities used to fulfill the requirements for quality
Nonconformity	Nonfulfilment of specified requirements. Project failure

In the above Table, we borrow some interpretations from the concept of the University Production System that has been introduced and discussed in detail by other researchers in the field[3]. These researchers formulated the University Production

System (UPS), that considers engineering departments as a sort of 'factory' producing three main products[10]:

- competent engineers, well educated and aware of their social responsibilities
- technical courses and programs
- applied research and contribution to the development of high technology products,

by exploiting human, material and information resources, and starting from raw material consisting of students entering from the high school.

QUALITY SYSTEM OBJECTIVES
Management responsibility, customer needs & requirements
Quality policy, Contract Review

QUALITY SYSTEM DESIGN
Quality management system, quality planning, system procedures
Design control
Document and data control
Measurement, analysis and improvement

SUPPLY OF REQUIRED RESOURCES
Purchasing
Customer-supplied product
Inspection, measuring and test equipment
Resource management – Infrastructure – Work environment

DEVELOPMENT OF QUALITY SYSTEM
Training, qualification and competence
Product Identification and Traceability
Statistical Techniques

APPLICATION OF QUALITY SYSTEM
Process Management
Inspection and test status
Control of non-conforming product
Corrective action
Handling, storage, packaging and delivery
Quality records
Internal Quality Auditing
Servicing

FEEDBACK

Figure 1 Schematic of ISO 9001-2000 quality loop

An objective related to quality is to meet and surpass customer needs and requirements, combined with the desire to effectively eliminate defective products[11]. Processes within the *quality system* transform customer requirements (required output) into the product bearing the ability to satisfy the requirements (actual output). Thus, we can employ current, twenty-element version of the ISO 9001 standard, approved in 1994, is under revision expected to be completed in year 2000. The new version, ISO DIS 9001-2000[12] is very much improved in its structure, and incorporates the twenty elements of current version in a more logical and systematic order, to avoid the danger of emphasis on documentation and loss of the focus on the *quality system*[13].

In order to better understand the *quality system* requirements, ISO 9001 elements may be categorized in a *loop* like that of ***Figure .*** To proceed further with application, we only keep this more compact set of processes in mind, and employ a more general set of guidelines for quality assurance, like the Deming's 14 points.

In the following paragraphs, the Deming's 14 points are employed as a starting point for the discussion and reference is made, whenever necessary, to related ISO 9001 elements:

3.1 Create constancy of purpose toward improvement of product and service, with the aim to become competitive and to stay in business, and to provide jobs.

The constancy of purpose can be formally expressed in a mission statement. Such a statement for a Mechanical Engineering Department might be:`To develop the skills, attitudes, and motivation in our students so they will become good engineers and be capable of making positive contributions to the companies or institutes they work, both in research, design, analysis, testing, re-design and servicing, performing in a technically competent, socially responsible, and ethical manner.' More specific mission statements for a Department's Laboratories, that is, its basic research units, are also necessary to stem from the Department's mission statement. Developing a mission statement requires a real understanding of just why the unit exists, and is the best starting point for an efficient re-engineering of the department and its units, in order to increase its overall effectiveness in producing good engineers, applied research results and curricula. Once the mission statement is developed, everyone employed in the research units and the Department, should come to an understanding of how he/she contributes to the stated mission. Assessment of the value added by a process may be also done by checking if this process adds value to the mission.

3.2 Adopt the new philosophy. We are in a new economic age. Western management must awaken to the challenge, must learn their responsibilities, and take on leadership for change.

The underlying principle of a significant part of European and national R&D projects, is the awareness of the necessity of the new philosophy in this new economic age. The responsibilities emanating from the participation in these multinational efforts should also be reflected in every aspect of the academic environment. The Department and its Laboratories, should insist on quality in everything: classroom instruction, homework, technical reporting to industrial partners, secrecy in industrial research, office organization, restroom cleaning, interactions with the legislature. To achieve this quality, an atmosphere of cooperation as opposed to competition is to be instilled, in the classroom as well as in the laboratory and the research group; management must ensure that the processes put in force encourage cooperation at every level: student to student and faculty to student - researcher. Faculty members and staff should constantly seek to supply the students with the necessary knowledge and skills to become good engineers, researchers innovators and developers. A well known relevant ISO 9001 element is the *Quality System*. Applied research is to be included in the *quality system*, documented with an appropriate *quality manual*, procedures, instructions and records, to allow for proper communication, audits and verification. As a starting point, we believe that the *Quality Manual* can address only applied research activities as the product. Procedures explaining in detail who does what, when and where, referring-to in detail to sets of instructions (e.g. for laboratory measurements, system testing), should be included. Another relevant ISO 9001 requirement is the Contract review. The research contracts must be translated in such way as to identify stated or implied customer requirements, thus providing the department's laboratories with a clear understanding of industrial customers' needs and specifications. This allows to evaluate if these needs can be achieved, but also, in a second step, to provide the customers with a clear understanding of the manner in which the department's research units (laboratories) shall meet them. Successful completion of contract review activities will enable the department's units to demonstrate, as a next step, their ability to translate customers' specifications into appropriate design of research projects and supporting curricula [8]. This refers to the *Design control* ISO 9001 element. Naturally, the design of research projects is a joint process in which the industrial partner will have important input to contribute. However, the department's units should be willing to identify the required input from the partner, to heavily invest in the design of the project, by realistically assessing the contribution of each partner and the feasibility of the schedule, and finally be willing to validate the project work programme against customer's requirements and the department's and its units' mission and research policy.

3.3 Cease dependence on inspection to achieve quality. Eliminate the need for inspection on a mass basis by building quality into the product in the first place.

The implication here is the following: we should focus on the product or service process. Don't depend on audits, tests, or inspections to build quality. Inspections will only keep bad products from hitting the market, but there are large costs already incurred when the academic process fail. The analogy in education is that the failed engineering student is scrap that must be either reworked (take the course again or get extra tutoring) or discarded. We need to develop processes in which there is less testing but more focus on progress in learning[14]. In engineering education, this is attained by heavily relying on the processing of case studies taken from real practice engineering problems. For example, instead of giving a particular test just to evaluate the undergraduate or postgraduate students, we could gain this extra piece of evaluative information by analyzing the students' response to a specially designed engineering design case. Instead of checking and re-checking research results before communicating them to the interested industrial partner, the research group could develop further techniques to cross check the results with the results of alternative methodologies. Can a process be changed to make inspections unnecessary or at least to reduce the need for inspections? Statistical process control can be an important tool in developing processes that do not require much inspection [15]. Statistical techniques is a related ISO 9001 element, that helps to control and improve the quality of education and research. The need for statistical techniques in learning, teaching and research should be established, and the identified techniques (e.g. statistical process control, analysis of variance, hypothesis testing, design of experiments), implemented and controlled.

3.4 End the practice of awarding business on the basis of price tag. Instead, minimize total cost. Move toward a single supplier for any one item, on a long-term relationship of loyalty and trust.

The lowest bid usually does not result in the lowest life-cycle cost. In all our processes, we need to focus on long-term costs and benefits. That may mean that the trendy new course not be offered if it means the failure of a course with more long-term value. In terms of financial incentives, salaries to senior and junior members of research groups should not be kept to a minimum, especially if the engineer proves himself capable of matching the high quality needs of the funding industrial partners. In the context of assessing long-term benefits, the award of a subcontract to an off-campus company may have lower first cost, but the inability to get adequate turn-around time or poorer quality may make the overall cost of that decision very high. Engineering professors often complain about the mathematicians' poor preparation of first- and second-year students for studying engineering sciences. The long-term costs of supplying efficient engineers to society and industry could be less if some of the resources of the university were spent on improving the teaching of mathematics to the newcomers with specially designed support courses and the involvement of engineers in their preparation and implementation. The purchasing ISO 9001 element, addresses the rational acquisition of necessary resources, including academic and support staff, information and material resources (hardware, software, equipment and facilities), as well as students, ensuring that these resources conform to the specified requirements. This will enable the university to fully exploit the acquired resources in producing high quality research without wasting the faculty, staff and students' time in non-productive activities. The department should invest on clear and demanding procedures covering the purchasing of hardware and software, possible subcontracting of equipment maintenance and the admission of postgraduate students, researchers and staff to research projects, keeping adequate records of these procedures will allow continuous improvement.

3.5 Improve constantly and forever the system of production and service, to improve quality and productivity, and thus constantly decrease costs.

Customers (students and industrial partners in applied research) should be increasingly satisfied, and if this does not happen, we should find out why and fix the situation immediately. If this happens, we should determine what it was in the process that made it so. In any case, we should analyze the process to determine what changes can be made to make it better. Incremental improvements must be made every year, encouraging innovation, but insisting upon incremental improvements, especially after the innovation[16]. Carefully designed questionnaires can be helpful for process analysis, but talking directly to the customer continues to be the best way to find out what the problems are. Also, when we talk directly to the industrial partners about their problems, they nearly always appreciate it, and make the `us versus them' attitude much less likely. A related ISO 9001 element is *Process control.* This element stresses the need to properly organize and schedule the research processes, in such a way that they can be conveniently controlled, by referring to documents describing how tasks and subtasks are carried out. This includes identification of the necessity of use of suitable equipment and working conditions, as well as the maintenance, handling and preservation of measurement and test equipment used in research activities. Process control allows continual improvement of experimental layouts, based on the revision, on a regular basis, of the processes and also the regular monitoring of new developments in test equipment and techniques.

3.6 Institute training

Training in the industry is a continuous process, where employees enroll in courses offered by academic institutions or industrial units with the appropriate qualifications. The same should be applicable to the faculty and staff. However, institute training may be assumed to be mainly effected on job. The faculty is certainly well educated in their disciplines but maybe not in the art of teaching, or the art of engineering design and application of its disciplines to real world design optimization cases. But the rest of the personnel should also learn better their job through participation in development seminars. Word processing classes help secretaries do their job better. Money spent on faculty and staff training has long-term payback. In addition, you should teach TQM to everyone: faculty, staff, and especially students. The more everyone knows about the management principles used on a daily basis, the easier it is for everyone to be part of it. *Training* is the related ISO 9001 element. Training of faculty, staff and researchers should be seriously taken into account, in order to maintain professional competence, and satisfy the ever increasing needs of our industrial partners. Keeping records of training activities is also helpful for the assessment of their effectiveness and for future planning.

3.7 Institute leadership (see Point 12 and Ch. 8[1]). The aim of supervision should be to help people and machines and gadgets to do a better job. Supervision of management is in need of overhaul as well as supervision of production workers.

Leadership should be emphasized instead of management. Each faculty member, laboratory director or group leader should try to be more of a teacher than a judge. The leader should insist on a creative environment for his group. Effective leaders will search for barriers to communication and productivity and remove them. A poorly lit classroom or a poorly designed research work place can have a significant effect on student and researchers' performance. An effective leader will immediately notice and fix this type of problems. Also, the examination, storage, maintenance, preservation, handling and proper usage of hardware and software provided by research sponsors, industry and governmental institutions and/or agencies should be documented by appropriate procedures and records. *Handling, storage, packaging and delivery*, is another related ISO 9001 element. This refers to the supervision of the proper handling, storage and maintenance of scientific and testing equipment and facilities. If we notice any damage or deterioration of equipment, we may implement corrective and preventive actions. Institute leadership is also apparent in the provision of a healthy, pleasant and safe work environment for the faculty, staff and students involved in the research activities. The possibility of self - funding of these provisions by the marketing of research results will further enhance their applicability to the whole department.

3.8 Drive out fear, so that everyone may work effectively for the company

In the academic environment, fear is often a factor in student and faculty performance. For students, any steps that can be taken to reduce the fear involved in taking a test or case study will pay large benefits in student performance and attitude. Allowing for a make-up exam, points for reworking missed problems on an exam, and dropping a low grade are examples of little things that can be done to reduce student fear. Teachers must balance their roles as educators versus evaluators. On the faculty and research staff side, fear can also play an important role. If a high price must be paid for failure, few people will be willing to risk experimenting with a promising new innovation, thus keeping a process improvement out of the system. If a teacher would like to try an innovative teaching technique, the effort should be applauded even if it is a failure. Certainly something of value will have come from innovative and difficult experiments. Researchers must have the opportunity to fail without the fear of demotion or lack of promotion opportunity. They should be encourage to test the extents of the possibilities of their equipment, even with the danger of damage, because the new knowledge acquired in this way is worth the risk.

3.9 Break down barriers between departments. People in research, design, sales, and production must work as a team, to foresee problems of production and in use that may be encountered with the product or service.

We should encourage cooperation, not competition between the Department's research units. The problems faced by industry today, nearly always require a multi-disciplinary approach in order to have a chance to find an acceptable solution. Our customers feel much more comfortable when they address their problems to an harmoniously cooperating ring of laboratories of the same Department, because their and our experience proved that bringing together engineers and scientists from various disciplines usually helps to solve difficult problems in applied research. This process is facilitated by the regular communication between researchers from different laboratories, in the form of seminars, unofficial presentations of unclassified intermediate research results, personal relations etc. Also, the Department must encourage the forming of cross-function teams to address problems and process improvements. A team made up of faculty, staff, and students will have a broader perspective in addressing issues than a more narrowly composed committee. Finally, when addressing problems in the educational process, we should address it with a team consisting of representatives from every involved organization, faculty, advisors, students, registrar, computer services, etc.

3.10 Eliminate slogans, exhortations, and targets for the work force asking for zero defects and new levels of productivity. Such exhortations only create adversarial relationships, as the bulk of the causes of low quality and low productivity belong to the system and thus lie beyond the power of the work force.

Instructing someone to do good is meaningless without the means to achieve that goal; instead, improvement of the processes is required, so that the goals can be achieved. Stating that 80% is the minimum acceptable score on an exam will not by itself achieve that goal. Stating that goal and then providing excellent instruction, arranging for study teams, giving extra help where needed, etc., will give the students a much better chance for success. Our students always ask us to prove them, by means of well organized case studies from real industrial R&D problem solving, in which way the advanced material we teach and require from them to study, is applied in real world design situations. Only then are they willing to increase their effort to the levels required to meet the goals set by the faculty.

3.11 (a) Eliminate work standards (quotas) on the factory floor. Substitute leadership. (b) Eliminate management by objective. Eliminate management by numbers, numerical goals. Substitute leadership.

It is often said that numbers are the crutches of poor supervision. On the assembly line, this principle is easy to see; in the academic setting, it is not as obvious but just as true. If we try to assess the laboratories' efficiency in terms of the number of papers issued per year or the total EURO's of industrial or EC funding attracted, quality could decrease. The number one priority should be quality. Only after the process is designed so that quality is assured should the questions of quantity be addressed. This should also mirrored on the type of research activities the department is engaged (a smaller number of highly paid, difficult research projects, instead of a bulk of low paid studies that could easily be carried out by specialized engineering offices).

3.12 (a) Remove barriers that rob the hourly worker of his right to pride of workmanship. The responsibility of supervisors must be changed from sheer numbers to quality. (b) Remove barriers that rob people in management and in engineering of their right to pride of workmanship. This means, *inter alia*, abolishment of the annual merit rating and of management by objective (see Ch. 3).

Moving from sheer numbers to quality is a natural objective in applied research, where the content of individual contributions and not the number of publications is usually important. In the academic setting, pride, a strong motivator, certainly flows from personal and group achievements, but there is also a good deal of pride in the institution itself. Often this institutional pride is a result of its past, or having survived a very demanding program of studies, but it can also stem from having had a part in the development of that program. If the students are included in some of the decision-making processes, they will develop a strong pride of ownership that can have a significant impact on their attitudes. The same is true when they are engaged in research projects, based on a careful selection procedure. Young engineers or even engineering students have been demonstrated exceptional performance in many cases. They have been able to quickly assimilate a project's essence, be employed in specialized tasks and work efficiently at night hours to achieve a good presentation of results. Human resources engineering has been used to profit from the various types of staff that could be employed in different research and support posts. The same is true for the selection of graduates that would be ideal for specific industrial research posts. In general, pride may be developed in the University environment, and interfaced with specific industrial partners' attitudes to lead to excellence. Using some of the elements of cooperative learning also empowers the students by sharing some of the teaching role with the faculty. A secretary who is allowed to choose how the work is to be done and has a voice in some of the administrative decisions that affect his/her work, will be much more productive in his/her contribution. A relevant ISO 9001 element is *Quality planning*, covering the identification, classification and weighing of product quality characteristics, establishing the objectives, requirements and constraints for quality, as well as the preparation of quality plans. A typical research quality plan should include: research objectives and specific knowledge/competencies to be developed, research prerequisites & statement of any incoming inspection of researcher background knowledge, detailed schedule and layout of deliverables, list of required software and laboratory test equipment, instructions for laboratory technicians, detailed inspection plan, including the type of tests planned.

3.13 Institute a vigorous program of education and self-improvement.

Everyone in the department must be included in the education process and be aware of and concerned for their immediate 'customer'. This is especially true for Ph.D.'s and undergraduate students engaged in the work. Rapidly evolving technologies require from the faculty, researchers and staff to engage in all aspects of their Laboratory work, to be willing to learn details of their equipment technology and be able to meet or supervise service and troubleshooting themselves. This is absolutely necessary in an age of increased complexity, where we can no longer overload our technical staff with every kind of technical problem faced during research and teaching activities. Our students and future engineers should be inspired with this new, task-oriented philosophy, that inspired the re-engineering of big international corporations in the nineties[17]. This requires a little more interest and interaction between each other's job in the same unit. Technicians who sit in on the courses that they support will have a much better idea of how their work contributes to the mission. Secretaries who learn about new techniques and technologies for use in the office are much more likely to suggest improvements to the processes they are exposed to. Faculty members who learn about TQM are much more likely to endorse the concept and to suggest new ways to implement it in their jobs. One cannot predict just what piece of knowledge will spark the idea that will lead to a significant process improvement.

3.14 Put everybody in the company to work to accomplish the transformation. The transformation is everybody's job.

Management, at every level in the hierarchical reporting line, but particularly at the very top, must support the TQM philosophy. Clarity of interpretation of Deming's 14 points to the mission and the associated processes could take place only after analyzing /debating the relationship between TQM and those processes. Only the essential documents and data pertaining to the *quality system* need to be addressed at a first step, in order to prevent overloading of the faculty and personnel with paperwork. It should be limited to a compact version of the Quality Manual, along with the most important procedures, instructions, records and research project work programmes. *Management responsibility* is a related ISO 9001 element. Overall objectives of the *quality system* are stated in a document called the *quality policy,* drafted and signed by the department head. For example: *The Department of Mechanical & Industrial Engineering is committed to high quality in teaching and research, aiming at covering the needs of our students and industrial partners. A documented and implemented quality assurance system supports this policy, which is understood and followed by all faculty, staff and researchers, and this is continuously checked and ensured by the chairman and the laboratory directors.* The scope and extents of responsibility and authority of the faculty and staff should be clearly indicated on organigrams. The department's management is responsible for the identification of need for additional resources and for conducting internal *Quality Audits*, to better assess quality system effectiveness. Records of the results of these audits must be regularly reviewed, to check if the actions prescribed have been completed. The above relate to management responsibilities, and the hierarchical reporting line, starting from the technician and student, and reaching the chairman, with their respective responsibilities:
All employees are responsible for:

- The quality of their own product and service, as well as
- Understanding and implementing the *quality system* and *quality policy* within their department

All managers (laboratory directors, faculty members, group leaders) are responsible for:

- Identifying resource requirements for management, performance of work and verification activities
- Ensuring that employees understand the *quality policy*
- Ensuring that employees receive training necessary to do their job
- Reviewing quality issues at their staff meetings and
- Use awards (of merit, excellence) and other programs to encourage employee participation in the quality improvement process.

4 STRATEGIC IMPLEMENTATION ISSUES

The most important issue associated with TQM application in the University environment seems to be to demonstrate measurable benefits from applying quality assurance in this context. Although eventually you will surely gain credit in this aspect, the process goes to a slow mature, whereas you need to quickly gain the trust of your customers. Because of the fact that your competitors may have already gained such a credit and fame, a strategy that would give the fastest results should be selected. In this aspect, we would suggest the application of the above-mentioned points to the applied research activities of the department.

Essential for the application of the points is an initial period with recording processes as they occur in the engineering department's environment.

Record the hours per week that the student, faculty member, staff, spends in various tasks:

- Student: classroom, lab, computer room, self-study, literature search, homework, case study
- Research engineer: design, analysis, testing, support and administrating activities
- Faculty member: teaching preparation, teaching, administration, management committees, design, analysis,
- Staff: testing,

Experience shows that introducing quality system issues in an engineering department's environment usually faces severe constraints by academics, who would like to safeguard their academic liberty and avoid inspection and documentation. On the other hand, if we focus on the establishment of the most essential features of a *quality system* that will enhance productivity in applied research from which most faculty and staff members will benefit, then endorsement of this policy is more probable and justification of the required documentation can be adequately effected for everybody involved.

The one factor that is the most influential in the success or failure of a TQM implementation effort is universal endorsement, in particular at the top. If management does not fully endorse TQM, it is unlikely that an implementation effort will be successful. Endorsing TQM represents a fundamental change in the way one does business in the academic environment. Less than full support by anyone in the chain of authority essentially condemns the effort to failure. We do not forget that faculty members are a very independent group of people, and consensus on any issue is unlikely. If one of the opponents in this effort of ours happen to be in our chain of command, we would have significant difficulty in achieving our goals. It was also very important to get the student's endorsement by making them part of the solution. We therefore have to teach them about TQM by letting them engage in research activities and showing to them the effect and acknowledgement of their job's quality by real industrial partners. In an industrial application, the customers will include the purchaser of the product or service, suppliers, subcontractors, etc. A careful identification of the customers in the university setting needs to be accomplished. It can rightly be argued that there are many customers of the university including the students, the employers of the school's graduates, the parents of the students, the taxpayers, the whole of society, the State Legislature, etc.

We argue that by identifying our students and industrial partners in research as our primary customers, we could end up satisfying all of the other customers. On the other hand, by focusing on a customer that is too far removed from the operation, it is very easy to overlook the needs of the more immediate customers.

It is not uncommon for universities to address the needs of industry in curriculum development; however, students are usually treated more as a product than a customer. It is likely that many of the problems that plague some universities stem from an effort to make a remote body happy while inadvertently ignoring the students[18]. This is a classic case of improperly defining the system. All relevant participants must be included in the educational system. Once all participants are identified, the relative importance of each participant can be established. Taking a systems approach to education can be a very useful endeavor. Customers must make an informed decision in deciding what they want, taking into account costs, performance needed, legal issues, etc.

Engineering faculties are not so willing to adopt ISO 9001 procedures, because they consider them as introducing a lot of unnecessary paperwork, without really solving any problems. Experience from previous applications of quality systems in education shows that sacrificing a part of our time in following strict and recordable procedures, only disturbs a little the growing of a valid and deep relation between professor and students. On the other hand, it covers a number of quality aspects of Engineering Education, that may be even more important for the future engineer who will enter a highly qualified and competitive environment in a job that will be necessary to conform to increasingly stringent quality standards. This is the main reason that motivated this work, because in our relations with engineering students on the one hand and R&D engineers on the other, we think that we should treat with the same *quality assurance* standards.

Excluding the time spent in education or information sessions, engineering companies must allocate the time devoted by their personnel to pure engineering work like:

- Design
- Analysis and
- Testing

In this process, they should also include accounting of other type of activities like

- Planning
- Time spent in meetings

This is done by means of special accounting procedures, in which each engineer must submit on a weekly basis an account of hours (or a percentage of time) spent in each project, with a differentiation among the above three categories. This procedure allows a valid accounting by the company and a reliable cost analysis for future projects.

The adoption of a similar system in Engineering Education seems to be a necessity today, because of the variety of ways in which the faculty and the personnel (also the students) could allocate their time. In this way the department's research units would be able to do a rational costing of their research activities, and communicate better with industrial partners. The lack of adopting a reliable accounting system in engineering faculties, causes significant problems in their operation today, that can no longer be ignored.

5 CONCLUSION

The concept of the Quality System (as described in the ISO 9001 supporting elements) along with Deming's ideas for quality management, provide a framework for the interpretation of quality assurance processes in Engineering Faculties. Systematic quality efforts in this direction can help Engineering faculties to reorganize their structure efficiently, provide focus on quality and achieve international recognition in their fields of expertise. Participating students and researchers can also see a validation and recognition of their work in their interaction with industrial/research partners. Here we argued that since this is an important aspect of University research, it could be used as a starting point for the introduction of quality assurance in engineering education and applied research in general.

Historically, application of TQM and ISO 9001 processes has proven to be a powerful tool in the academic setting even though it was developed primarily with manufacturing processes in mind. A strategic approach to the implementation of these schemes was debated here with the following key points being identified:

- gain the support of everyone in the academic hierarchy,
- identify the primary customers as our students and research partners,
- focus on refining the process to attain our goals, and
- use Deming's 14 Points and the related ISO 9001 elements as a guide and checklist during the implementation effort.

In this paper we present such a strategy that gives priority to *quality assurance* in applied research and interfacing with industrial partners.

SHORT BIOGRAPHIES

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