Graduate Engineering Education Emphasizing Continuous Quality Improvement

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Abstract

A proposed program and plan of execution for integrating continuous quality improvement principles, methods and practice into the graduate education and research programs of engineering and science students and faculty is presented. The objectives of the program, which is being developed cooperatively between the Semiconductor Research Corporation (SRC) and North Carolina State University, are to instill Continuous Quality Improvement (CQI) principles and practices in the university research culture, conduct research of greater relevance to industry and reduce the time to completion of advanced degree requirements while better preparing graduates to become productive more rapidly on entering industry or academia. Initial implementation will be accomplished with a pilot program that can be scaled up to all participating SRC universities and many of the U.S. semiconductor corporations. This program will also provide a model for other technology based industrial sectors looking to universities for the cutting edge discovery, invention and innovation necessary to compete in a global marketplace.

Background

The proposed program has grown out of the interest by the Semiconductor Research Corporation in developing a Supplier CQI initiative and a project funded by the NSF supported Engineering Education Coalition (EEC) SUCCEED. The SRC identifies its suppliers as the universities that conduct semiconductor research for SRC and that prepare graduate students in the physical sciences and engineering for careers in the semi-conductor industry. The goals of the CQI initiative are to have the technical graduates enter the semiconductor industry more quickly, become effective and productive contributors more rapidly and to improve the quality, relevance and productivity of semi-conductor research conducted on university campuses. The objectives of the SRC Supplier CQI initiative are: (1) to teach CQI to science and engineering graduate students, (2) educate research faculty in CQI principles and practices, (3) have CQI applied in the conduct and performance of semiconductor related research and (4) introduce CQI into the process of research and graduate education administration. These objectives parallel recommendations presented in the National Research Council sponsored project report, “Reshaping the Graduate Education of Scientists and Engineers” 2.

North Carolina State University (NCSU) has proposed to work with SRC in the development of a program to meet their Supplier CQI initiative objectives based on three specific motivations. The program would provide opportunities to: (1) improve the graduate education and the research process on the NCSU campus, (2) provide leadership in this type of effort for the research and graduate education community as a whole and (3) take advantage of a SUCCEED funded Quality Improvement Partnership (QIP) program with industry proven at the undergraduate level that can be adapted to graduate education.

The QIP program is an interdisciplinary upper division undergraduate industrial quality internship activity hat grew out the TQM University Challenge. Beginning with North Carolina State University and Milliken and Company in 1992 the project has developed with assistance from the SUCCEED NSF EEC project into a program involving five universities in the southeast and multiple industrial supporters. A unique feature of the program is its multidisciplinary make-up involving students and faculty from departments in engineering, business and management statistics, engineering technology, textiles and other disciplines. The program prepares upper division students to work in multi-functional teams on industrial sites during the summer to address and resolve real quality production and operations problems. During the preceding spring semester the student participants enroll in a specially designed course emphasizing and developing skills in the application of quality tools and processes. The preparation course was developed by a team of instructors who consulted extensively with management and training associates at Milliken and Company on course objectives and content. Faculty and site personnel interact weekly with student teams during the summer project experience. Success is measured in terms of realistic return on investment criteria established by the industrial sponsors. The details of the program and its benefits are described in several papers[3'4'5'6].

Program Objectives and Features

The overall goal of the proposed graduate level program is to bring about systemic reform of the university graduate education and research process through the application of quality principles and practices together with a close and effective industrial partnership through SRC to produce a CQI research culture on university campuses. The principle components of the educational portion of the program consist of rescheduling and modifying the plans of formal study with integrated relevant team based research project activity for both Masters and Doctoral candidates. This will shorten the time to complete degree requirements; provide a series of specially designed immersion workshops to instruct students and faculty in continuous quality methods and principles as applied to the research environment, include industrial internships emphasizing cross functional team approaches to relevant industrial research needs, develop the student and faculties technology management skills and provide focused research residency experience directly related to the students anticipated professional practice.

The educational and research program efforts will be based on teams of students and faculty both on campus and in interaction with industry site participants. Significant corporate sponsorship will be needed to provide support for students and their project and research activity. This will remove from the students the burden of generating income which in many instances is a major cause of delays in completion of degree requirements. The required support will need to extend through a research residency during which a close working relationship will be developed between the university research team of faculty and students and the industry that is supporting noncompetitive semiconductor research on the campus.

Educational Program Details

In the first year of graduate study participating students will enroll in 12-15 credit hours of course work per semester. Although this is a larger course load than usually carried by frost year graduate students it will be possible since they will be fully supported and can devote all of their attention to the program of study. This schedule will effectively allow students to complete all degree requirements for most Masters' Degrees in engineering and science in less than a year and a half. Prior to enrolling, or very early in their first semester, the student will be assisted in identifying a faculty member to serve as their graduate advisor throughout their entire program. The student's graduate committee will be established and with their assistance the plan of work will be developed. Repeated interaction will take place between the student and the advisor during the frost year to

promote an effective working relationship and to insure staying with the schedule of the program. During the first semester students will "also attend a 20 hour two and a half day immersion workshop that will provide them with an overview of the semiconductor industry, the mission and objectives of the SRC, SIA and SEMATECH - and the goals, objectives and operation of the new program.

In the second semester of the frost year all students will participate in forty hours of CQI workshops. This is essentially the equivalent of a 3 credit hour semester course. The instruction will be accomplished through a series of immersion workshops each scheduled to last about two and a half days. The subject material covered in the workshops will be coordinated with and assist in the process of selecting and planning an industry based research project to be conducted by a multi-functional team during the following summer. These summer research projects will be carried out at industry sites with intensive and frequent interaction between students, faculty and site personnel. Prior to the summer internship the students will attend another 20 hour immersion workshop that will concentrate on data analysis and presentation tools and skills. At the end of the summer internships the student teams will prepare and present reports on the outcome of their research efforts to their industry sponsors in a day long event.

At this point the students will have essentially completed all requirements for a Masters Degree. In those instances where specific departments or disciplines require a project report the summer experience can be used as the basis to satisfy that requirement. Hence, by no later than the end of the fall term of their second year all of the students should have passed their final oral examination for the Master's Degree. This schedule will have reduced the cycle time for the degree from what normally is 2 to 2 1/2 years to about sixteen months.

Students will again take 12-15 credit hours of course work per semester during the second year of the program. This will result in satisfying a major portion of the plan of study course requirements for the Doctoral Degree by the end of the second year. During each of these semesters the students will also take an additional twenty hours of advanced CQI workshops. These again will be scheduled as intensive two and a half day immersion experiences. One objective of this instruction will be to prepare the students to perform technical management functions during their second summer in support of the next first year student industrial internships. During the spring semester the student, faculty advisors and industry mentors will identify and agree on a dissertation research topic and plan the remainder of the students program.

In the industrial project during the second summer the student will work on a project related to their dissertation and develop the basis for a thesis proposal. By the end of the second summer or during the fall term of the third year the student will enter candidacy for the Doctoral Degree and enroll in additional courses as prescribed by the plan of study to support the dissertation research. The remainder of the third year (and what ever additional time is required) the student will complete course requirements and concentrate on the conduct of the dissertation research and the final thesis preparation and defense. It is anticipated that this schedule will accelerate the present cycle time for completing both the Masters and Doctoral degrees to about three and a half years or four years. Currently this process is taking anywhere from five to seven years.

An important issue this accelerated rate of degree completion raises is that faculty researchers who have brought these students along are rewarded by losing their trusted and valuable research associates sooner. To address this problem students after graduation will continue their association with their faculty advisors in a research residency for a period of one to three years. The student will become a research associate to a faculty advisor in the noncompetitive semiconductor research under support by the SRC. These research associates can also play an important role in providing increased liaison between the SRC members companies and the university research effort supported by the SRC. In this fashion highly effective research teams consisting of

senior faculty directors, faculty associates, research residents, doctoral students and masters students will evolve as the program expands.

CQI Workshop Contents and Schedule

The CQI Workshops will be in an immersion format to begin on a Thursday morning and extend through Saturday noon. Four such workshops together with a special Program Introduction are planned for first year students. The workshops will consist of formal subject material presentations integrated with team based active and cooperative learning activities. The objectives of the workshops will be to teach CQI methods, develop skills in their use and apply this ability to the planning and conduct of the first summer intern research experience. Following the Program Introduction (Prepare) session the workshops will follow the pattern of the Deming PDSA (Plan, Do, Study, Act) cycle. Table I represents an abbreviated summary of proposed topics for the material content and example assignments and activity of these immersion events. The eventual content of the workshops will be developed in consultation with both industry and other academic practitioners of CQI. The procedure will be similar to that used to develop the preparation course for the QIP program except that for the SRC workshops, the consultation will be national in scope.

The advanced CQI workshops for second year graduate students, also in an immersion format, will concentrate and expand on the application of statistical techniques and advanced quality methods (Quality Function Deployment, Design of Experiments, robust design, Statistical Metrology, etc.) along with greater in depth coverage of and practice in strategic planning, project and technology management, leadership development and interpersonal and communication skills.

Program Initiation and Team Composition

It is proposed to begin the program this summer with a pilot precursor internship project activity involving three to four universities and industrial participants. This same type of pre-program implementation effort was used very successfully in the development of the QIP program with Milliken and Company. The CQI preparation of the participating students and faculty will be take place in two stages. In May all participants, university and industry, will attend a two and a half day workshop for an overview of applicable CQI principles and methods together with program operation and logistics details. This will be followed by a week of immersion instruction for the students in the expansion and application of the previous CQI overview. The second stage will be continuing instruction in CQI to all participants while the project is underway. This will typically take place periodically on the average of a day every two weeks during the ten week on-site project effort. The students will be chosen from first year graduate students at the participating institutions. This effort will provide both valuable information and an initial cadre of faculty and students with direct experience to assist with the implementation of the Phase I of the formal program in the fall of 1996.

The student/faculty/industry research teams for Phase I of the formal program will be constituted to be both multi-functional and multidisciplinary. A variety of team sizes and compositions will be used to demonstrate the flexibility of the team approach. Table 2 gives a summary of options suggested for team composition. The composition of the teams will be a joint decision of SRC and the participating universities and industry partners in the formal program. One or two technical faculty advisors and at least one industry advisor will support each team. The teams will be supported by three additional faculty; one to provide coordination for all operational and administrative requirements, one to provide both statistical and management support and one to act as a CQI team facilitator. The collected group of the student's graduate program chairs, some of which will serve as the technical faculty team members, will also serve in an advisory capacity.

To implement Phase I this fall several groups of two to four universities in different regions of the country will be identified in the summer and invited to participate. These will be chosen from institutions at which SRC is currently supporting semiconductor research and should be geographically close enough in each region to provide for convenient communication and direct interaction with each other. Two to four SRC member companies in the same regions will also be recruited to participate. The latest electronic means will be used for communication between all parties but it is recognized that face to face meetings and interactions will be both useful and necessary. Overall program coordination and administration will be provided by North Carolina State University and SRC in Research Triangle Park.

Advantages and Benefits

There are a number of advantages to begin this program as proposed. The probability of success will be increased by beginning with a small precursor internship project activity this summer. The effort is small enough to be easily managed while being large enough to demonstrate the program concept and test some features of an expanded program. The experience gained will be invaluable for implementing the formal program and the risk associated with the initial investment will be minimized.

Selecting participating universities and companies for Phase I that are in geographic proximity and that are now actively involved with the SRC will further promote success of the initial implementation. Using a mix of team compositions will demonstrate the potential for use in a variety of industrial situations. Experience with the QIP program at the undergraduate level indicates that the cost of the 10 week summer internship research team project experience will be about $10,000 per student plus faculty and project support with an expected pay back in less than one year. Experience with the QIP program has been that the return on investment to the sponsor is many fold more than the cost. It is anticipated that these projects will produce similar results.

Although this program is directed towards the specific needs of the semiconductor industry and developing effective partnership between universities and this industry it will serve as one example of how systemic reform in graduate education and research can take place. Hopefully this program can become a model for other similar initiatives to create effective partnerships with different U.S. industry sectors in their continuing effort to remain competitive in the world marketplace.

Role of Top Management

The proposed program to address the SRC Supplier CQI initiative focuses on those individuals actually engaged in semiconductor education and research, namely the faculty, graduate students and industry mentors. However, ask any CQI consultant and they will tell you that a quality program must begin with top management. Deming preached this uncompromising requirement in all his four day seminars and in most of his books[7]. He was famous for literally walking away from invited consulting opportunities if the chief executive of the organization was not going to lead the change.

Consequently, a parallel activity has been proposed by the SRC whereby corporate top management from the semiconductor industry will meet with the top management at the SRC universities to promote CQI on campus. This interaction will inevitably evolve into long term partnerships requiring a continuing dialogue at all levels of management to address the very real problems with bringing CQI to the academic and research missions of the university. In fact, there has been only moderate progress in applying CQI to teaching and learning and little if any to the actual research process beyond contract administration.

Currently, the Total Quality (TQ) Forums initiated by Motorola, IBM, Milliken, Proctor and Gamble and Xerox bring together top executives from major U.S. corporations and the top executives at the major North American universities offering degrees in engineering and management. The proposed program will build on these TQ Forums by focusing on removing the barriers to faculty, students and administrators learning CQI, applying CQI to their research, integrating the team internships and research residencies into their degree requirements, and providing research faculty with the necessary hardware, space, and human resource requirements.

A three and a half day "kick-off' meeting is planned for summer 1996 to link the top management at the SRC with those that will be involved in the team internship projects during the summer of 1997. Attendees at this meeting will be top management from the SRC, including the directors of the eight science areas and their internal CQI team, selected faculty currently doing semiconductor research through the SRC that are interested in participating in summer team projects, semiconductor industry mentors that already play a vital role with the graduate students and provide the semiconductor industry's perspective and several graduate deans and research administrators from some of the SRC universities. The primary purpose of the meeting will be to focus on and explain the proposed program in detail to obtain buy-in from the stakeholders that will be intimately involved in the success of Phase I. This meeting will also provide the opportunity to introduce the attendees to the CQI principles and practices most applicable to semiconductor research, focusing heavily on statistical techniques and analysis and strategic planning.

In fall 1996, a follow-on meeting of all stakeholders in Phase I will be held for the purpose of finalizing the details of how the CQI immersion workshops and the summer team projects will integrate into the plans of study of the students that will be recruited to participate. The process of establishing an independent evaluation and assessment plan will also be initiated as the program begins. This will insure that the results of the projects can be established from an objective data-driven standpoint, not a anecdotal subjective view. An advisory board will be constituted representing the SRC, semiconductor industry, research faculty, students, and university graduate education and research administration constituencies to review program progress and provide guidance for improvements from their specific perspectives.

Program Expansion

Eventually the program will be expanded to include all interested universities involved with SRC as well as all interested SRC member companies and locations. As each phase is initiated the new university and industry participants will begin their involvement as an observer in the year preceding the actual program implementation to provide for a smooth transition into the actual program activities.

The Preparation Workshop materials will be developed in a form that can be used by all university-industry partnerships in much the same way that the QIP Preparation Course materials are being developed in transportable form. The Preparation Workshops may themselves take place in the different regions to permit direct interaction by SRC universities and industry partners. The key to having Preparation Workshops located in several regions will be having a single organization, such as the Center for Creative Leadership, that has the capability to organize and administer the logistics of such an arrangement.

Summary

It is the firm conviction of the authors and consistent with views of others[2] that the current university graduate education and research process is in need of systemic reform Only then can these programs be

responsive to the research and technical manpower development needs of high-tech U.S. industry in its continuing effort to remain' competitive in the world marketplace. With the accelerating rate at which change is occurring in the modern world any system that is unable to respond continuously to its customer's changing - needs is doomed. It is sure to quickly find itself non competitive and in real danger of being replaced. This is a very real crisis and potential outcome that research universities in this country must recognize and respond to. This critical need must be met if our way of life and standard of living are to be maintained as our nation moves into the twenty first century.

The proposed program embodies concepts and processes that have been applied successfully by many U.S. firms and industries to improve their competitive position in the market place. These methods can do the same for university graduate education and research. Not only will it make this critical national resource more responsive it will also increase the efficiency, relevance and productivity of our research universities; all key factors in being competitive.

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Table I Contents of CQI Workshops

Program Introduction (October) - *Prepare*

Material Content
- Semiconductor Industry Overview
- SIA / SRC / SEMATECH Missions
- Precompetitive Goals and Objectives
- SIA Technology Roadmaps
- New Education & Research Systems
- Team Project Goals & Objectives
- Low Ropes Experience

Assignments/Activity
- Develop System Maps of Potential Project Areas
- Read *Seven Habits - Covey*

Workshop I (January) - *Plan*

Material Content
- Safety &Environmental Issues
- PDSA Cycle
- Management and Planning Tools
- QC tools (except Control Charts)
- Team Building
- Project Management

Assignments/Activities
- Form Project Teams and Plan Research Project
- Read *Four Days with Dr. Deming* - Latzko and Saunders

Workshop II (March) -Do

Material Content
- System Variation and Control
- Design of Experiments
- Sampling and SPC (Control Charts)
- Team Exercises

Assignments/Activities
- Conduct Experiments and Collect Data
- Read *Presentation Design* ***Book*** - Rabb

Workshop III (May) - Study

Material Content
- Presenting Research Progress
- Data Analysis and Information Display
- Decision Formulation
- Effective Presentation and Communication

Assignments/Activities
- Analyze Project Results &Formulate Conclusions
- Develop Final Recommendations and Presentation

Project Presentation (August) - *Act*

Objectives
- Present Project Results and Recommendations
- Develop Action Plans for Continuing Efforts
- Celebrate

Table 2 Options for Team Compositions

Total Students	University Disciplines			Industry Associates	Faculty Support (days per wk)
	Technical	Statistics	Management		
6	4	1	1	0	2
4	3 3	1 0	0 1	2-4 2-4	2 2
3	3	0	0	0	1
3	3 2 2	0 1 0	0 0 1	1-5 1-5 1-5	1.5 1.5 1.5
2	2 1 1	0 1 0	0 0 1	1-6 1-6 1-6	1 1 1
1	1 0 0	0 1 0	0 0 1	2-7 2-7 2-7	0.5 0.5 0.5