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Management Structure Designed to Facilitate Changing Engineering Curricula*

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We have designed a management structure of an engineering program to facilitate innovation and change. Our focus is on the faulty and the tight coupling that occurs between faculty, professional disciplinary societies, accreditation, and curriculum. The concept of loosely coupling the design and management of an engineering program in relation to external stakeholders has resulted in approximately 20 different curricular options being offered during the program's 45-year history. Currently, the program has five options, one of which, precollege teacher preparation, is the first of its kind in the USA. A key to the success of this program has been the flexibility that results from having a loosely coupled system of faculty, management, accreditation, and curriculum. As engineering programs are being increasingly asked to accommodate changes given a changing global profession, schools must find ways to expedite this process. The management structure described exemplifies how programs may facilitate program changes.

Keywords: loose coupling; management; engineering; curriculum development

INTRODUCTION

THE RELATIONSHIP BETWEEN the management structure of a curriculum and the propensity for creating change is explored below. A contrast is drawn between the management style typically used in engineering programs and a non-traditional approach that has facilitated numerous curricular changes over a 45-year period.

When reviewing the broad sweep of engineering education history we see several periods of significant change—most having been initiated in response to major social events, such as World Wars I and II or the launch of Sputnik [1]. Today's call for change lacks this type of focused catalyzing event, but a call for change continues to grow [2, 3] and the current issues of sustainability, etc. may become the next catalyst for change.

An important question to ask in light of these calls for reform is: can the current structure of engineering education respond to the pressures for change? And if it does, what types of change are likely to occur? To answer these questions, we look closely at the management structure of undergraduate engineering education programs through the lenses of tightly coupled and loosely coupled systems theories described by Weick and others [4–6].

Note in this respect that the development of engineering curricula has become tightly coupled to the professional societies through the faculty. Consequently, the emergence of new innovative degree types has slowed dramatically from the early years of engineering education. Then consider an alternative management approach that is loosely coupled to faculty and professional societies in a manner that encourages development of new programs and degree types.

TRADITIONAL MANAGEMENT—TIGHT COUPLING

In the early years of the development of engineering education, 1862–1893, which Grayson [1] labels as a period of rapid expansion, a diversity of disciplines was created. Importantly, Grayson points out that the creation of professional societies followed the development of curricula and therefore had not yet taken a leadership role in curriculum development. Before the professional societies gained their current prominence in engineering education there were 68 types of undergraduate engineering degree titles in 1904, as opposed to the current listing of 23 [7] for 2007. Accreditation was also nonexistent for engineering education until much later, starting around 1932. Therefore, the early period of development was a time when external constituents were less structured than today's environment.

Today, engineering education is a very structured enterprise both in terms of its management and the resulting curriculum. Engineering programs are typically organized as departments within a college, with a faculty head or chair along with a collection of faculty, sometimes grouped by disciplines or sub-disciplines. Curriculum is the providence of the faculty who are responsible for determining its content. Because engineering considers itself a profession, curriculum is also influenced through both the specialty accreditation

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organization for engineering, such as ABET [8], and through engineering professional organizations. The result of this organization is a highly structured curriculum that is slow to change. If we trace the evolution of any particular disciplinary curriculum offerings in a traditional engineering program, there tend to be continuous evolutionary changes on a regular basis. What tends not to occur are revolutionary changes unless some type of major external event precipitates a push for change. For example, the launch of Sputnik led to significant changes in the engineering curriculum in the United States.

Curriculum is a part of the tripartite faculty mission of teaching, research, and service. The connection to research and the negative effect this can have on the development of curriculum has been explored elsewhere [9] and therefore will not be discussed further here. Our focus will be on the faulty and the tight coupling that occurs between faculty, professional disciplinary societies, accreditation, and curriculum. The connections between these groups play an important role in the development and maintenance of engineering programs. Orton and Weick [5] have described the ramifications of tightly coupled systems: these systems are responsive to external constituents, but their responses lack distinctiveness.

As faculty serve as the main developers of curriculum, they serve as the connections between the curriculum and external constituents. Serving as this central point of contact, faculty can be generators of change, facilitators of change, and mediators of change. For example, new courses are always being developed as a result of a faculty member's desire to teach topics related to a particular area of research competence. As these courses become incorporated into the curriculum, the overall emphasis of the curriculum evolves.

Faculty also serve as facilitators of change in response to external constituents or conditions. When a new area of emphasis in a discipline becomes important, faculty are responsible for deciding how it is incorporated into the curriculum. Or when a topic loses its importance, as surveying has in most civil engineering curricula, faculty decide when to remove it from the curriculum and what shall replace it. Again, these processes contribute to the ever-evolving curriculum.

Finally, faculty can also be moderators of change, tempering the calls/demands for change that can come from any number of external groups or sources. It is important that faculty avoid allowing the curriculum to become overly impacted by passing trends that can rise quickly, and often fall just as quickly.

In each of these roles, the faculty remain tightly coupled (connected) to their discipline-specific professional societies. Faculty maintain close ties with their professional organizations, some say faculty maintain greater allegiance to their discipline societies than to their institutions or departments [10]. A result of these professional connections is that important topics are propagated to all members of the societies, resulting in wide acceptance by the profession. This is one reason that when faculty do respond to the need to change, the resulting changes, or responses, are often shared by most engineering programs. Distinctiveness may occur at the micro-level of an individual course approach, but curricula overall do not become very different as programs are compared across different institutions.

This coupling to professional societies also plays an important role in the ABET and similar accreditation processes. In addition to general criteria for all engineering programs ABET and similar processes also include professional criteria requirements for all programs and these are developed by the appropriate professional societies. Similarly to the effect of professional societies on faculty, these additional criteria encourage fairly common responses by engineering programs—distinctiveness is not encouraged.

The traditional organization structure described above is designed for maintaining the status quo, not facilitating change. The strong connection of curriculum to first faculty, and second to external organizations, keeps the rate of change at a moderate pace. As an alternative, we will describe an engineering undergraduate degree program that exists without these tight connections to either faculty or external professional organizations.

At this point it is important, to briefly discuss (by way of a US. case study) a major shift in the underlying philosophy of engineering accreditation taken by ABET around the year 2000. At that time, the agency switched from an approach that was auditing of inputs to an outcomes-based approach. One of the main objectives of this change was to focus on student learning. At the same time, it was felt that this new approach would result in greater diversity in engineering programs. The new criteria allowed for more flexibility on the part of engineering programs to self-define the specific goals and objectives for their degree programs. In fact, a recent study of deans and departments heads indicates that this has resulted in curricular changes—although most faculty attribute this to their own initiative instead of being influenced by ABET [11]. Still, the very nature of specialty accreditation is to enforce a fairly high level of commonality to engineering degree programs and to keep programs from straying too far from the "norm."

The final group of external constituents who have contributed to the maintainance of the traditional approach to engineering curricula are the employers. Engineering firms tend to want to hire engineers with skill sets that are similar to those of their existing employees. It is easy for a mechanical engineering firm to hire a mechanical engineering graduate because they understand the background and technical areas of competencies the graduate will bring with them to their employment. If, on the other hand, a recent graduate had developed a unique set of skills through some non-traditional engineering degree program, the graduate must work very hard to sell himself or herself to the potential employer.

In summary, engineering curricula continually evolve over time. Faculty play a major role in implementing these changes, but they are influenced primarily by the professional societies they associate with. Accreditation also plays a significant role in this evolutionary process. Ultimately, all of these processes tend to encourage fairly common responses by all engineering programs.

THE NEED FOR CHANGE

If there were no great need for change in engineering education, the stability of programs instilled by the above management structure would be acceptable. But this is not the case. Similar to the late 1950s at the launch of the Sputnik satellite by the Soviet Union, engineering education is under growing pressure to change, maybe radically. Numerous national-level calls for reform of engineering education have been sounded in response to reduced enrolments [12], a growing and interconnected global economy, and a general perception that the role of engineering in society must change. Some of the calls for change are from within the profession itself, e.g. the NAE [13] and others [3]. Others come form the greater public forum, such as the need to respond to the growing threat of globalization to the health and wellbeing of the US [14]. So it appears that we have entered a period when changes are required but the management structures in place may not provide the natural support to encourage and facilitate changes. Unlike the Sputnik era, when a perceived crisis of national confidence spurred dramatic changes to engineering education, the current situation does not have a focused rallying event to start a firestorm of change that can overcome the barriers of change-resistant management. Some authors have suggested [15] that the times may require that we create our own "crisis" to jumpstart the next great wave of change in engineering education.

Exactly what types of change are being called for by the many critics? A major theme is the need for engineers who can work in interdisciplinary environments. The complexity of engineering projects has increased dramatically, requiring engineers who can work across disciplinary boundaries as well as geographic boundaries. The question becomes: how does a profession deeply steeped in disciplinary approaches break from this tradition to create a new type of engineer? In other words, can the education of engineers, so deeply embedded in a disciplinary structure, change to address these emerging needs of society? Or is the current structure unfavorable to these desires?

DIFFERENT MANAGEMENT STRUCTURE

Why does the current structure, that depends so much on disciplinary segregation and external constituents, hinder revolutionary change? To understand this, we will use system theory modeling to describe the infrastructure governing engineering education. System theories allow us to describe and analyze the components of the educational system, and the relationships between these components. It is the relationships between components that will provide insight into how and why the disciplinary dominated management structure tends to allow for evolutionary change but hinders revolutionary change.

The concept of characterizing organization and management in higher education in terms of loose coupling mechanisms probably originated with Weick [6]. Although he appeared to be referring to k-12 school systems, Rubin [16], Eckel and Kezar [17] and Birnbaum [4], apply this concept to higher education.

The approach taken here is to apply the system model of loose coupling to the curricular system of an engineering program. This extends loose coupling beyond the management structure to also include the technical core of the curriculum as part of the system. The goal is to illuminate adaptability in curriculum development within the broad context that includes program design and management, technical content, faculty, and accreditation. The hypothesis is that a loosely coupled system is more adaptable and open to change than more tightly coupled systems, contrary to the conclusions of Rubin [16]. Rubin's study focused on times of financial retrenchment and evaluated the structural coupling between campus units to each other (horizontal) and to management (vertical) along with the environment. Resource allocation to units within the university was a main concern of Rubin's work. Rubin suggests moderately tight couplings in the vertical direction and to the environment acting as tempering effects to changing too quickly, which could disregard long-term trends. But Rubin also acknowledges that loose horizontal coupling results in creative solutions.

Since the first definition and subsequent applications, further clarification of the loose coupling concept has occurred [5]. Orton and Weick describe the dialectical interpretation of loose coupling: tight coupling refers to a system that is responsive to external stimulus but in a non-distinctive manner; a decoupled system has distinctiveness but is not responsive, and finally a loosely coupled system is responsive in a distinctive manner. It is in the spirit of this definition of loosely coupled systems that we base the argument that the Colorado State University Engineering Science Major described herein is and has been successful as a source of curricular innovation. All engineering programs are responsive to the external stimuli of discipline specific organizations and accreditation, but engineering science has been particularly distinctive because of its loosely coupled program management system.

Presently this one-degree program (a B.S. in Engineering Science) offers five options: A dual degree program with Liberal Arts, International Engineering (also a dual degree with Liberal Arts), Engineering Physics, Engineering Space, and Engineering Education (the newest option.) Although all these options fall under one degree, they are remarkably different. Two are dual degree programs that require five years of study, whereas the engineering education option takes 4.5 years, and the other two require four years. The Engineering Science degree programs comprise combinations of courses available in the four traditional engineering departments in the college, along with courses available in other colleges within the university.

Engineering Science at CSU has no departmental structure, nor faculty or courses associated exclusively with the program. Instead, the program is managed out of the Associate Dean for Academic and Student Affairs office. This office provides many of the services such as coordinating advising and maintaining student files that are typically handled within department structures. Faculty from other engineering departments are solicited to serve as advisors to students in existing options based on both faculty interest and student needs. For example, space propulsion experts from the mechanical engineering department advise the Engineering Space students, while a physics professor assists with the advising of engineering physics students. With the dual degrees and the engineering education degree, students have advisors from both engineering and liberal arts or the school of education, respectively.

Curriculum management for Engineering Science poses both challenges and opportunities. Since the program does not have any of its own courses, the programs depend on the availability of courses within other programs. This affords the program flexibility in designing a curriculum by using appropriate courses from a variety of sources. But it also presents a risk because of this dependency on others. If a department-based program decides to change, or drop a course used by Engineering Science, the program often has little political power to influence the department's decisions.

The more important issue of curriculum development is the design of new curricula. An historical analysis of the Engineering Science program's 45+ years of operation illustrates the great number of changes that have occurred in terms of offerings in this program. Several degree options have come and gone, new ones have been added, while some have remained throughout. Whereas there are five options currently, a total of 20 options have been available during its history—a remarkable record of change compared to traditional engineering degree offerings.

Accreditation is tightly connected to the curriculum for the Engineering Science program as it is accredited the same as all programs in the college. But there is a major difference in that the professional disciplinary societies are not as directly connected since general engineering programs do not have any requirements generated by those societies associated with them. This results in a program that can take full advantage of the flexibility intended in the new ABET requirements that started in 2000.

Unlike traditional departments, the creation of new options in the Engineering Science program can come from several sources and can proceed quickly. The newly created engineering education option is an example. This new program, described elsewhere [18], was started by a faculty member from the School of Education. The professor had a previous program in another college that developed middle school and high school technology teachers. When the technology program was eliminated, the faculty member approached Engineering about trying something new by teaming with the School of Education to produce technology education teachers. That meeting, which included the dean of engineering and the associate dean for academic affairs in engineering resulted in the decision to proceed. A new program of study was designed jointly with the School of Education. Within six months of the initial meeting the college and university curriculum committees had approved the program. Shortly after the State Department of Education and the Colorado Commission of Higher Education gave final approval. The important points here include:

1) A new engineering degree program was initiated through a request from a faculty member from outside engineering.
2) The approval process was expedited to the college curriculum committee by not requiring a department level approval –the college dean's office was able to move the curriculum forward. Accreditation was also quickly gained because the options in engineering science all fall under the accredited degree of engineering science – therefore a new program option does not appear as a new degree program in the formal definition of accreditation.
3) A unique solution to a national issue was developed.

The case of the engineering education program is an excellent example of the flexibility of a management approach that includes loosely coupled systems between the faculty and the curriculum. Recalling Orton and Weick's [5] explanation that loosely coupled systems will result in distinctive responses we need to see if that is the case for this example. Many colleges of engineering have responded to the call for greater interaction between higher education and k-12 schooling. The literature is filled with examples of programs developed by engineering colleges. What is remarkable is that all of these responses can be categorized under a few headings: content development, teacher assistance, and outreach. There are many examples in each category:

1) Engineering programs have helped develop content for delivery by current k-12 teachers [19, 20].
2) Providing programs, typically during the summer, for k-12 teachers to get professional development focused on engineering content is also fairly common [21].
3) Outreach programs in which engineers visit k-12 schools and deliver context are also popular [22], or to provide extracurricular activities flourish [22, 23].

Although providers may claim some distinctiveness in their approaches, the similarities outweigh the differences.

The ES program described here is much more distinctive, the characteristic that differentiates loosely coupled systems from tightly coupled systems. The ES program is the only current program (as of 2008) available in the US that develops a new type of teacher for k-12 by combining an undergraduate degree in engineering with formal teacher training. A goal of this program has been to change the system by infusing the k-12 system with an entirely different type of teacher from the start. This does not claim that the other approaches are not valid –k-12 education is a big issue and it requires multiple solutions. Our claim is that because the ES program has a loosely coupled system between curriculum and faculty, the solution developed is more distinct than that developed from tightly coupled, traditional engineering programs.

RESPONDING TO CHANGE

So far the point has been made that a loosely coupled system of management for an engineering program can result in flexible, quickly changing curricula. Now we briefly discuss why this is valuable. As has already been discussed above, the engineering profession has recently come under significant pressure to change to accommodate the rapidly changing needs of an increasingly global society. The practicing world of engineering is changing at a rate that may be difficult for the more traditional engineering programs to stay a pace. Just as the business world has often proclaimed the need for rapid reaction to such concepts as just-in-time supply and manufacturing, the engineering profession needs to become more nimble and accommodating to changing conditions. It is our contention that having more engineering programs designed and managed with change in mind, instead of treating change as something to be resisted, would be beneficial to the engineering profession. At the same time, the need for the traditional programs continues to be important. A blend of innovative programs and stable traditional programs would result in a healthy engineering profession.

To sustain and grow more programs that are managed to facilitate change requires a shift in management philosophy. Colleges and faculty must be willing to allow the loose coupling between faculty and curriculum described above for the Engineering Science program. This will also require that accreditation continues to allows such programs the current style of freedom from extra constraining requirements so often associated (appropriately for traditional disciplines) with the professional associations. As Farnsworth comments [24] "Though essential to maintaining the integrity of our system of higher education, accreditation in its various forms also serves as one of the major impediments to positive institutional improvement . . . the institution takes great risk if it determines that it could better serve students by radically altering its curriculum." To date, engineering accreditation allows for these types of radical changes in some limited environments, such as programs that are not tightly coupled to the professional organizations. It is important that this flexibility is maintained, or even expanded, in the future, if engineering curricula are to become more dynamic and flexible.

This leads to another question: can this model work elsewhere? The simple answer is yes! The CSU Engineering Science program exists in a traditional college of engineering. It has the advantage of requiring very little funding or management resources. On the other hand, as the history of the program has shown (see appendix), loose coupling to faculty also makes it an easy target for elimination or negligence. The key to its success has been that the program has always had a champion to support the program. It also requires an administration that understands the unique role that it plays within the overall structure of the college.

What are the weaknesses of the model used by Engineering Science? A major problem for programs with this loose coupling is that it can also weaken the connections to both inside and outside constituents in issues other than curricula, e.g. student recruitment, and the placement of graduates. Department structures serve as ". . . symbolic approaches to legitimize institution (program) to internal and external constituents." [25] Without this legitimization from the symbol of a department, other mechanisms must be used. We would suggest that another way to connect to external constituents is through the student graduates. The alumni from the ES program have been very successful at "selling" themselves to employers, which has resulted in a strong connection to potential employers for current students.

The recruitment of students may be the more difficult task. Even though many high school students don't fully understand the distinctions between traditional engineering programs, they usually do at least recognize the department names. One of the first questions from potential students, and even more so from their parents or guardians, is how difficult is it for ES students to get jobs? Here, having a history of strong employment for graduates is beneficial. But times are changing and students are starting to understand the strength of being entrepreneurial in their career preparation. So programs like ES can and should be successful because they are a legitimate response to the changing needs of the engineering profession.

SUMMARY

In this study of change of engineering curriculum we have discussed an innovative approach to engaging engineering education in the pre-collegiate education system. This innovation was developed in the context of a loosely coupled management structure [5]. The management model in Engineering Science facilitates and encourages both a flexible and dynamic approach to curricula development and implementation. The Engineering Science program at Colorado State University has 45 years of successful operation and has undergone numerous changes and transformations throughout its history. The program has provided approximately 20 curricular options to students during this period, with five current options. It is unlikely that any traditional engineering college can match this record of innovation and change over a similar time. Although on the surface the program might be criticized for having gone through too many changes, there is reason to view this history as a success. What this program has done is operate on the assumption that to be responsive to the needs of society requires making changes quickly, both in terms of adding and dropping programs of study. The only change more difficult to make than developing new curricula is dropping curricula that are no longer relevant. This program has excelled at both.

A key to this success is the existence of what we refer to as a loosely coupled system of external constituents, faculty, and curriculum. Unlike traditional engineering programs, faculty do not have the same level of ownership of the curriculum, in part because the program does not maintain any of its own courses. The advantage of the type of loosely coupled management structure used for CSU's ES program is the ability, and propensity to develop distinctive responses to the changing needs of the engineering profession. During its history, the ES program has developed many different degree options in response to particular needs.

The model presented above is perfectly suited to the changes needed in an increasingly global engineering profession. In the United States the majority of engineering curricula reflect the science-heavy approach spurred on by the cold war and the launch of Sputnik in 1957. Today's world demands a more responsive education system that can rapidly change, while at the same time maintain quality. The ES program at CSU is one example of a responsive program. It is not suggested that this is the only approach. Comprehensive change in education should be a combination of solutions, some very innovative and distinct, and others that are more traditionally and widely adopted.

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APPENDIX

In 1964, Professor Jack Cermak, a Civil Engineering professor at Colorado State University, instituted a unique and flexible undergraduate engineering science major. The major did not have any budget, office space, courses or faculty. Faculty members were "borrowed," at no cost, from the traditional engineering departments to serve as academic advisors to the engineering science majors. The engineering science program consisted of a single degree with a variety of options where the number of options was allowed to grow or shrink over the years as driven by student demand.

The chairperson was selected by the dean and operated from his or her office. Faculty advisors for each option were selected by the chairperson from interested faculty from the traditional departments. Typically, an advisor might advise six to ten engineering science students.

The accredited engineering science program consists of the following core. In the first year students must take five credit hours of chemistry including a chemistry laboratory, four credit hours of calculus based mathematics and five credit hours of engineering physics. The second year requires an additional four credit hours of chemistry including a second chemistry laboratory, another eight credit hours of calculus- based mathematics, five credit hours of engineering physics, three credit hours of engineering mechanics (statics), three credit hours of thermal sciences, three credit hours of college composition, and eleven credit hours of courses meeting the university core curriculum requirements. The third year requirements are three credit hours of engineering mechanics (dynamics), three or four credit hours of fluid mechanics, and four credit hours of differential equations. The requirement for the fourth year is a three credit hour course in statistics for engineers. The remaining credit hours to reach a total of 136 credit hours are selected by the student with approval by the student's advisor. This flexibility is unparalleled in the college and allows for many variations on the degree.

As discussed above, the engineering science curriculum consisted of a mainly specified first two years, which paralleled the curricula in the other traditional engineering departments. Each engineering science student, in conjunction with his or her advisor, selected courses for the third and fourth years from a long and flexible list of engineering and non-engineering courses. In this way, it was possible to create new engineering programs as needed. Some programs took on a nearly fixed curriculum whereas a creative student could actually design his or her own unique engineering program—such programs were called "the individual option" and permitted a number of engineering undergraduate students to use engineering as an undergraduate degree to meet the entrance requirements for medicine, law and veterinary science programs.

Over the years engineering science options have included atmospheric science, bio-engineering, energy conversion, engineering mechanics, engineering physics, natural resource engineering, sanitary engineering, space propulsion, systems engineering, biochemical engineering, systems science and optimization, computing engineering, space engineering and industrial engineering. More recent innovations include a dual degree program in engineering and liberal arts or social sciences, media studies, and a new option that prepares K-12 teachers with an engineering science education.

Some options grew to become formal parts of other programs such as Electrical and Computer Engineering, Chemical and Biological Engineering, and Civil and Environmental Engineering. Note here that in all three of these cases, the departments became blended departments. No new departments were created. Other engineering science options faded away as demand lagged.

Through the intervening years, many faculty members have served as chairperson or as faculty advisors. At times the program has enjoyed a budget and a support secretary. At other times these benefits have disappeared. Various deans have understood the nature of the program while others have tried to do away with it. The program has been successfully accredited over its entire history. Accreditation has not often been easy, but it has been achieved after the visitors have observed the power and come to understand the nature and flexibility of the program.

More than 450 students have earned a B.S. in Engineering Science degree over its 45-year history. The entering students usually have the highest SAT (and/or ACT) scores in the College and the University for that matter. Engineering Science has proved to be enduring and a most useful tool in the development and management of engineering curricula at Colorado State University.

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