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Quality Assurance in Engineering Education: A Systems Perspective

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To the Graduate Council:

I am submitting herewith a thesis written by Mildred Genevieve Louidor entitled "Quality Assurance in Engineering Education: A Systems Perspective." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Industrial Engineering.

Charles Aikens, Major Professor

We have read this thesis and recommend its acceptance:

Denise Jackson, Gregory Sedrick

Accepted for the Council:
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Vice Provost and Dean of the Graduate School

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QUALITY ASSURANCE IN ENGINEERING EDUCATION: A SYSTEMS PERSPECTIVE

A Thesis Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Mildred Genevieve Louidor
August 2010

DEDICATION

This thesis is dedicated to my mother, Genevieve Maria Edouard. Thank you for being the mother that you are and for always being a champion of your children. Thank you for teaching us to value education!

ACKNOWLEDGEMENTS

First, I would like to thank God for seeing me through this process. I know that ALL is possible ONLY with his willingness! I would like to thank my Master's Committee members for their time and guidance! Dr. Aikens, thank you for being my advisor and for encouraging me to do research in my chosen research area, engineering education. Dr. Jackson, thank you for your unwavering support and kindness during my time here at UT. Dr. Sedrick, thank you for your support. Next I would like to acknowledge, the Engineering Diversity Programs Office. Mr. Pippin, thank you for always caring and seeing students as primary stakeholders of the education system! Ms. Clark, thank you for all that you do. I would also like to thank Dr. Adedeji Badiru for all his help in making my transition to UT a smooth one. Last, but certainly not least, thank you to all my family and friends that have helped make this journey a positive experience. One thing I have learned is the value of a strong support system! Thank you to my mother, Genevieve Maria Edouard and my siblings Melissa, Nathan-Christopher and Rick for their love and continuous support! Thank you to Mrs. Nura Goodson for being the dependable friend that you are! Thank you to my dear friend Rolando Jose Acosta-Amado for being a big brother to me during my time at UT. Your wisdom, support and encouragement will never be forgotten!

ABSTRACT

Engineering education reform has been a topic of discussion for the last twenty years. The concern has only intensified in recent years as stakeholders strive to improve quality in engineering education. Today, stakeholders are recognizing that one of the keys to successful engineering education reform is in taking a systems view of higher education. Academic departments within the higher education system are organized around academic disciplines for the purpose of creating, transferring, and applying knowledge in three principal areas: teaching, research and service. This study addresses the need for quality improvement in the engineering higher education system by first completing a literature review in order to identify recurring themes on the issue. A proposed systems view is presented. The thesis builds a case for viewing students as the primary stakeholder based on stakeholder theory concepts. The application of a systems view is then used to identify the impacts of the recurring issues on the identified stakeholders of the system. Recommendations are made to address the system's issues.

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CHAPTER I
INTRODUCTION

Purpose of the Study

Public demand for quality in higher education has increased for all disciplines including engineering in the last 20 years. Several publications have addressed the complexity of the higher education system which makes quality assurance difficult (Mason, 2009; O’Shea, 2007; Tam, 2001). In addition, leaders in the field of engineering education now accept that we must take a systems view of engineering education in order to successfully reform engineering programs and satisfy all stakeholders. This is eloquently explained in the book *Educating the Engineer 2020* (Clough, 2005):

> “Our goal to ensure effective engineering education should be pursued within the context of a comprehensive examination of all relevant aspects of the interrelated system of systems of engineering education, engineering practice, the K-12 feeder system, and the global economic system.”

The definition provided by Robert Freeman, who is credited for first detailing stakeholder theory, is used to define the term stakeholder, any group or individual that can affect or is affected by the achievement of a corporation’s purpose (Freeman, 1984).

This study addresses the lack of a systems view for improving the quality of engineering higher education by first completing a literature review to summarize recurring themes, focusing primarily on the engineering higher education system. A systems view of engineering higher education is presented. A proposal for viewing undergraduate engineering students as primary stakeholders is made; primary stakeholder is defined as the person, group or organization that directly receives a service (Sallis, 2002). Stakeholder theory and systems thinking is applied to discuss the challenges of the system. Lastly, recommendations are made for improving the quality of engineering higher education.

The principles of this thesis are applicable for the entire higher education system, but the engineering higher education is the sub-system in focus. The primary stakeholder of the system studied is the undergraduate engineering student. It is also understood that in order to have a systems view of engineering higher education, its interactions with stakeholders outside its system will also be addressed.

The essential emphasis of industrial engineering is on systems integration and incorporates supporting sub-disciplines relative to the various systems components named in the definition (e.g., ergonomics, plant layout, planning and scheduling). Therefore, industrial engineers are ideal candidates for taking a systems perspective of the engineering higher education system.

General Information

According to the National Science Board (NSB), higher education in science and engineering has received increased attention in the U.S. in recent years because it is viewed as an important component of the U.S. economic competitiveness (NSB, 2010). As a result, there is more attention by the nation to increase recruitment and retention rates. National efforts have helped increased the number of science and engineering student enrollment; the number of such degrees awarded have steadily increased in the last 15 years and this trend is expected to continue through 2017 (NSB, 2010). This increase is expected to plateau and therefore simply addressing attrition in higher education will not be sufficient to meet workforce needs (U.S. House, Committee on Science and Technology, 2010). According to the committee, reform efforts that address the quality of education in STEM (science, technology, engineering and mathematics) education throughout the entire U.S. education system will help institutions achieve the goal of making engineering education more attractive to a larger percentage of the population.

The U.S. higher education system consists of a large number of diverse academic institutions that vary in their missions, learning environments, selectivity, religious affiliation, types of students served, types of degrees offered, and whether public or private and for-profit or nonprofit which adds to the complexity of the higher education system (NSB, 2010). As previously mentioned, a systems view addresses the complexity of the higher education system. Research institutions are the leading producers of science and engineering degrees at the bachelor's, master's, and doctoral levels. In 2007, research institutions (i.e., doctorate-granting institutions with very high research activity) awarded 70% of science and engineering doctoral degrees, 40% of master's degrees, and 36% of bachelor's degrees in science and engineering fields according to the Carnegie Classification of Institutions of Higher Education, which is widely used in higher education research to characterize and control for differences in academic institutions (NSB, 2010). In 2007, U.S. academic institutions awarded more than 2.9 million associate's, bachelor's, master's, and doctoral degrees; 23% of these degrees were in science and engineering (refer to Appendix A).

The terms higher education system or engineering higher education system are widely used in literature, but the question of whether we (stakeholders of the higher education system) truly take a systems view of the higher education is debatable. Members of the House of Representative Committee on Science and Technology identify taking a systems view of education as an opportunity for improving quality in the education system. On February 4, 2010, five of the committee members testified regarding the current state of undergraduate and graduate education in STEM fields in the United States. The purpose of the hearing was to examine ways to improve the quality and effectiveness of STEM education in order to better prepare students with the skills needed to join the 21st century workforce (U.S. House, Committee on Science and Technology, 2010). The following are excerpts from the hearing where committee members discuss the need for a systems view of engineering and science higher education.

> *Education is a complex and integrated system; this structure is an opportunity for leveraging change. The same features that challenge us to improve our educational system provide us opportunities to solve these challenges. Because components of our educational system are coupled with each other, we can effect change in the entire system by carefully seeding change at critical junctures. Higher education is a critical and often overlooked juncture. –Dr. Noah Finkelstein, University of Colorado*

> *Graduate education is a comprehensive system that is inter-related with undergraduate education and, in STEM, with postdoctoral training, and should be deliberately developed and improved as a system. It is connected to undergraduate education*

through research experiences for undergraduates and the role of mentoring as well as through teaching experiences in classrooms and laboratories. It is also inextricably linked to the research enterprise by its dependence on faculty mentors and through connections to postdoctoral trainees. – Dr. Karen Klomparens, Michigan State University

The nation has accepted that we have challenges that need to be addressed in order to remain globally competitive. As a result, the Science and Technology Committee developed the COMPETES Act in 2007; refer to Appendix B for the first page of the act. One of the challenges identified is in providing high-quality STEM education to all students in the education system; adequate national quantitative measures of quality do not yet exist according to the National Science Board (NSB, 2010).

STAKEHOLDER THEORY

This thesis builds a case for applying stakeholder theory in higher education, particularly, engineering higher education in order to understand the role of each stakeholder of the system. In addition, adopting stakeholder theory in academic departments can help ensure that primary stakeholders' (students') quality of service (education) is upheld. A stakeholder is defined as any group or individual that can affect or is affected by the achievement of a corporation's purpose (Freeman, 1984). While stakeholder theory has been advanced in industry and the word *institution* or *organization* could readily be substituted for *corporation* in Freeman's definition, there is less research in the public and non-profit areas, especially in the case of higher education (Chapleo & Simms, 2010).

Engineering Education as a Service

Due to the lack of uniformity in students it is best to view the output of the education system as a service rather than viewing educated students as the output. Not all students entering the system are uniform and therefore, it is difficult to capture the value-added to each individual student entering and leaving the system. Education leader, Lynton Gray explains this difficulty in the following statement (Sallis, 2002).

> *"Human beings are notoriously non-standard, and they bring into educational situations a range of experiences, emotions and opinions which cannot be kept in the background of the operation, judging quality is very different from inspecting the output of a factory, or judging the service provided by a retail outlet."* (excerpt from *Total Quality Management in Education* by Edward Sallis, 2002)

Stakeholder Analysis

Stakeholder analysis is a technique often used to identify and assess the roles of stakeholders in an organization, and its proponents argue that it is imperative that a stakeholder perspective be taken during the very early stages of quality improvement initiatives (MSH & UNICEF, 1998). It is important for engineering departments to perform a stakeholder analysis prior to the recommendation of any quality improvement measures.

A stakeholder analysis by the University of Portsmouth collected data by interviewing thirteen members of the university's community carefully selected for their expert systems knowledge of higher education (Chapleo & Simms, 2010). The experts were asked to identify who in their opinion were the recipients of, or otherwise had a stake in, university services. This process resulted in the list of thirty possible stakeholder groups summarized in Table 1. It is of interest that the only group that all thirteen experts agreed on was the *students.* The panel of experts also identified three types of influences that a stakeholder can have on a university: student recruitment and satisfaction; policies and strategies; and impact on revenue (Chapleo & Simms, 2010). In addition, the panel categorized the stakeholders as having the following levels of impact on the three types of influence: direct; less direct/partial; or detached/indirect or no impact. Figure 1 is a result of stakeholders considered to have direct influence on each sphere of influence; it is recognized that other stakeholders have different levels of influence on universities. For instance, learned societies (professional organizations and other bodies relevant to universities) were found to have detached/indirect or no impact on student recruitment and satisfaction, less direct/partial on strategic direction and detached/indirect or no impact on revenue. Figure 1 reveals that “students” is the only stakeholder group that is a member of all three spheres of direct influence. This would seem to justify placing the student in a relatively favored stakeholder position. We have elected to simply call the students *primary system stakeholders.* This does not mean to imply that the interest of other non-primary stakeholders do not require consideration in system design and operating strategy. Nevertheless this insight supports a position that students must be central to the design and operation of any effective system of higher education.

It is important to note that some of the findings of the panel might differ across different countries and perhaps even academic departments outside of

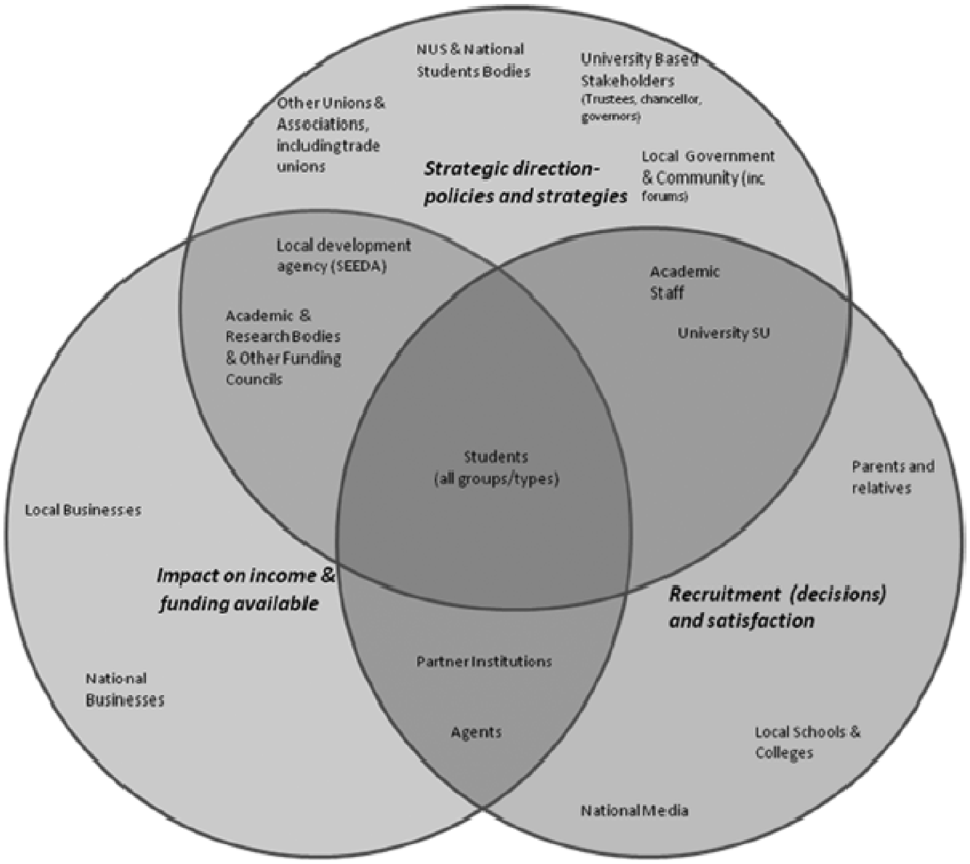


Figure 1. Understanding the key stakeholders and their influence on the University (Adapted from Chapleo & Simms, 2010)

Table 1. Frequency of identification of stakeholders by interviewees (adapted from Chapleo & Simms, 2010).

Group	Tally
Students	13
Local employers/businesses	10
University staff	10
Academic & research bodies/bunding councils	9
Local Government/city/authorities	9
Local community	7
Local Schools & colleges	7
Governors	6
Parents, influencers & student 'funders'	6
National Employers/businesses	6
Government & EU	6
Course accreditors & professional bodies	3
'Learnered' societies	3
Networking Socieites/lobby groups	2
Partner Institutions	2
Media/press	2
Tax payer	2
DIUS	2
Agents	2
Trade unions	1
A-level boards & bodies	1
UK HE marketing orgs (e.g. Hobsons)	1
Local police	1
Other NGO's	1
National charities	1
NUS	1
Other Student Organisations	1
Local Charities	1
Trustees	1
Chancellor	1

the United Kingdom. For instance, in the United States, the local and or state government would most likely be considered to have direct impact on a university's revenue, particulalry, in STEM disciplines.

While it may be appropriate to not give equal treatment to the interests of all stakeholder groups, the stakeholder influence is not independent across various groups. Jongbloed et al discuss the interdependence of stakeholders of a university in the journal article *Higher Education and its Communities: Interconnections, Interdependence and a Research Agenda*. The authors also apply stakeholder concepts developed by Mitchell et al to higher education to help explain the attention paid to various stakeholders and their relationship with universities. The priority given to stakeholders by organizations vary; stakeholder salience is positively related to the cumulative power of three attributes that is perceived to be present- power, legitimacy and urgency, as defined below. (Jongbloed, Enders & Salerno, 2008):

Power: relationship among social actors where person A can persuade person B to do something that person B would not do normally.

Legitimacy: the generalized perception or assumption that the action of an entity (person or organization) is desirable, appropriate or proper.

Urgency: degree to which stakeholder needs call for immediate action. Any system stakeholder will possess at least one of the three attributes. Figure 2 is a stakeholder typology that categorizes stakeholders into three major groupings, and further partitions the groups into seven classes according to the how many of the three attributes discussed above are present (Mitchell, Agle & Wood, 1997).

1. *Latent stakeholders* possess only one attribute; therefore this group contains three classes.
    - a. Class 1: dormant stakeholder (power)
    - b. Class 2: discretionary stakeholder (legitimacy)
    - c. Class 3: demanding stakeholder (urgency)
2. *Expectant stakeholders* possess two of the three attributes; hence this group also contains three classes.
    - a. Class 4: dominant (power & legitimacy)
    - b. Class 5: dangerous (power & urgency)
    - c. Class 6: Dependent (legitimacy & urgency)
3. *Definitive stakeholders* possess all three attributes; therefore this group forms a single class.
    - a. Class 7: definitive (power, legitimacy and urgency)

The identification of primary stakeholders becomes an exercise in determining which stakeholder groups are definitive. Based on this definition, several groups could make the primary cut. For example, in the case of public universities, the government could be classified as possessing a Class 7 definitive stake, as the role of the government is to ensure that higher education meets the interests of students and society in general (Jongbloed, Enders & Salerno, 2008). According to Jongbloed et al, the government is considered to be definitive due to the importance of and broad span of influence of public funding on universities. Funding is a creator of power, legitimacy, and urgency. It can also be argued that the process of funding universities creates class status

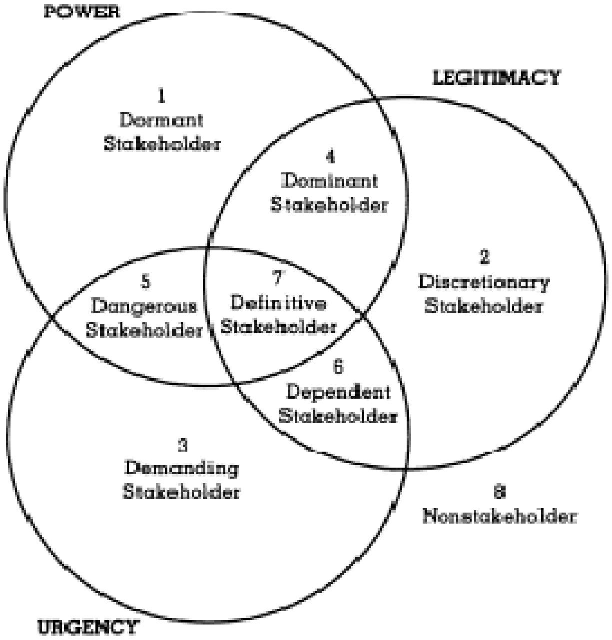


Figure 2. Stakeholder Typology (Adapted from Mitchell et al)

for other stakeholders for whom the funding is provided. Indeed other groups, such as empowered employees, may also be in some instances migrating toward Class 7 status. We would eliminate the government as a primary stakeholder in light of the Figure 1 taxonomy as the government's impact is limited to strategic direction (Chapleo & Simms, 2009). As taking care of student needs can be considered to be core to the higher education system (Jongbloed, Enders & Salerno, 2008), and coupling the definitive status of students with the influence domains depicted in Figure 1 we conclude that students should be considered the single primary stakeholder group and that the interests of other stakeholder groups should be considered in the context of how those interests impact students.

This thesis identifies the following stakeholders of higher education:

The student = **Primary stakeholder**
Parents/Employers = **Secondary stakeholder**
Gov't/Society = **Tertiary stakeholder**
Faculty/support staff = **Internal stakeholder**

The proposed model for engineering education reform employs the following stakeholder definitions from the literature and views education as a service (Sallis, 2002):

Primary stakeholder: person directly receiving the service- the student. In addition, the student is a primary stakeholder because they are the only group that has both the power to impact the university in all three spheres of influence and possess all the Class 7 attributes - power, legitimacy and urgency. These are the characteristics that provide them a favored position in system design.

Secondary stakeholder: all of whom have a direct stake in the education of one or more students. These stakeholders have the power to impact the university in one or two spheres of influence and are classified as either latent or expectant. For example parents are considered to have direct impact on student recruitment and satisfaction (Chapleo & Simms, 2009), and possess power that can be instrumental in forcing universities to be more transparent and accountable, and ;to adopt more cost-conscious operating principles (Jongbloed, Enders & Salerno, 2008). University administrators are typically Class 4 expectant stakeholders who have power and legitimacy; however there is a trend towards Class 7 status for this group due to the urgent demands brought about by changing technologies, economic conditions, and societal values (Jongbloed, Enders & Salerno, 2008). The administrator stakeholder is seen to have a direct impact on university revenue (Chapleo & Simms, 2009). This is also true of academic faculty who are consistently under pressure to bring in externally-funded research projects.

Tertiary stakeholder: critical constituent that has a less direct stake such as industry or the labor market, or government, or society as a whole.

Internal stakeholder: employees of the institution that participate in the system's primary and support value streams and in so doing have stake in system outcomes. This includes groups such as faculty, staff and administration. Employees of universities, particularly faculty, have legitimacy attributes since they are an integral part of the education system. Employees of a university have direct influence on recruitment decisions and student satisfaction. Although the last decade has seen increasing research interest in the area of stakeholder theory for higher education, the focus has not typically treated student needs as deserving the highest priority. This is perplexing since one can assume that in higher education sustainability depends on students (numbers, quality and loyalty). If our premise that students are the sole primary stakeholders of higher education is true, it logically follows that the majority of all system processes should focus on creating student value. The current convention that is prevalent in the hundreds of universities across the U.S. unfortunately lacks this perspective. This can be explained from an excerpt from the classic 1975 management article by Steven Kerr entitled “On the Folly of Rewarding A, While Hoping for B”. In this article, Kerr presents examples in society where we hope for outcome A while rewarding outcome B. In the case of higher education, Kerr argues that, society *hopes* that teachers will not neglect their teaching responsibilities but *rewards* them almost entirely for research and publications (generally the case at large and prestigious universities) (Kerr, 1975). Although that article is over 35 years old, it appears to still be relevant today. Kerr also argues that punishment for poor teaching is also rare. Contrary to current practice the model portrayed in Figure 3 would require the three traditional metrics used for faculty performance (teaching, research and service) to work together interdependently in the interest of better satisfying student needs. A critical examination of this model from a stakeholder perspective leads to some important stakeholder-specific questions concerning various system processes and to what extent those processes add value:

1. Primary Stakeholder: the Student

Teaching: How are we ensuring quality teaching? Is the cliché good researchers are good teachers a fallacy that needs to be challenged?

Research: Does the research that is actually performed add value to the learning experiences of the primary stakeholder group?

Service How do service activities impact students? To what extent are students involved? Is service integrated into the curriculum through service-learning opportunities?

2. Secondary & Tertiary Stakeholders: Parents, employers, gov't & society

Teaching:

-Are students learning enough of what is needed to satisfy the expectations of future employers?

-Are government assistance programs to improve quality in STEM education making a positive impact on the education system?

Research: Are research activities adding value to secondary and tertiary stakeholders?

Service: Are public service activities helping to improve the higher education system as a whole (for example-pre-college programs).

3. Internal Stakeholders: Faculty & support staff

Is the current reward system encouraging faculty members to put students as the central focus of the system, thereby promoting teaching or pedagogy?

It is not our attempt to begin to answer these questions here; however these question frame our thinking in the need to move in a direction of an improved stakeholder-centered system.

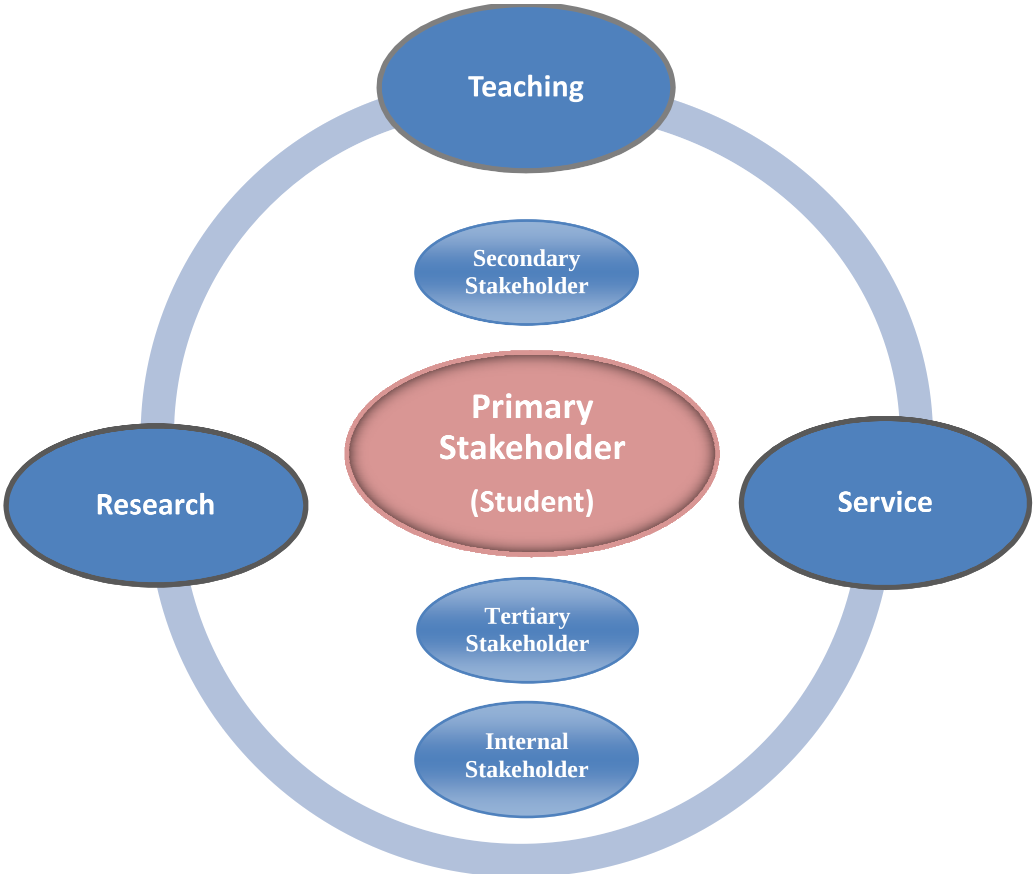


Figure 3: Students as the Primary Stakeholders that are a central component of the Higher Education System

CHAPTER II
LITERATURE REVIEW

Engineering Higher Education Reform

History

The engineering education reform of the 1990s was preceded by the assessment movement in the mid 1980's. Since then, there has been increasing pressure on institutions of higher education to be held more accountable to their stakeholders (Olds, Moskal & Ronald, 2005). Parents, government officials, industry and other stakeholders began to expect to see results of student assessment outcomes. According to Alexander Astin, Professor of Higher Education Emeritus at the University of California, Los Angeles and past Director of Research for both the American Council of Education and the National Merit Scholarship Corporation, the major catalyst of the assessment movement in the United States is perhaps the performance funding system developed for public higher institutions in Tennessee in 1979 (Astin, 1991). The Tennessee Performance Funding Program is a performance-based incentive program that financially rewards public colleges and universities for successful institutional performance on selected student outcomes and related academic and institutional assessments; the Tennessee Higher Education Commission (THEC) has been assigned responsibility for administering the program (THEC). Tennessee was the first state to implement such a program. To date, at least nineteen other states have implemented performance funding policies (THEC).

In the last 20 years, numerous reports, articles, books and studies have been prepared by the American Society for Engineering Education, National Academic Press, the National Science Board, the National Science Foundation, and the American Society of Civil Engineers that discuss the critical need for engineering education reform (Galloway, 2007). As a result, the 1990s was marked by numerous efforts from constituents of the engineering educational system to address the need for reform. The Engineering Deans' Council (EDC) formally called for a redesign of engineering curricula nationally in 1994. Along with the American Society of Engineering Education (ASEE), a major professional non-profit organization for engineering education in the US, the EDC started a project entitled, *Engineering Education for a Changing World* which proclaimed that engineering education must expose students to "technical knowledge and capabilities, flexibility, and an understanding of the societal context of engineering" (ASEE, 1994). In 1995, the National Science Foundation (NSF) followed with a report entitled "Restructuring Engineering Education: A Focus on Change", which expressed similar findings as ASEE's "Engineering Education for a Changing World" (NSF, 1995). The Industry-University-Government Roundtable for Enhancing Engineering Education (IUGREEE) was formed in 1995 to provide a collaboratively developed voice, vision and action for engineering education reform (McMaster et al, 1999). According to IUGREEE, there are additional skills that 21st century engineering professionals must possess in the future that were not as critical for 20th century engineers. Many of these skills are interpersonal and leadership type skills. Table 2 is a results of the IUGREEE roundtable discussion which shows the additonal skills in bold italics. One of the attributes identitifed by the IUGREEE that has not been discussed as much in engineering literature is the idea of engineering students managing their own educational process as shown below in Table 2. There has been numerous literature that discuss the need for improving student engagement but not on the idea of students "managing" their own educational process which has a lot of merit. Although undergraduate students are expected to take an active role in their own educational experience, it is not customary for students to manage their own educational experience. This is particularly problematic in the field of engineering, where technology changes more quickly than the educational curricula (McGinnis, 2002).

For instance, in the case of industrial engineering, scholars have found that over the past 25 years, the curriculum has not kept pace with technology changes, in the domains in which industrial engineers practice, and changes in the tools available to solve problems in those domains (McGinnis, 2002). If the result of the roundtable discussion has merit, one question remains: is there a need for a change in engineering students' attitudes towards their own educational experience as constituents?

Today

The emergence of the area of engineering education departments in the last five years reflects a response to the rising concern for the quality of education in the areas of science, technology, engineering, and mathematics

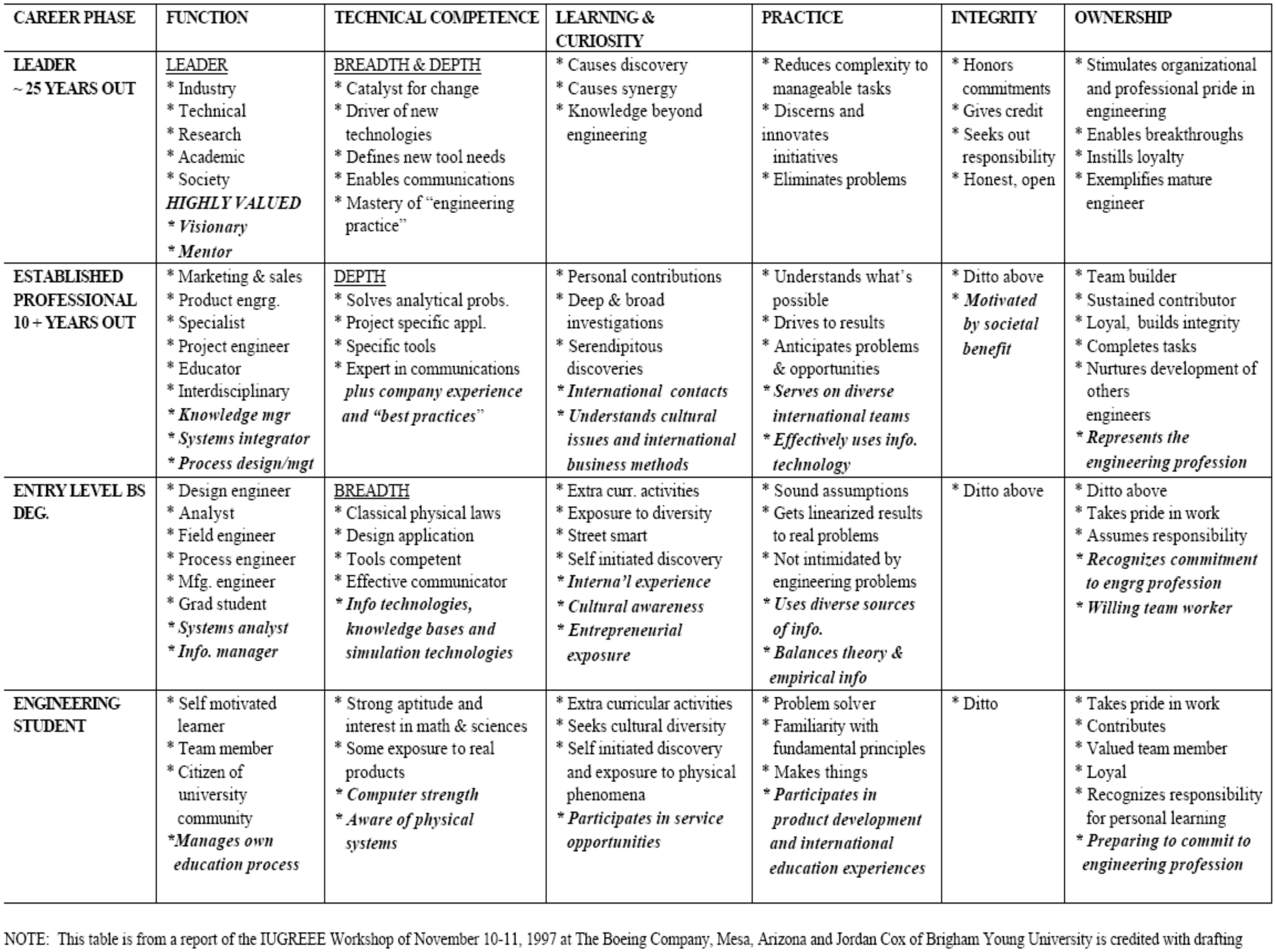
(STEM). In 2005, Purdue University became the first university in the world to offer graduate programs in engineering education for students interested in studying the art of teaching engineering and science subject areas (Purdue University). Virginia Tech established an engineering education department also the same year. Today, other universities such as Utah State University also offer graduate degrees in engineering education. According to Purdue's engineering education website, such a program allows students to investigate the following:

- How to use technology, teaming, service-learning, and advising to promote student learning, interest, and retention in engineering
- How to create and implement problem-solving, design, and other engineering curricula that develop life-long learning skills and student self-confidence while promoting diversity
- How to assess teaching and learning

An insightful report prepared by the National Academy of Engineering (NAE) regarding the future of engineering education is *Educating the Engineer of 2020*. In *Educating the Engineer of 2020*, distinguished educators and practicing engineers from diverse backgrounds identify current technological trends and attributes of the engineer of 2020 and offer recommendations on how to better prepare future undergraduate engineering students for the future. The recommendations from this project are the following (Clough, 2005):

1. The B.S. degree should be considered as a pre-engineering or "engineer in training" degree.
2. Engineering programs should be accredited at both the B.S. and M.S. levels, so that the M.S. degree can be recognized as the engineering "professional" degree.
3. Institutions should take advantage of the flexibility inherent in the EC2000 accreditation criteria of ABET, Incorporated (previously known as the Accreditation Board for Engineering and Technology) in developing curricula, and students should be introduced to the "essence" of engineering early in their undergraduate careers.

Table 2. Engineering in 2010 (Attributes of the 90's in regular font, *attributes of the early 21st century in bold italics)*.



CAREER PHASE	FUNCTION	TECHNICAL COMPETENCE	LEARNING & CURIOSITY	PRACTICE	INTEGRITY	OWNERSHIP
LEADER ~ 25 YEARS OUT	LEADER * Industry * Technical * Research * Academic * Society ***HIGHLY VALUED*** **** Visionary*** **** Mentor***	BREADTH & DEPTH * Catalyst for change * Driver of new technologies * Defines new tool needs * Enables communications * Mastery of "engineering practice"	* Causes discovery * Causes synergy * Knowledge beyond engineering	* Reduces complexity to manageable tasks * Discerns and innovates initiatives * Eliminates problems	* Honors commitments * Gives credit * Seeks out responsibility * Honest, open	* Stimulates organizational and professional pride in engineering * Enables breakthroughs * Instills loyalty * Exemplifies mature engineer
ESTABLISHED PROFESSIONAL 10 + YEARS OUT	* Marketing & sales * Product engrg. * Specialist * Project engineer * Educator * Interdisciplinary **** Knowledge mgr*** **** Systems integrator*** **** Process design/mgt***	DEPTH * Solves analytical probs. * Project specific appl. * Specific tools * Expert in communications ***plus company experience and "best practices"***	* Personal contributions * Deep & broad investigations * Serendipitous discoveries **** International contacts*** **** Understands cultural issues and international business methods***	* Understands what's possible * Drives to results * Anticipates problems & opportunities **** Serves on diverse international teams*** **** Effectively uses info. technology***	* Ditto above **** Motivated by societal benefit***	* Team builder * Sustained contributor * Loyal, builds integrity * Completes tasks * Nurtures development of others engineers **** Represents the engineering profession***
ENTRY LEVEL BS DEG.	* Design engineer * Analyst * Field engineer * Process engineer * Mfg. engineer * Grad student **** Systems analyst*** **** Info. manager***	BREADTH * Classical physical laws * Design application * Tools competent * Effective communicator **** Info technologies, knowledge bases and simulation technologies***	* Extra curr. activities * Exposure to diversity * Street smart * Self initiated discovery **** Interna'l experience*** **** Cultural awareness*** **** Entrepreneurial exposure***	* Sound assumptions * Gets linearized results to real problems * Not intimidated by engineering problems **** Uses diverse sources of info.*** **** Balances theory & empirical info***	* Ditto above	* Ditto above * Takes pride in work * Assumes responsibility **** Recognizes commitment to engrg profession*** **** Willing team worker***
ENGINEERING STUDENT	* Self motivated learner * Team member * Citizen of university community ****Manages own education process***	* Strong aptitude and interest in math & sciences * Some exposure to real products **** Computer strength*** **** Aware of physical systems***	* Extra curricular activities * Seeks cultural diversity * Self initiated discovery and exposure to physical phenomena **** Participates in service opportunities***	* Problem solver * Familiarity with fundamental principles * Makes things **** Participates in product development and international education experiences***	* Ditto	* Takes pride in work * Contributes * Valued team member * Loyal * Recognizes responsibility for personal learning **** Preparing to commit to engineering profession***

NOTE: This table is from a report of the IUGREEE Workshop of November 10-11, 1997 at The Boeing Company, Mesa, Arizona and Jordan Cox of Brigham Young University is credited with drafting

4. Colleges and universities should endorse research in engineering education as a valued and rewarded activity for engineering faculty and should develop new standards for faculty qualifications.
5. In addition to producing engineers who have been taught the advances in core knowledge and are capable of defining and solving problems in the short term, institutions must teach students how to be lifelong learners.
6. Engineering educators should introduce interdisciplinary learning in the undergraduate curriculum and explore the use of case studies of engineering successes and failures as a learning tool.
7. Four-year schools should accept the responsibility of working with local community colleges to achieve workable articulation with their two-year engineering programs.
8. Institutions should encourage domestic students to obtain M.S. and/or Ph.D. degrees.
9. The engineering education establishment should participate in efforts to improve public understanding of engineering and the technology literacy of the public and efforts to improve math, science, and engineering education at the K-12 level.
10. The National Science Foundation should collect or assist collection of data on program approach and student outcomes for engineering departments/schools so that prospective freshman can better understand the “marketplace” of available engineering baccalaureate programs.

These ten recommendations are consistent with the recurring themes found in engineering education reform literature which identify the gaps in the system. The literature research performed identifies five main recurring issues negatively affecting engineering departments in the United States – cultural change issues, lack of promotion of the field, curriculum deficiencies, imbalanced reward system for faculty and lack of pedagogical training for faculty as shown in Table 3. The ten recommendations of *Educating the Engineer of 2020* can be classified under these themes as follows:

- Recommendations 1& 2: **Curriculum deficiencies**
- Recommendations 3& 7 –10: **Lack of promotion of the field**

- Recommendations 4: **Imbalanced faculty reward system**
- Recommendations 5: **Culture change issues**
- Recommendations 6: **Curriculum deficiencies and pedagogical training for faculty**

Curriculum deficiencies

The need for curriculum reform is perhaps the issues most discussed in engineering education literature in the last 20 years. In particular, there is a need to reassess the topics taught in engineering education. Several recent books have been written in the form of proposals to urge the engineering community to rethink the engineering curriculum. One book, *Engineering Education Reform* by Dr. Patricia Galloway, past president of the American Society of Civil Engineers and a certified professional engineer in 14 states and 2 other countries (Australia and Canada) proposes reforming engineering education based on her plethora of domestic and international experience. Dr. Galloway identifies the following issues in engineering education: understanding the concept of globalization, understanding issues confronting engineers of the 21st century, lack of competencies that would allow engineering students to rise to leadership within government and industry and the curricula deficiencies (Galloway, 2007). These issues are specifically described below:

- Globalization: Many of the complex issues of the 21st century can only be addresses through engineering collaborations between nations. Issues:
    1. Increase in aging population and the increasing health care costs associated with it
    2. Decaying infrastructure

Table 3. Major Recurring Issues from Literature Search

Major Issue(s) Identified	Publication Title	Summary of Publication	Year	Authors
1,2,3,4	*Engineering Education for a Changing World*	"In today's world and in the future, engineering education programs must not only teach the fundamentals of engineering theory, experimentation and practice, but be RELEVANT, ATTRACTIVE and CONNECTED."	1994	American Society of Engineering Education
1,2,3,4,5	*Restructuring Engineering Education: A Focus on Change*	Overall recommendations: promotion of diversity, new faculty rewards system, new assessment/evaluation for students & faculty and campus-wide changes needed	1995	National Science Foundation
1,2,4	*Industry-University-Government Roundtable for Enhancing Engineering Education (IUGREEE) White Paper*	Additional skills that 21st century engineering professionals must possess in the future are presented that were not as critical for 20th century engineers. Highlight: 21st century engineering students managing their own education	1999	McMasters et al
1,4	*A Brave New World: Industrial Engineering Scholars are Leading the Crusade for an Improved Curriculum*	Academic curriculum has not kept pace with technology changes, in the domains in which industrial engineers practice, and changes in the tools available to solve problems in those domains.	2002	McGinnis
1,2,4,5	*A Center for Scholarly Research in Engineering Education at the National Academy of Engineering White Paper*	Education center developed to lingering issues: faculty resistance & attitudes towards reform, declining enrollments and industry skepticism. Such a center promotes developing improved curricula & pedagogical practices in engineering education.	2002	National Academy of Engineers (NAE)
1,4	*Engineering Subject Centre Guide: Learning and Teaching Theory for Engineering Academics*	The ultimate goal of higher education should be for students to take control. This promotes life-long learning.	2004	Houghton
1,2,3,4	*Needs and Possibilities for Engineering Education: One Industrial/Academic Perspective*	Systemic view of engineering education to address key issues facing the system: lack of course integration & development as a profession. Most serious issue: decreasing interest in the system by prospective students.	2004	Magee
1,2,3,4,5	*Educating the Engineer of 2020: Adapting Engineering Education to the New Century*	NSF's EEC (engineering education coalition) program results were considered through 4 different "lenses":	2005	Clough (Chair) National Academy of

Table 3 Cont'd. Major Recurring Issues from Literature Search

		content, expectations, methodology and systematic reform. NAE requested the overview to support its Engineer of 2020 Project, which defines how engineering in the twenty-first century will be refashioned.		Engineers (NAE)
1, 3, 4 & 5	*Preparing Engineering Faculty as Educators*	More focus should be placed on developing faculty members' pedagogical skills. "Improvements must begin with faculty members, the people on the "front lines" of education."	2006	Ambrose & Norman
1,2,3,5	*Engineering Change: A Study of the Impact of EC2000*	The implementation of the EC2000 accreditation criteria has had a positive, and sometimes substantial, impact on engineering programs, student experiences, and student learning.	2006	Lattuca et al
1, 2, 4	*The 21st Century Engineer: A Proposal for Engineering Education Reform*	Author contends that the engineering 4 year degree is inadequate and proposes a new master's degree in professional engineering management.	2007	Galloway
1,2,5	*Educating Engineers: Designing for the Future Field*	"Although engineering schools aim to prepare students for the profession, they are heavily influenced by academic traditions that do not always support the profession's needs."	2008	Sheppard et al
1,2,3,4,5	*Strengthening Undergraduate and Graduate STEM Education*	Key action item to enhance STEM: pedagogical training, improved teaching practices and center for integration of teaching, research & learning	2010	Mathieu

Legend:

1. **Curriculum deficiencies**
2. **Lack of promotion of the field**
3. **Imbalanced faculty reward system**
4. **Cultural change issues (faculty resistance to change and need for promoting life-long learning)**
5. **Lack of pedagogical training for faculty**

    3. Increasing demand for portable water
    4. Responsible consumption and protection of natural resources
    5. Homeland security & public safety
    6. Global warming
    7. Natural disasters
    8. Ethics, bribery, and corruption in the global workplace
- Present-day engineers believe that technological prowess is all that is needed to succeed—a wrong assumption
    1. They have little to no training in the “soft” skills required to succeed in today’s global professional community
    2. Although engineering is still a respected profession, the professional standing of the engineer has diminished over the years which has resulted in lower remuneration than enjoyed, for example, by practitioners of law or medicine.

As a solution, Galloway recommends making the B.S. degree a pre-engineering or “engineer in training” degree and that the master’s degree be considered the professional degree as also recommended by the National Academy of Engineering in the book: Educating the Engineer of 2020”. Adding courses to the curriculum is not a realistic or viable solution since the typical undergraduate engineering program already requires 10 percent more credits than non-technical degrees (Galloway, 2007). “A jam-packed curriculum focused on technical knowledge is the means for preparing students for a profession that demands a complex mix of formal, contextual, societal, tacit and explicit knowledge” (Sheppard et al, 2008). It is speculated that more engineering education reform literature will discuss requiring master’s degree certification required in order for engineering to practice professionally. This is an interesting recurring solution to engineering higher education reform curriculum deficiency proposed in the literature search (Galloway, 2007; Clough, 2005; Magee, 2004).

Lack of promotion of the engineering field

As previously mentioned, the House of Representative Committee on Science and Engineering, identified the need for engineering and science departments to finds ways attract a larger percentage of the population since the number of students choosing these members is expected to plateau (U.S. House, Committee on Science and Technology, 2010).

In the area of promotion of engineering a major issue is that the public in general has little understanding of the nature of engineering and the value of an engineering education (Clough, 2005). According to the Taylor Research & Consulting Group, only 35 percent of college students believe an engineering degree is “worth the extra effort” (AICPA, 2004). This concern was expressed by a member of the Canadian Committee on Women in Engineering in the following quote:

> “One of the biggest problems I see in attracting students into engineering is the image, or more correctly the lack of image, of the engineering profession. If a person were asked what doctors or lawyers do, the response would be immediate doctors treat sick people and lawyers argue legal cases in court. These answers are simplistic and don't begin to address all the duties of doctors and lawyers, but they are nevertheless typical responses. If the same person were asked what an engineer does, the response may be 'I don't really know.' or, worse yet, 'They drive trains.'“ -Tracy V. Murray, P.E., Atomic Energy Canada, Montreal Forum

Scholars have cited the need to promote the field of engineering to underrepresented groups. It is forecasted that Hispanic Americans will account for 17 percent of the US population and African Americans will constitute 12.8

percent by 2020 while the percent of Caucasians will decline from 75.6 percent in 2000 to 63.7 percent (Clough, 2005). Historically Hispanic Americans and African Americans have been underrepresented in engineering and science fields. Therefore, the engineering profession will need to come up with solutions that will attract underrepresented groups.

Imbalanced faculty reward system

Another critical issue that is now appearing as an issue in engineering education reform literature is the imbalance of faculty reward systems. The following recent testimony (February 2010) by one of the committee members of the House of Representative Committee on Science and Technology reports research findings on this issue:

> *Research shows that currently very few STEM faculty are aware of or employ findings of research about teaching in their classroom instruction. This is not stubbornness or lack of interest - the reality is that our higher education system does not adequately promote or reward either pre-service or in-service faculty development. In fact, the weight of external research funding has tipped the scales of reward at universities – and increasingly more often at colleges – strongly toward funded research activities. Any associated gains in the teaching and learning of undergraduates are seen as collateral, albeit very real, benefits. Without a change in both message and rewards we are assured of replicating the current system, which has been extraordinarily successful in producing an invaluable scientific elite but much less successful in developing STEM skills broadly. –Dr. Robert D. Mathieu, University of Wisconsin – Madison*

Institutional, disciplinary and Federal reward systems – tenure, promotion, grant funding, awards, salaries – greatly reinforce the primacy of superb research over superb teaching (Mathieu, 2010).

Culture change issues

The culture change issues identified regarding engineering education reform can only be addressed by encouraging stakeholders to change some of their perceptions. The stakeholders of particular interest are faculty, students and parents based on the idea that these stakeholders have direct influence on influencing attitude changes necessary for reform.

First we will discuss the culture change necessary for faculty in engineering departments. According to Ambrose and Norman the answer to the following question posed in the book *Educating the Engineer 2020*, “What will or should engineering education be like today, or in the future, to prepare the next generation of students for effective engagement in the engineering profession of 2020 (Clough, 2005)?” is faculty – those who design the educational environment; but first, faculty members collectively, will need to first accept that there is need for engineering education reform (Ambrose & Norman, 2006).

Although there is an abundance of research on recommendations for improving engineering education there is little attention paid to the idea of students managing their own education process, a characteristic previously discussed in this chapter. Faculty and parents have the ability to influence students the most and therefore can affect their attitudes towards such a change. The theory of students managing their own education process is further discussed in the chapter 5 of this thesis.

Pedagogical training for faculty

STEM and faculty of US universities receive little to no pedagogical training (Mathieu, 2010). In order to apply improved teaching methods found in research it is critical for faculty to receive pedagogical training. In addition, 90% of students were found to have left STEM disciplines due to poor teaching according to “Talking About Leaving” a book based on a three-year, seven-campus study that looks at why STEM students switch to non-stem disciplines (Seymour & Hewitt, 1997).

Many of the issues previously discussed influence each other. For instance, the current faculty reward system influences pedagogical training measures. Overwhelming pressures for faculty to write grants and publish, along with committee responsibilities and other demands, often force faculty to neglect their will to improve teaching skills (Ambrose & Norman, 2006).

The issues discussed in this section are echoed in a recent study perform by the Center for the Advancement of Engineering Education (CAEE). CAEE began in January 2003 with funding from the National Science Foundation’s Engineering and Education & Human Resources Directories (ESI-0227558). The Academic Pathways Study (APS) represents the largest portion of CAEE’s research and is a 5 year longitudinal and cross-sectional study of engineering undergraduates’ learning experiences and the transition to work (Atman et al, 2009). According to CAEE, the APS is unique in providing an opportunity for educators to consider each aspect as one piece of a larger puzzle: *how to meet the learning needs of all students, speak to their passions and help them develop the complex set of skills needed to meet the grand engineering challenges of 2020* (CAEE, 2009). The APS findings allow us to address the needs of the primary stakeholders of the engineering higher education system. Refer to appendix C for a summary of the findings (Atman et al, 2009).

Quality Assurance in Engineering Education

Forming a universal definition of quality can be challenging since most people have different views of the word. Defining quality for engineering education is particularly challenging because of the complex nature of the higher education system. One needs to address various current related issues such as the way to view students and employers, the role of non-technical courses, the use of technology in the classroom, and the life-expectancy of education in order to have a holistic view of engineering quality (Ibrahim, 1999). Before introducing the adopted definition of quality for this thesis it is important to explain why quality in engineering education is important. Ibrahim succinctly explains the relevance of having a definition for quality in engineering education by stating that the need arises because of the desire to communicate that a particular institution provides quality education with the consequence of attracting more students, more funds, more job offers for the graduates, and more recognition (Ibrahim, 1999). In other words, from a systems perspective, a quality definition is important in order to better serve the stakeholders of the engineering education system. In his book, *Total Quality Management in Education*, Edward Sallis identifies four quality imperatives of an educational system shown below in figure 4 (Sallis, 2002).

The thesis will adopt the following definition of quality: a perception of how well the balanced needs of all stakeholders have been met or exceeded (Aikens, 2010). This definition is similar to that of Sallis' definition of quality: that of which satisfies and exceeds customer needs and wants. Aikens also identifies three main drivers for quality in education: accountability, alignment and assessment as summarized below in figure 5. Both Sallis and Aikens argue that quality management theories should be applied in the educational setting to ensure quality in education while understanding the complex nature of education compared to for profit institutions.

The idea of applying quality assurance measures in engineering higher education requires a systems view where the “product” and “stakeholders” are

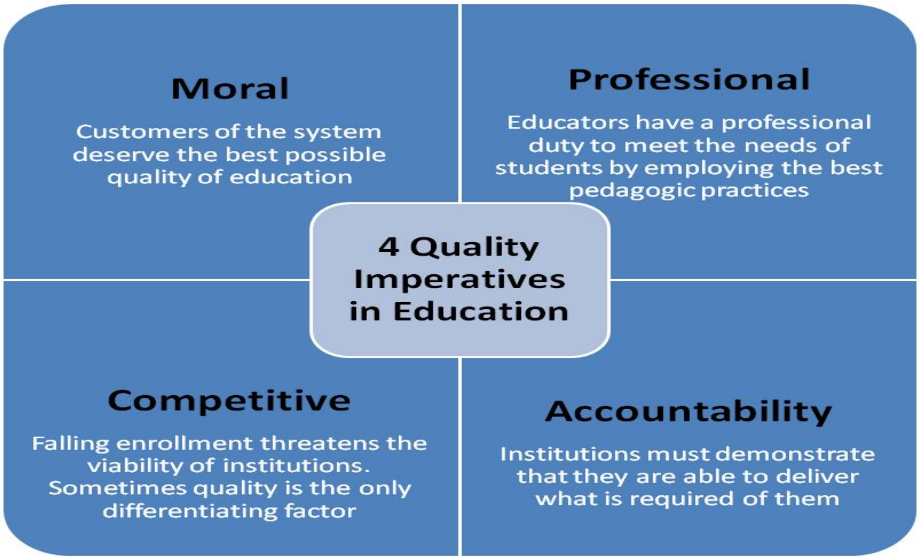


Figure 4: Edward Sallis’ 4 Quality Imperatives of Educational Systems

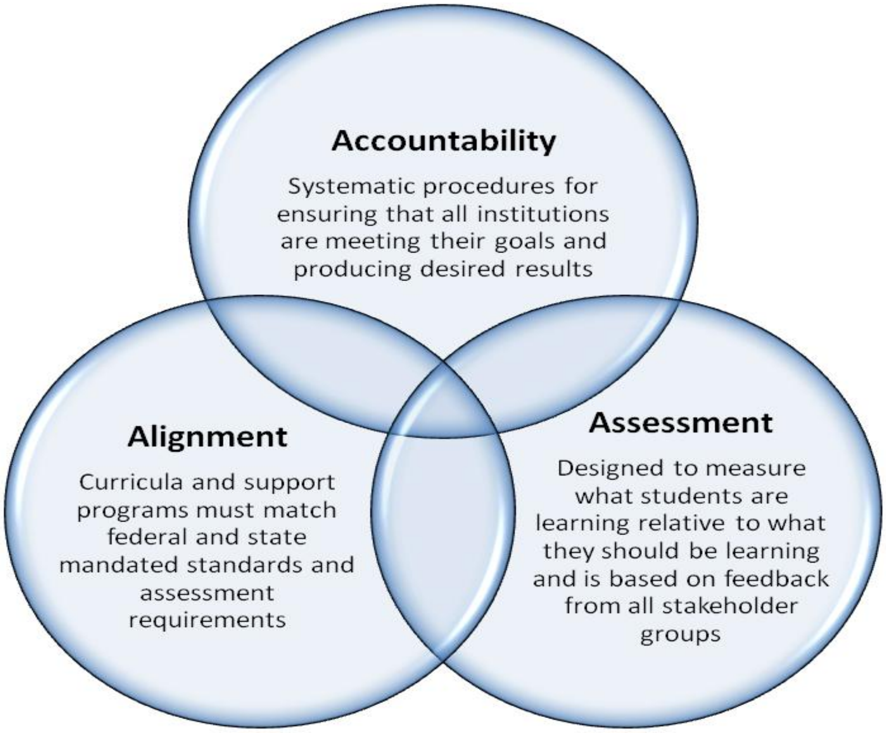


Figure 5. C. Harold Aikens' 3 Drivers for Quality in Education

identified which leads us to the next section of the thesis: “Higher Education as a System”.

CHAPTER III
HIGHER EDUCATION AS A SYSTEM

Proposed System Model: Academic Unit

A system may be defined as a group of entities and their inter-relationships working toward a common goal (Whitley & Betley, 2007). A commonly-accepted generic model of a system is shown in figure 6. In general, systems have subsystems that function individually and interact with one another as customers and suppliers; systems also are part of a super-system with which it interacts as a subsystem or major internal entity. Systems have boundaries that separate them from their environment; however, systems interact with their environment. They receive inputs from entities in the environment, and after processing them, they send outputs to those entities. An academic unit may be viewed as a system or as a subsystem as shown in figure 7, given that it is generally a part of a college or university (the super-system). An academic unit exists to respond to a demand for knowledge from its stakeholders. This demand enters the system as input from stakeholders. The system responds by subjecting the demand to processes (e.g., teaching, service and research) that consume resources from suppliers. The series of processes produce an output (educated students and new knowledge in the field) that goes back into the environment as a system output and generates certain outcomes for itself, the environment and the constituents. Thus, academic units are involved in knowledge processes – capture of existing knowledge, generation of new knowledge, transferring of knowledge to students, and dissemination of gained knowledge to colleagues. The knowledge processes mentioned above fall under the category of knowledge management, the process of transforming information and intellectual assets into value (Kidwell, Linde & Johnson, 2000). The application of the knowledge management terms used in figure 7 is discussed below:

1. Create knowledge – includes research findings from faculty and students of an academic unit.
2. Transfer knowledge – includes the dissemination of new research to society and imparting knowledge to students that will prepare them for their chosen career path. We adopt the definition provided by Argote & Ingram; knowledge transfer is the process through which one unit (e.g., group, department, or division) is affected by the experience of another (Jackson, Louidor & Aikens, 2008).
3. Acquire knowledge - in order to produce the output, appropriate input variables (students & faculty) must gain knowledge or skills.

The main processes, teaching, research and service include the following:

1. Teaching – instruction and guidance provided by faculty in and out of the classroom. In the case of outside classroom teaching, a significant amount of the faculty member's time is often spent guiding student research (for example, student thesis work). Classroom preparation is also part of the teaching activities expected to be performed by instructors in higher education.

2. Research – Research in most science and engineering departments is not a *process* or an activity but a finished *product* and therefore publication is crucial (Mancing, 1991). It is acknowledged that research processes must occur to produce such finished products.
3. Service - Service activities can be grouped into two categories: institutional service (all the activities that are not directly to teaching and research but that indirectly contribute to these missions) and professional service (i.e. professors who hold offices or serve on committees and boards in professional organizations) (Mancing, 1991).

Figure 6 is a simplified model of an academic unit. Most would agree that there are several complexities to be addressed when looking at an academic unit. As a system becomes more complex, they become more vulnerable to failure; for this reason, a formalized methodology known as ‘‘systems engineering’’ is often applied in industry to the management of large systems (O’Shea, 2007). In his paper, *A Systems View of Learning in Education”*, O’Shea argues that the use of systems engineering concepts in education would be likely to reduce failure rates and improve quality. This system is understandably resistant to change because of significant perceptions of outstanding achievement (Magee, 2004).

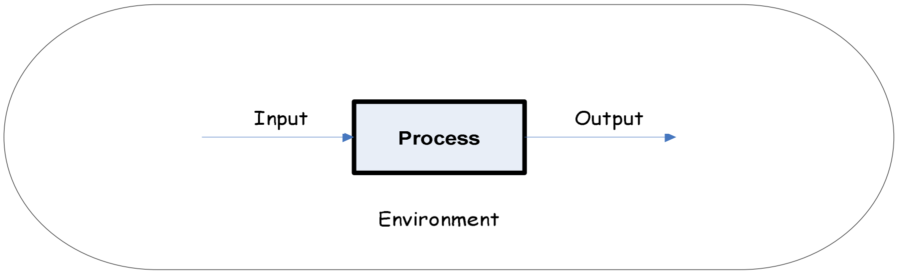


Figure 6. A System

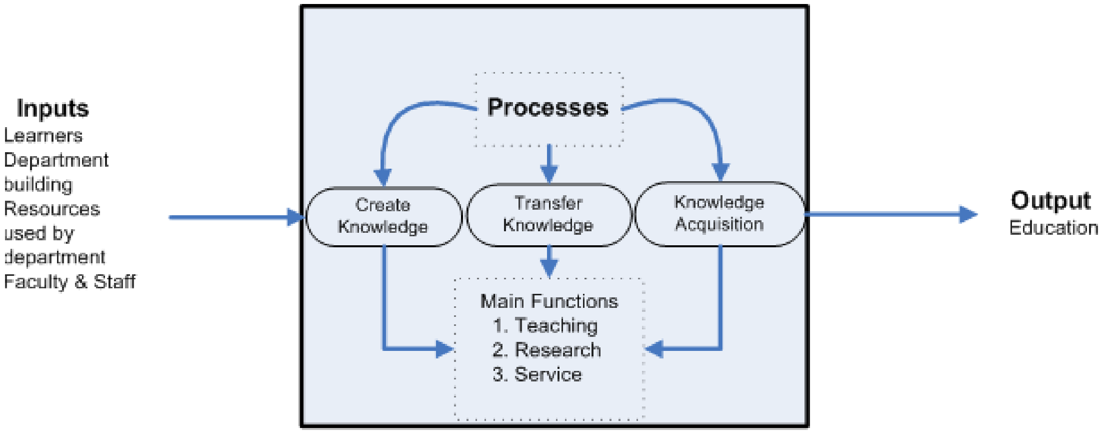


Figure 7. Academic Unit System

A more detailed and perhaps more accurate view of an academic unit captures additional inputs and processes that are critical to an academic unit such as securing funding, an activity that often takes up a lot of faculty members' time. Although this activity is often linked to research, it has been separated as its own activity since the process itself can include activities like grant and or proposal writing which is not research itself. Figure 8 is presented below.

In looking at the entire engineering education system, MIT professor, Christopher Magee proposes a model (figure 9) that can be used to identify key processes and stakeholders that have the ability to promote or resist change. According to Magee, if a given idea is strongly opposed by a ***key*** and powerful stakeholder, it does not have high implementation potential even with strong support from other stakeholders (Magee, 2004).

Complexity of the System

Engineering higher education is a highly complex industry. For instance:

Variability of input – different types of students (traditional versus nontraditional) or university transfer student versus high school graduates.

Variability of process - changing faculty research interests, differing expertise and perspectives, choice of textbooks

Other variability- classroom venues and sizes, variation of technologies available and timetabling options

A major factor adding to the complexity of the system is the wide range of stakeholders compared to industry. Each stakeholder possesses different forms of power and has the ability to influence reform measures. Magee points out the power of key stakeholders on the engineering education system:

Faculty: Those who excel at research and bring in funding to academic departments can have a powerful voice. The faculties who also cooperate and compete internally are significantly powerful in research institutions (Magee, 2004).

Government Bodies & Foundations: Organizations such as NSF have significant power since they provide a considerable amount of funding to academic departments.

Students: Although students may not be aware, they have power to affect change in the system. "The prospective student has power through choice and this choice involves not only which university but which field of study to pursue. The apparent reduction in appeal in engineering education over the past decades is thus likely to be the most significant driver for change in the system" (Magee, 2004).

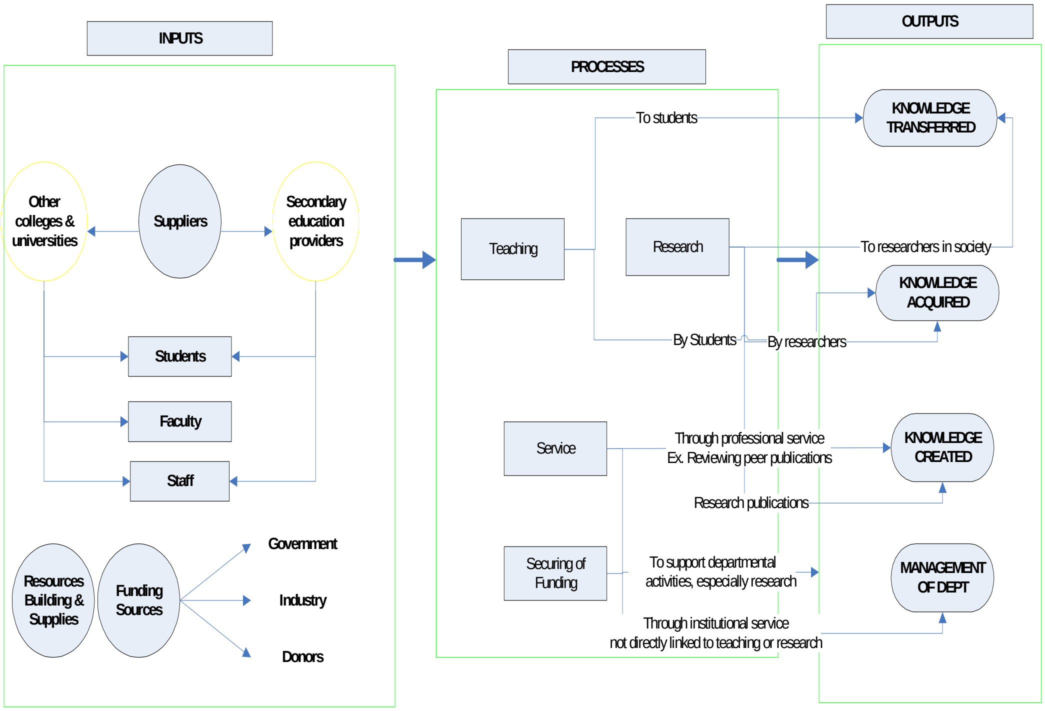


Figure 8. Detailed View of an Academic Unit

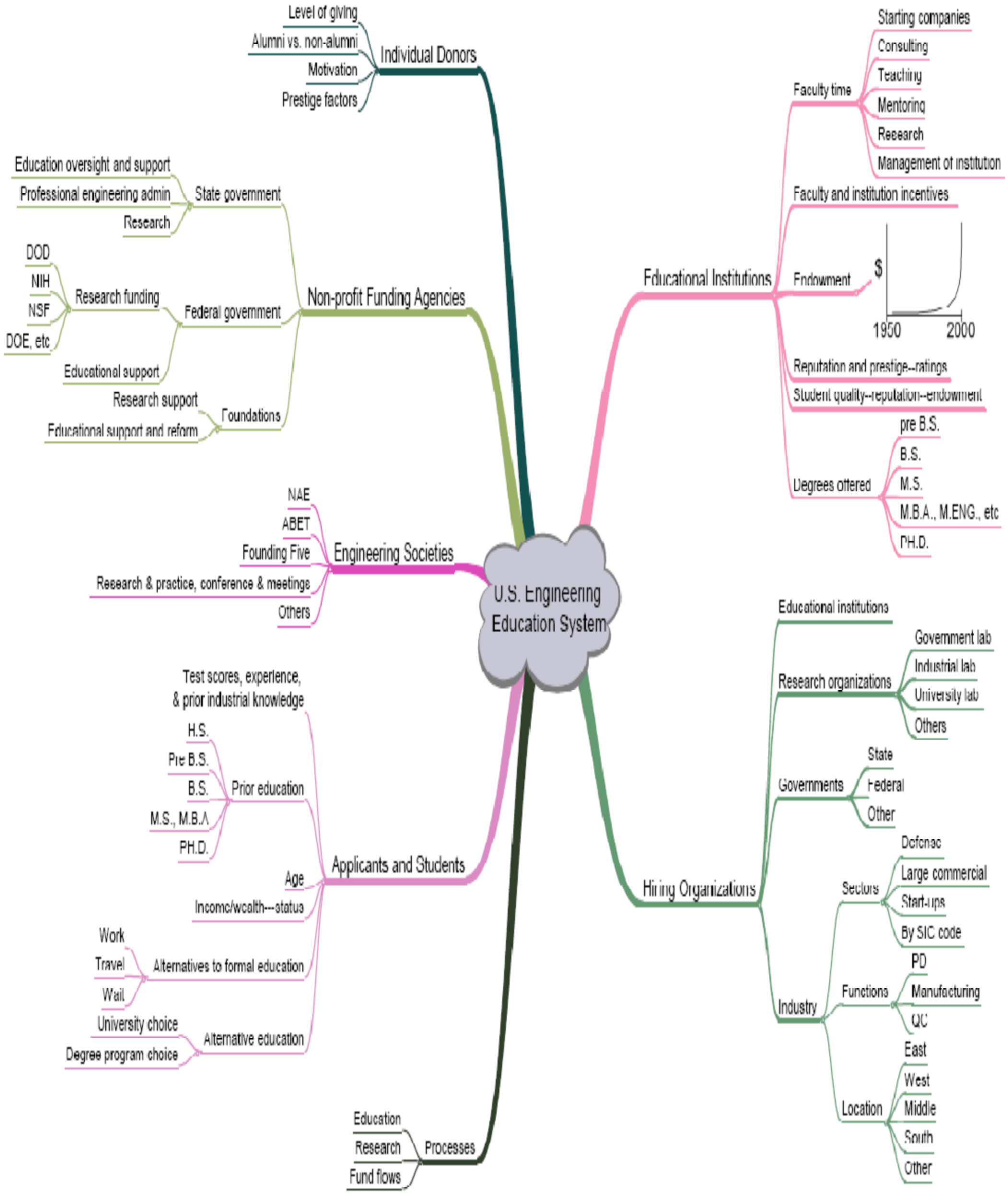


Figure 9. Engineering Education System

CHAPTER IV
RESULTS AND DISCUSSION

Systems View Application

The literature search in chapter 2 reveals five principle recurring themes that have impacts on the performance of engineering departments throughout the United States. In considering the main activities (teaching, research and service) that characterize the system's principle value-streams we have investigated how various stakeholder groups interact and individually and collectively are affected by the recurring themes and in turn in figure 10, which was constructed using the following steps. The following steps were taken to map Figure 10:

1. The stakeholder groups shown in column 1 have been mapped to those thematic issues (shown in column 2) that must be overcome for meaningful system reform. The arrows connecting stakeholders with issues have been constructed where either the stakeholder group is considered to have a relatively high impact on the issue or is a direct contributing source (i.e. *cause*).
2. Each thematic issue has been mapped to the system processes it directly affects.
3. Lastly, each process is mapped to the stakeholder directly affected or compromised as a result of each issue affecting the process.

Overview

Some further elaboration of Figure 10 is appropriate, and additional findings from the Academic Pathways study included in Appendix C, corroborate our mappings.

Culture Issues: With respect to culture, the stakeholders of particular interest are faculty, students and parents since these stakeholders have the most direct influence on attitude changes necessary for reform as previously discussed in Chapter 2. The APS findings address how parents and faculty influence the academic experience of a student (Appendix C).

Lack of engineering field promotion: Government funding and support is critical for promoting the engineering field. For instance, scholarship and research funding help faculty members attract students to study engineering. Faculty is also mapped to this activity because they affect students' academic experience. In addition, non-academic (not faculty) staff members are also mapped as a direct link to this issue since some administrative positions are devoted to the promotion of engineering through activities such as recruitment.

Curriculum deficiencies & lack of pedagogical training: Faculty members are the direct link to these issues. Although support from other stakeholders like the government can help faculty make changes by providing resources, ultimately these changes are implemented by faculty.

Imbalanced reward system for faculty: As previously cited, the reward system for faculty is considered by many stakeholders to be imbalanced causing less attention to be paid to teaching excellence. The direct links to this issue are current faculty attitudes and beliefs and government and industry supporters. Government and industry often reward the system based on research activity.

Teaching is the activity with the most links in the figure 10 and is thus the activity that is compromised the most. Students and faculty are the stakeholders directly affected by teaching. Students are the direct recipients of the service (teaching) while faculty members provide the service. Teaching is mapped to faculty from the point of view that teaching issues directly impact educators' ability to perform their job. Although the student is the primary stakeholder of the system it is the stakeholder impacted the most by all the recurring issues. Figure 10 shows the complexity of the system and how all stakeholders affect the main processes of the academic unit, teaching, research and service.

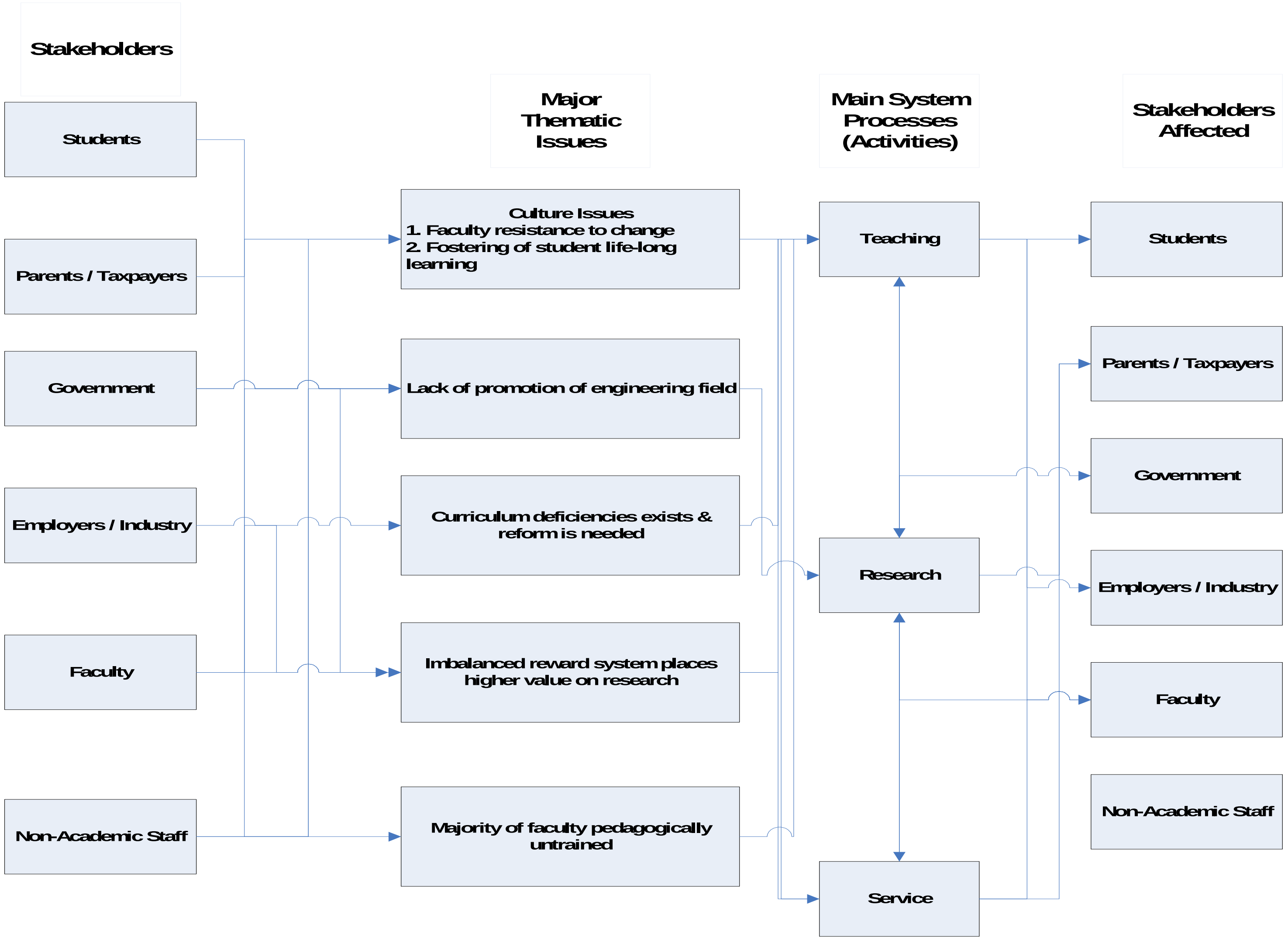


Figure 10: Major Issues Affecting the Quality of the Engineering Education System: Impact on Stakeholders

CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

The literature research performed identifies the influence of all the stakeholders in the engineering higher education system. It is clear that there is a need for changing some of the attitudes or perspectives of key stakeholders in the system. As previously mentioned, it is important to understand students' (primary stakeholders) attitudes towards managing their own education. Although undergraduate students are expected to take an active role in their own educational experience, it is not customary for students to manage their own educational experience. This is particularly problematic in the field of engineering, where technology changes more quickly than the educational curricula. As previously cited in the literature research, for instance, scholars have found that over the past 25 years, the curriculum has not kept pace with technology changes, in the domains in which industrial engineers practice, and changes in the tools available to solve problems in those domains (McGinnis, 1997). The Industry-University-Government Roundtable for Enhancing Engineering Education (IUGREEE) was formed in 1995 to provide a collaboratively developed voice, vision and action for engineering education reform and is comprised of university representatives, government, professional societies and other agency participants. According to IUGREE members, engineering students of the future will need to take a more active role in managing their own educational experiences. Particularly, engineering students will need to take personal responsibility in ensuring that the content of their respective curricula keep pace with the changing demands of industry. The conclusion of the roundtable discussion begs a very important question: is there a fundamental need for a change in student attitudes towards their own individual educational experiences and the part they must play in it?

More research is necessary to investigate the prevailing attitudes of undergraduate engineering students; such studies would need to first establish an operational definition of what is meant by “managing one’s education process.” A case would then need to be made for the need for cultural change. This would have considerable impacts on engineering academic departments that are unaccustomed to abrogating any of their traditional faculty responsibilities for curriculum or teaching in favor of some new and radical teacher/student partnership arrangement.

The thesis research led to a development of a focal construct called *educational process self-management (EPSM)*—what are engineering undergraduate students’ behaviors and attitudes towards managing their own learning. The idea here is that educators should enable students to manage what they do as part of their learning processes (Houghton, 2004). *EPSM* is similar to the idea behind career management. Many sources define career management as a lifelong, self-monitored process of career planning that involves choosing and setting personal goals, and coming up with an execution strategy. Career management often identifies the role of a manger as an employee’s supporter. Many human resource departments today provide career planning support to employees. Similar to career planning, *EPSM* can be described as a student's commitment to lifelong, self-monitored process of academic learning that involves choosing and setting personal academic goals, and coming up with a plan to achieve desired outcomes. In *EPSM*, the instructor's role is to help the student achieve and measure desired outcomes. It is interesting to note that counseling at this level is not something that academic faculty are comfortable with, as a general rule, or have the skill set necessary to perform effectively. Faculty members know what it means to "advise" students – however, under *EPSM*, roles change dramatically and instead of the professor *controlling* the educational experience – and in most cases in an autocratic manner – each faculty member engages with each student to match his/her experience to the students' needs as dictated by career goals. This of course places a custom face on the experience and a degree of uniqueness that is student specific. Other constructs that are part of the theory are based on the principles of accountability and outcomes. Since the mid 1980's there has been increased pressure for accountability in higher education. *Accountability* means institutions are willing to answer to all its relevant stakeholders on how well those stakeholders perceive they are achieving stated goals and purpose (Olds, Moskal and Miller, 2005). In the late 1980s, many states passed laws requiring public universities to submit annual reports on their assessment of student outcomes (Olds, Moskal and Miller, 2005). In engineering academic departments as a minimum follow ABET's (Accreditation Board for Engineering and Technology) accreditation criteria to define outcomes. ABET program outcomes are narrow statements that describe what students are expected to know and be able to do by the time of graduation. These relate to the skills, knowledge, and behaviors that students acquire in their matriculation through the program (Missouri S&T 2007-2008 Undergraduate Catalog, page 201). General ABET outcome criteria are the following:

a. Ability to apply mathematics, science and engineering principles.
b. Ability to design and conduct experiments, analyze and interpret data.
c. Ability to design a system, component, or process to meet desired needs.
d. Ability to function on multidisciplinary teams.
e. Ability to identify, formulate and solve engineering problems.
f. Understanding of professional and ethical responsibility.
g. Ability to communicate effectively.
h. The broad education necessary to understand the impact of engineering solutions in a global and societal context.
i. Recognition of the need for and an ability to engage in life-long learning.
j. Knowledge of contemporary issues.
k. Ability to use the techniques, skills and modern engineering tools necessary for engineering practice.

ABET a-k are outcomes for all engineering disciplines. In addition, all engineering disciplines have specific outcomes related to their field.

The idea behind *EPSM* is that self-management can lead to better outcome results as shown in figure 11. The non-technical and “soft-skill” ABET outcomes (d, f, g, h, i and j) are not only difficult to teach but also challenging to measure. For instance, an academic department that encourages *EPSM* would inherently foster outcome “i”.

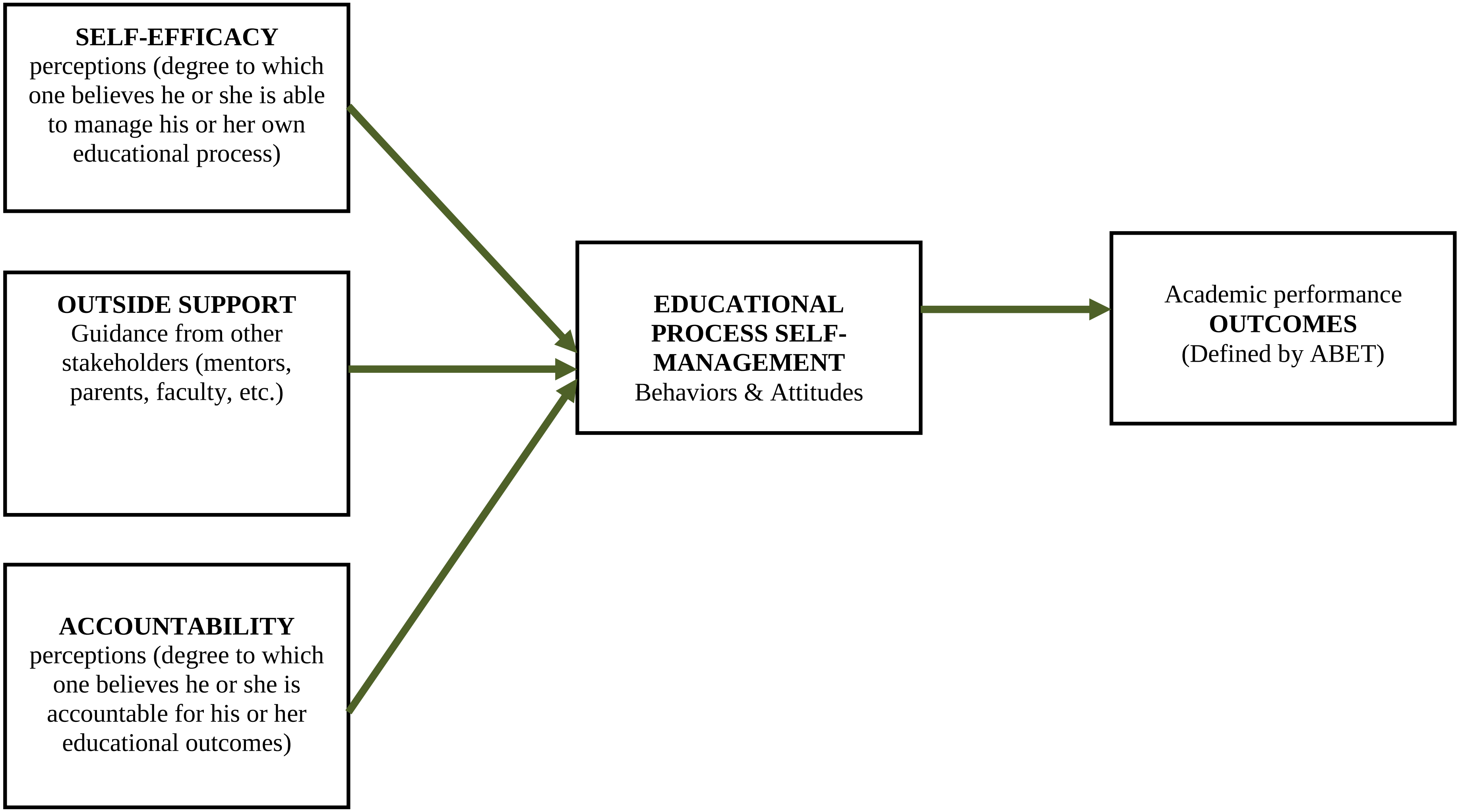


Figure 11. Educational Process Self- Management Influence on Engineering Academic Outcomes

The following propositions are made regarding the expected results of the survey:

1. Students with higher measures of self-efficacy, accountability and outside assistance from their academic environment will score higher on the education process self-management scale.
2. Students that score high on the educational process self-management scale will have more positive academic performance outcomes.
3. Students with high scores on the educational self-management scale will score highest in accountability and outside assistance measures than self-efficacy indicating that self-efficacy has less of an impact on educational process self-management.
4. Students' perceptions (self-efficacy and accountability) can change due to interactions with the academic environment (this would be based on self-reported answers from the students).
    a. Students that self-report entering the system with low perceptions that have low interactions with his or her academic environment will likely score lower on the educational self-management scale than those that had positive interactions. This indicates that the academic environment has the ability to positively affect the behaviors and attitudes of students.

Questions for future research as also presented in the stakeholder theory section of this thesis. The questions take a systems view and questions whether the main activities of the system add sufficient value to the stakeholders. Addressing these questions may lead to a way to balance the needs of all stakeholders of higher education thereby improving the quality in the system; quality is a perception of how well the balanced needs of all stakeholders have been met or exceeded (Aikens, 2010).

Chapter four's results reveal the stakeholders' influences on the engineering higher education system, specifically related to the main issues identified in literature. It is recommended that non academic staff be empowered more in engineering departments to assist in securing funding. This will help address the problem of faculty members' reward system being imbalanced. Faculty members would have more time to devote to teaching and service activities.

The challenge of improving the quality of education for engineering students is an issue that involves changing the roles of all stakeholders in the system. This requires a systems view in order to address the root cause of the problems facing departments today. There is a plethora of knowledge created regarding improving engineering education in the United States, but reform can only happen if all stakeholders agree that there is a problem and commit to making changes. A proposal is now made to address the major issues affecting engineering departments today. For ease of reference a list of the recurring issues is listed below:

1. Curriculum deficiencies
2. Lack of promotion of the field
3. Culture change issues
4. Lack of pedagogical training for faculty
5. Imbalanced faculty reward system

This thesis identified the many stakeholders that engineering higher education must satisfy while building a case for making students the primary focus. It seems reasonable to make the claim that aiming for synergy would be in the best interest of an academic department. One way to do this would be to encourage academic departments to adopt the “hedgehog concept” by Jim Collins, author of *Good to Great* and focus on what they can excel at and are passionate about collectively (Collins, 2001). For instance, one industrial engineering department might have faculty members that excel in manufacturing and therefore it might be in the best interest of the department to focus research areas in manufacturing and work together. Specialization provides several benefits:

1. It enables departments to more easily promote engineering disciplines. One of the challenges cited in the literature was that the general public did not understand clearly what engineers do. By specializing, departments will be able to better explain applications and relevance of engineering in society while continuing to provide the same technical foundation to students.

2. Specialization can bring synergy to faculty members' main job functions, teaching, research and service. Research performed can be brought to the classroom. This would add value to the primary stakeholders, the students. In addition, students who are attracted to such a program would more likely be interested in research experience that would further add value to their education. Specialization makes it easier for departments to partner with local businesses since they can provide such companies with relevant solutions. In addition, students would have the ability to work on company projects with faculty, thereby introducing students to the value of research and service.
3. It is expected that specialization would encourage faculty and students to remain current with issues facing their specialty area. For instance, ABET outcome “h” would become inherent in the system. This also addresses curriculum deficiencies previously identified, for instance, understanding the social context of engineering solutions.

Such a reform would require departments to scan their environment and identify specialization opportunities. One logical step would be to look for potential businesses to partner with. Often times, an area or region has certain industries that migrate there. For example, some universities in the state of Michigan might want to specialize in manufacturing since some of the major U.S. automotive companies are stationed there.

Table 4 summarizes the benefits discussed above by indicating which issues are addressed as a result of academic departments specializing. Table 4 also makes three other recommendations- requiring undergraduate students to do continuous research, providing pedagogical training to faculty and adding additional staff to help secure funds (for example: grant writing and or seeking business partnerships in the community). It is recommended that students choose a specific research topic by the time they start their major courses. Research can encourage students to participate in life-long learning. In addition, research can help students better understand their course subjects and discipline as a whole.

Table 4. Mapping of issues and recommendations

ORGINAL SYSTEM	PROPOSED CHANGE	1	2	3	4	5
General subjects	Hedgehog Concept	X	X	X		X
No pedagogical training	Continuous pedagogical training	X		X	X	
Undergrad research not necessary for graduation	Continuous undergrad research requirement	X	X	X		
Faculty secure funding	Empower or hire non-academic staff to assist					X

Legend

1. **Curriculum deficiencies**
2. **Lack of promotion of the field**
3. **Culture change issues (resistance to change & life-long learning)**
4. **Lack of pedagogical training for faculty**
5. **Imbalanced faculty reward system**

The recommendations made are indeed non-traditional but address the issues facing the system which may improve the quality of engineering higher education for all stakeholders, especially the primary stakeholder – the student. The contributions made in this thesis are the following:

1. Providing a comprehensive literature review of engineering education reform in the last 20 years in order to identify major issues affecting the system.
2. A systems view of higher education is presented.
3. A proposal for viewing undergraduate engineering students as primary stakeholders is made.
4. Recommendations are made for improving the quality of engineering education.

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APPENDIX

Appendix A

Degrees Awarded in 2007 by Carnegie Classification

S&E degrees awarded, by degree level, Carnegie institution type, and field: 2007

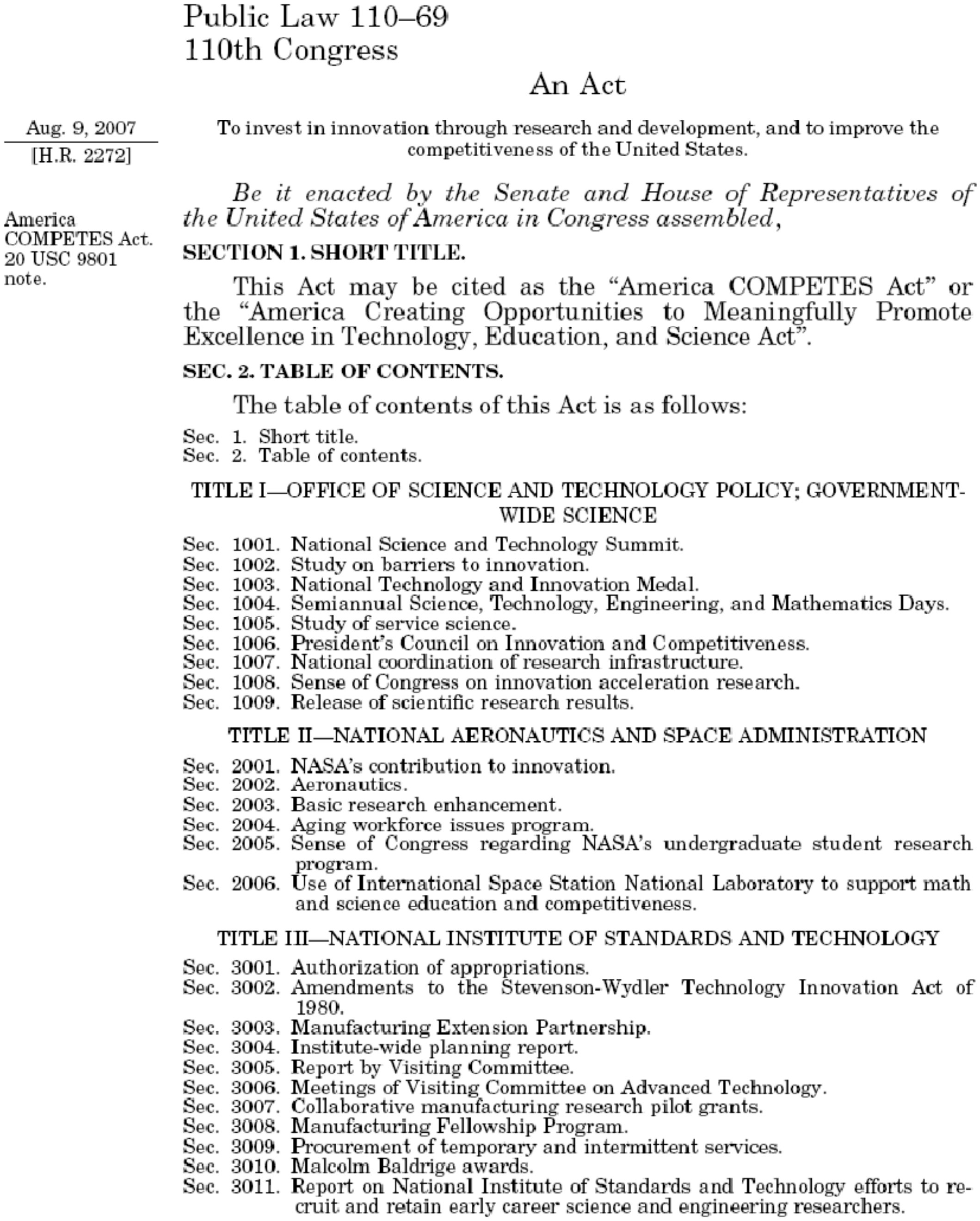
Degree/institution type	All fields	S&E field									
		All S&E	Agricultural sciences	Biological sciences	Computer sciences	Earth, atmospheric, and ocean sciences	Mathematics	Physical sciences	Psychology	Social sciences	Engineering
Associate's	733,151	47,485	1,790	2,224	27,680	69	827	1,946	2,213	8,464	2,272
Doctorate-granting universities—very high research activity	3,761	62	33	0	23	0	0	0	0	6	0
Doctorate-granting universities—high research activity	2,940	135	51	13	66	0	0	2	0	2	1
Doctoral/research universities	5,926	237	1	2	222	0	2	9	0	1	0
Master's colleges and universities	34,101	1,355	13	25	1,096	6	7	53	40	105	10
Baccalaureate colleges	39,392	2,726	158	69	1,904	0	8	14	192	231	150
Associate's colleges	614,240	39,091	1,497	2,034	20,868	63	808	1,857	1,957	7,925	2,082
Medical schools and medical centers	535	0	0	0	0	0	0	0	0	0	0
Schools of engineering	38	25	0	0	15	0	0	0	0	0	10
Other specialized institutions	18,913	3,025	12	63	2,921	0	0	11	4	1	13
Tribal colleges	1,568	274	25	17	46	0	0	0	4	176	6
Not classified	11,737	555	0	1	519	0	2	0	16	17	0
Bachelor's	1,541,704	485,772	17,696	79,348	42,596	4,077	15,551	17,007	90,498	150,725	68,274
Doctorate-granting universities—very high research activity	367,989	174,291	8,247	29,874	6,801	1,428	5,118	5,693	24,128	58,300	34,702
Doctorate-granting universities—high research activity	244,390	79,577	3,217	12,562	4,908	727	1,978	2,338	14,235	22,896	16,716
Doctoral/research universities	102,967	25,322	405	3,587	4,180	174	805	801	5,253	7,999	2,118
Master's colleges and universities	556,454	134,449	3,973	20,781	15,155	1,146	5,111	5,062	33,629	39,926	9,666
Baccalaureate colleges	203,779	63,246	1,785	11,577	6,117	596	2,520	3,077	12,743	21,180	3,651
Associate's colleges	4,419	1,078	33	169	767	0	0	0	87	20	2
Medical schools and medical centers	5,646	46	0	46	0	0	0	0	0	0	0
Schools of engineering	1,543	1,405	0	11	71	6	15	28	0	1	1,273
Other specialized institutions	45,012	4,799	4	719	3,446	0	1	8	326	227	68
Tribal colleges	165	60	13	0	2	0	0	0	0	45	0
Not classified	9,340	1,499	19	22	1,149	0	3	0	97	131	78
Master's	610,469	120,278	4,126	8,794	16,314	1,632	5,035	4,243	18,594	30,604	30,936
Doctorate-granting universities–very high research activity	153,015	48,496	2,134	4,084	5,306	813	2,761	2,495	1,590	12,832	16,481
Doctorate-granting universities–high research activity	92,531	25,728	941	1,776	3,597	643	1,064	978	2,216	6,147	8,366
Doctoral/research universities	77,439	11,157	239	475	1,969	40	282	242	3,378	2,957	1,575
Master's colleges and universities	237,322	29,788	751	1,669	4,776	123	907	495	8,728	8,220	4,119
Baccalaureate colleges	15,170	1,169	46	56	155	6	9	29	559	197	112
Associate's colleges	76	10	0	0	0	0	0	0	8	0	2
Medical schools and medical centers	6,782	828	2	670	0	2	0	3	61	39	51
Schools of engineering	400	204	0	0	11	5	0	0	0	0	188
Other specialized institutions	22,396	2,467	0	51	246	0	12	1	2,007	129	21
Tribal colleges	17	0	0	0	0	0	0	0	0	0	0
Not classified	5,321	431	13	13	254	0	0	0	47	83	21
Doctorate	60,887	32,588	1,068	6,703	1,597	727	1,356	4,209	4,696	4,166	8,066
Doctorate-granting universities–very high research activity	35,373	22,762	812	4,818	1,200	583	1,109	3,326	1,255	3,188	6,471
Doctorate-granting universities–high research activity	10,629	5,622	222	833	275	133	224	784	1,036	720	1,395
Doctoral/research universities	6,411	1,920	17	106	96	5	19	58	1,351	162	106
Master's colleges and universities	3,243	468	12	27	25	3	2	14	270	45	70
Baccalaureate colleges	361	40	0	7	0	0	2	4	24	2	1
Medical schools and medical centers	2,302	1,082	5	899	1	0	0	21	116	21	19
Schools of engineering	7	7	0	0	0	3	0	0	0	0	4
Other specialized institutions	2,503	660	0	3	0	0	0	2	636	19	0
Not classified	58	27	0	10	0	0	0	0	8	9	0

SOURCES: National Center for Education Statistics, Integrated Postsecondary Education Data System, Completions Survey; and National Science Foundation, Division of Science Resources Statistics, Integrated Science and Engineering Resources Data System (WebCASPAR), http://webcaspar.nsf.gov.

Science and Engineering Indicators 2010

Appendix B

America Competes Act (Page 1)



Public Law 110–69
110th Congress

An Act

Aug. 9, 2007
[H.R. 2272]

To invest in innovation through research and development, and to improve the competitiveness of the United States.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

America COMPETES Act.
20 USC 9801 note.

SECTION 1. SHORT TITLE.

This Act may be cited as the "America COMPETES Act" or the "America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act".

SEC. 2. TABLE OF CONTENTS.

The table of contents of this Act is as follows:

Appendix C

Academic Pathway Study Findings Summary Tables (Atman et al, 2009)

College Experience

Interaction with Instructors	Academic Involvement	Curriculum Overload	Learning Outside the Classroom	Extracurricular Activities	Satisfaction
Seniors interact more with instructors than do 1st years (all majors)	Seniors are less academically involved in their courses than 1st years (all majors)	Senior men report more difficulty in balancing their personal & academic lives than do 1st years	More seniors have had research, co-op and internship experiences than 1st years.	Greater engineering activity for seniors than 1st years	Seniors less than 1st years with overall experience (all majors)
		Women report more difficulty with balance than men at both levels	Many report these experiences are the primary source of their learning about engineering work	Women participate more in both types of activities	Seniors less than 1st years with instructors & are less academically involved (all majors)
				URM men greater than non-URM in non-engineering activities	URM lower from beginning to end

Motivation

Sources	Patterns	Gender Differences
Primary motivators: intrinsic (behavioral & psychological) & social good	Little difference between 1st years and seniors	Senior men: rank order - intrinsic behavioral, intrinsic psychological & social good
In rank order: financial considerations, mentors & family	URM and non-URM similar with 3 of 6 motivators (parental, mentor & behavioral)	Senior women: intrinsic psychological and behavioral & social good are leading motivators
	URM men may be more motivated than non-URM men	Women more motivated by mentors than men
	Differences within different engineering disciplines	

Confidence

Math & Science	Open-ended Problem Solving
Comparable between 1st and senior years	Comparable among 1st year and senior women
Men consistently more confident than women regardless of standing	Higher in senior men than 1st year men

Social Skills

Social Skills Confidence	Professional & Interpersonal
Seniors: Predicted by family income (socio-economic status) & non-engineering extracurricular participation	Approximately 50% of seniors both have low confidence in professional & interpersonal skills & perceive them to be of low importance to an engineering career
Freshmen: Predicted by non-engineering extracurricular participation, frequency of faculty interaction & family income (more weakly)	Most socially confident students tend to lean away from pursuing engineering work after they graduate

Appendix C(Cont’d)

Knowledge of Engineering

Sources of Engineering Knowledge	Math & Science
Number of sources cited greater for seniors than 1st years	Both 1st years and seniors perceive math and science skills as more important than professional and interpersonal skills
Seniors more than 1st years report it coming from co-op and internship experiences	Men: URM seniors report greater gains in knowledge over the 4 years than do non-URM seniors. They ascribe greater importance to math & science & professional and interpersonal skills than do non-URM
Seniors: co-op & internship experience most frequently reported source followed by course-related experiences	Women: for seniors, knowledge is strongly correlated with their self-reported level of knowledge of engineering *before* entering college Men: for seniors, knowledge gain is correlated with frequency of instructor interactions, satisfaction with instructors, research experience, extra-curricular involvement and school-related sources
No difference between 1st years and seniors in how frequently they cited school related experiences as a source	

Students’ Future Plans

Future Plans	Graduate Work	Combination of Plans
80% seniors say yes to engineering work 20% are leaning away Less than 10% unsure about entering engineering	Top predictor: senior GPA & intrinsic psychological motivation Top negative predictor: confidence in professional and interpersonal skills	30% seniors see themselves as “engineering only” while 60% are considering a combination engineering and non-engineering and graduate jobs and schooling
25% of seniors are unsure (plans for engineering graduate school, non-engineering jobs, or non-engineering graduate school)	Almost twice as many URM seniors express interest in graduate work (more than non-URM)	Men are slightly more likely to focus only on engineering than women

Transition to the Workplace (Recent Graduates)

Learning on the Job	Teamwork & Communication	Gender Differences	Non-engineering Employment
Steep learning curve encountered and often felt the need to teach themselves	Teams changed from small groups in school to larger teams that are often multi-disciplined	Women reported often feeling discriminated against	60% undergrads anticipate having multiple jobs in different fields
Math was “done” for them by spreadsheets & other software tools	Weak in communication skills, teamwork and understanding organization contexts & constraints	Many reported feeling uncomfortable about being outnumbered in the workplace	Undergraduates' thoughts about career options can be swayed by a single experience such as an internship, interactions with faculty, or advice from a mentor
Many report having to learn industry-specific language			Institutional differences can contribute strongly to the varying levels of commitment to engineering careers
Many felt less in control of deadlines at work compared to school			Student decisions about their post-graduate plans often take place without the direct influence of engineering faculty and staff, who could conceivably provide valuable insights and guidance

VITA

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