AN IPPD APPROACH PROVIDING A MODULAR FRAMEWORK TO CLOSING THE CAPABILITY GAP AND PREPARING A 21ST CENTURY WORKFORCE

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LIST OF SYMBOLS AND ABBREVIATIONS

ABET	Accreditation Board for Engineering and Technology
AIAA	American Institute for Aeronautics and Astronautics
AMA	American Management Association
ASEE	American Society for Engineering Education
ASME	American Society of Mechanical Engineers
ASTD	American Society for Training and Development
BHEF	Business-Higher Education Forum
BYU	Brigham Young University
COTS	Commercial-off –the-shelf
CRM	Common Research Model
DOL	Department of Labor
GDP	Gross Domestic Product
IPPD	Integrated Product and Process Development
IPT	Integrated Product Team
M.B.A.	Masters in Business Administration
MIT	Massachusetts Institute of Technology
MOOC	Massive, Open, Online Course
I/UCRC	Industry University Cooperative Research Center
IPPD	Integrated Product and Process Development
MMORPG	Massive Multiplayer Online Role Playing Games
NASA	National Aeronautics and Space Administration
NSF	National Science Foundation

NSPE	National Society of Practicing Engineers
OECD	Organization for Economic Co-operation and Development
R&D	Research and Development
ROI	Return on Investment
SME	Subject Matter Expert
SMET	Science, Mathematics, Engineering, Technology
STEM	Science, Technology, Engineering, Mathematics
TUEE	Transforming Undergraduate Engineering Education
UAV	Unmanned Aerial Vehicle
US	United States

SUMMARY

The United States is facing a critical workforce challenge, even though current unemployment is around 6.7%, employers find it difficult to find applicants that can satisfy all job requirements. This problem is especially pronounced in the manufacturing sector where a critical skills gap has developed, a problem that is exasperated by workforce demographics. A large number of employees across the various manufacturing sub-disciplines are eligible to retire now or in the near future. This gray tsunami requires swift action as well as long lasting change resulting in a workforce pipeline that can provide Science, Technology, Engineering, and Mathematics (STEM) majors in sufficient quantity and quality to satisfy not only the needs of STEM industries, but also of those companies outside of the STEM sector that hire STEM graduates.

The research shown here will identify overt symptoms describing the capability gap, will identify specific skills describing the gap, educational causes why the gaps have not yet been addressed or is difficult to address, and lastly educational remedies that can contribute to closing the capability gap. A significant body of literature focusing on engineering in higher education has been evaluated and findings will be presented here. A multidisciplinary, collaborative capstone program will be described which implements some of the findings from this study in an active learning environment for students working on distributed teams across the US. Preliminary findings regarding the impact of these measures on the quantity of engineers to the US economy will be evaluated.

CHAPTER I

INTRODUCTION

Reading through a magazine or newspaper articles from the past months and years mentions of the skills gap are commonplace. Headlines such as “Redefining Education to Close the Workforce Skills Gap” [1], “Stubborn Skills Gap in America’s Work Force” [2], or “No Shortage? New STEM data could derail entrepreneurs’ push for immigration changes” [3] can be found in a variety of places and adequately display the complexity and challenges that exist around the skills gap. While there appears to be an argument over the premise of the skills gap, it is rather a debate about how to best close it. In fact this debate was already well under way close to two decades ago as this headline “Thinking Ahead: U.S. Schools Fail to Fill the Skills Gap” [4] from the 80’s in the New York Times shows.

There are three areas that describe much of the skills gap: healthcare, education, and STEM [5]. The research will focus on the STEM area, however any solution will have to include educators. A discussion regarding the skills gap in education will therefor also be presented. Finding a pathway to close the STEM skills gap is paramount to the nation’s prosperity. The manufacturing sector, which employs a large number of STEM workers, is responsible for 12% of the Gross Domestic Product (GDP), 60% of exports, and 69% of private R&D spending [6]. The benefits of a thriving manufacturing sector extend to many more than the 9% of the U.S. population that are employed therein. Given that more than 70% of the science and engineering workforce have at least a Bachelor’s degree [7] and that 95% of all jobs in STEM require a postsecondary education [8], this research focuses in particular on higher education and what changes can be made therein to improve the quality and quantity of graduates. This assumption is further corroborated by a workforce model developed by the Business Higher Education Forum (BHEF), analysis of which shows that "strengthening STEM undergraduate education as the highest leverage strategy to meet employers' critical STEM workforce needs in the short-term." [9] While others argue that a better approach might be through reforms to the early education system [10], this approach is not further pursued here for multiple reasons. While the author does not disagree with the premise that early childhood education has the ability to significantly influence a child's educational future, pursuing any changes presents multiple hurdles, not the least of which is the federalized nature of the education system. While this challenge does apply to higher education to an extent, it is less pronounced as colleges often cater to a regional if not national or even international student audience. Furthermore the timescales required to evaluate the impact of changes to early childhood education renders any but the largest and thus most expensive efforts almost impossible. Another avenue of addressing the skills gap focuses on those already in the workforce, they need "skills, credentials, and networking capabilities." [11] While professional education (and re-education) certainly has different requirements than higher education, there are also similarities.

Addressing the skills gap has many similarities to complex systems design often seen in the aerospace industry. A variety of customers (students, employers, universities, government) all place various, often times competing, requirements on the education system (K-12, Higher Education, Professional Education) as a whole. This research will evaluate how an Integrated Product and Process Development (IPPD) [12] framework can be utilized to develop solutions that will provide benefits to all stakeholders. A detailed literature search of various sources will be presented that aims to more fully define the exact scope of the skills gap as well as possible educational solutions to close it. As will be detailed later, previous research does not fully describe this problem it only addresses aspects thereof.

While some of the gap is associated with hard technical skills, executives realize that now more than ever employees need to be able to “think critically, solve problems, innovate, collaborate, and communicate more effectively” [13] in order for their business to excel. The Conference Board reports that “the business community … is calling for higher standards of workforce excellence consistent with the demands of the 21st century.” [14] They go on to define those standards as “substantial content knowledge and information technology skills; advanced thinking skills, flexibility to adapt to change; and interpersonal skills to succeed in multi-cultural, cross-functional teams.” They go a step further and state that “The lingua franca in business—it’s mostly projects. “ They, as the author, wonder why projects are not more commonly used as an educational tool in engineering education. Casner-Lotto and Barrington call for “research (into) promising models for incorporating more hands-on and practical experience for students in the curricula and seek(ing) ways to involve community organizations and businesses to pilot workforce-applicable learning opportunities.” [14] It is exactly requests for help such as this one, that motivated the author to pursue the topic of mitigating the skills gap for the benefit of all parties involved for this research.

CHAPTER II

ESTABLISHING THE NEED

The IPPD methodology has been used on a variety of projects, both in the civilian and defense sector [12, 15, 16]. It aims to provide a framework within which decisions about the entire product lifecycle can be made in a logical and reproducible manner, eliminating some of the fuzzieness found in engineering design, or at the very least providing a structure to contain it.

It brings together systems engineering methods, quality engineering methods, and decision support processes. The IPPD methodology is broken into six distinct steps: establish the need, define the problem, establish value, generate feasible alternatives, evaluate alternatives, and make a decision as can be seen in Figure 1. In this methodology the various systems engineering methods provide product design driven inputs to the framework, while the quality engineering methods generate inputs from a process driven design standpoint. This enhances Integrated Product Teams (IPT's) ability to consider all phases of the lifecycle early in the lifecycle, resulting in less rework, less expensive products, and most importantly better designs for those products. Various tools from each of the perspective disciplines can be found within the IPPD framework, e.g. the 7 management and planning (M&P) tools or robust design assessments out of the area of quality engineering methods, or requirements analysis and systems decomposition out of the area of systems engineering methods. Each of these tools provides a distinct benefit, but it is the joining of all the various tools that provides the true benefit of the IPPD methodology and enables a more holistic design approach.

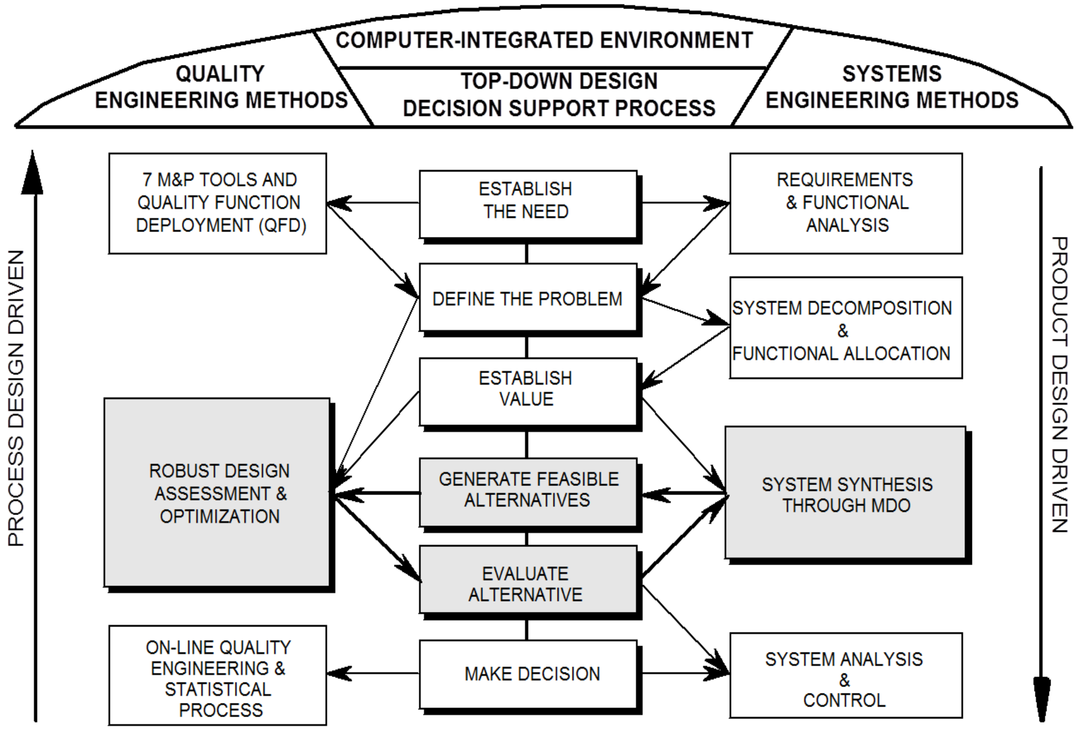

Figure 1. IPPD Methodology[12]

The first step in the IPPD methodology requires that the need is established. As was shown in the introduction headlines in the popular news might lead one to believe that this step has not been completed. The author's intent is to shows that sufficient data exists that shows there is truly a need for reform in engineering education to address the growing skills gap and that decision and policy makers should move to the next steps in solving the process.

A study by McKinsey [17] projects that by 2020 there will be a shortfall of 1.5 million workers with the appropriate college degree, a survey found that engineering positions are the most difficult to fill [18], nine out of the top 10 majors with the highest median earning are in engineering while none of the lowest 10 are. [19] Furthermore discounted lifetime earnings are $500,000 higher for STEM majors than non-STEM majors [17], supply side economics would suggest that there should be a surge in STEM graduates.

While there has been a sharp increase in the overall number of STEM degrees awarded over the last 15 years, it can be seen that a majority of this increase comes in social and behavioral sciences, although all sub disciplines (with the exception of Computer Science) have shown a steady albeit small increase in the number of graduates [20]. Unfortunately unemployment rates in the fastest growing group, social and behavioral science, are five times higher than for engineering graduates [17]. While there have been attempts to increase the quantity and quality of STEM graduates, only small advances have been made, leaving businesses in the difficult position to determine what they can do right now [21]. The unemployment rate of recent engineering graduates is lower than the national average, but still high at 7.4% [22]. This is in contrast to the overall unemployment rate for scientists and engineers of 4.3%. [7] This high unemployment rate in recent graduates coupled with the demand information presented previously indicates that many applicants do not meet industry minimum standards. Couple that with the fact that out of the 12.6 million individuals with their highest degree in science and engineering (S&E) only 3.9 million (30.9%) work in S&E occupations [20] and the problem becomes even further magnified. A Georgetown University study indicates that this "diversion of STEM talent and STEM workers into other occupations results from the increasing value of the competencies." [23] They are further defined as "the set of core cognitive knowledge, skills, and abilities—that are associated with STEM occupations, and the noncognitive work interests and work values associated with STEM occupations.” [23] This indicates that there are some graduates that possess the appropriate skills, those that are most sought after by STEM and non-STEM employers, but these skills are not widespread. The Society of Manufacturing Engineering (SME) describes it well saying: “The manufacturing education efforts and actions are many, but the people and resources are few. We need to focus on those activities that bring the greatest benefits.” [24] This research aims to answer this clarion call of identifying the best paths forward.

The American Society for Training and Development’s (ASTD) statement that “employers in high-skills STEM fields (science, technology, engineering, and math) … also will be hard-pressed to find adequate talent in coming years.”[5] introduces another challenge regarding the skills gap, the growing age of the labor force. The Center on Education and the Workforce at Georgetown University predicts that “there will be 2 million job openings between 2008 and 2018 in the Manufacturing industry as a result of retirement.” [23] In 2010 33% of the S&E labor force were over 50 years old, the median age was 44 years old. [7] This trend can be explained by the demographics of the US population which benefitted from a large number of new births immediately following World War II, which provided a great boost to the economy, but are now retiring or getting ready to retire. The effect of this is particularly felt in the aerospace industry, a workforce study found that at large companies 42.9% of employees are older than 50 years with an additional 17.2% in the 46-50 year old bracket. [25] The Department of Defense indicates similar age distribution patterns [26] pointing towards a wide spread problem. At The Boeing Company the average age is 48 [27] with about a quarter of the nation’s aerospace workforce already eligible for retirement [28]. This flood of retirees will have an impact on the nation as a whole but “the impact it will have on STEM and its competitor occupations is disproportionate. ” [23] Another complication is provided by the fact that less than 2/3’s of graduates are eligible for a security clearance [29], this is an obvious problem for the Department of Defense, but also for industry as they aim to drive efficiency by sharing components, and thus employees, across commercial and defense applications.

Chapter III

Define the Problem

Having identified the need the problem now needs to be defined further prior to developing solutions. A Georgetown University study indicates that we should focus "on developing curricula that put academic competencies into applied career and technical pedagogies and link them to postsecondary programs in the same career clusters." [23] They go on to say that a "mix of job-specific technical preparation plus preparation in other disciplines is becoming increasingly advantageous across a wide array of occupations." [8] So what are these "applied career pedagogies" and "other disciplines" referred to in their report?

This chapter aims to define the specific skills that are seen as lacking and proposes some possible educational remedies to address these challenges. As Lafer notes, "the notion of 'skill' has been one of the most elusive and hardest to-define concepts in labor economics." [30] He warns of the "range of tasks, knowledge and abilities that are deemed to be required" [30] because they do not provide educational institutions with "scope and relative importance," [30] but admits that "such training could be integrated into existing educational and training courses" [30] although it "runs the risk of displacing valuable occupationally or task specific technical content." [30]

A report by McKinsey Company echoes the concern for scarce resources in education and advocates careful use thereof, but maintains that innovation must take place. [17] Similarly the Society of Manufacturing Engineers suggests that various activities should be assessed so they can be broadly distributed if successful. [24] The

AAR Cooperation, an aviation service provider, advocates that the skills gap "has created recruitment, hiring and retention challenges for employers" [21] and that "educational institutions have been slow to implement needed changes." [21] A study by Carnevale et al. agrees that educational institutions are the appropriate forum to address this skills gap since "the learning curve is gentlest when these competencies are introduced to students within a practical framework and appropriate context." [8]

It was found by the author that a great many people are concerned with the skills gap. Government, industry, trade groups and others address the skills gap from a macroeconomic perspective, identifying broad areas of desired improvements. Professional organizations take care to more carefully classify gaps into specific skills while instructors, psychologists, and learning scientists work together to improve or find new approaches to better teach individual skills. What is lacking is a common framework that combines the work that has been done by a great number of people to provide decision makers with the ability to review requirements and constraints placed on the educational system by all involved parties.

It was felt that this could best be seen by looking on the one hand at the overt symptoms of the skills gap and the specific skills addressing this symptom and on the other at the educational cause at the root of these deficiencies as well as potential remedies. Table 1 shows the varying sources of information regarding the skills gap in each of the aforementioned areas. It should be noted that as one progresses though the spectrum from overt symptom to educational remedy the number of sources cited increases significantly. This is due to the fact that the broad gaps are usually assessed together, while remedies for specific skills are often only addressed one or a few at a time, due to the in depth work required for each. It should also be noted that the type of source differs significantly.

Table 1. Overview of Literature regarding the Skills Gap

Overt Symptom (10)	Skill (14)	Educational Cause (17)	Educational Remedy (26)
• American Management Association (1) • American Society for Training and Development (1) • Center for American Progress (1) • Deloitte & Manufacturing Institute (1) • Georgetown University (1) • Manpower Group (1) • McKinsey & Company (1) • Organization for Economic Co-Operation and Development (1) • The Conference Board (1) • Book (1)	• American Management Association (1) • American Society for Training and Development (1) • America's Edge (1) • Department of Labor (1) • Georgetown University (2) • Journal of Engineering Education (1) • Journal of Process Mechanical Engineering (1) • Organization for Economic Co-Operation and Development (1) • Society of Manufacturing Engineers (1) • The Conference Board (1) • Books (3)	• American Association for the Advancement of Sciences (1) • Assessment & Evaluation in Higher Education (2) • Enhancing the Learner Education in Higher Education (1) • Journal of Engineering Education (7) • Journal of Higher Education (2) • Journal of Marketing Education (1) • Journal of Process Mechanical Engineering (1) • Review of Educational Research (1) • Book (1)	• American Association for the Advancement of Sciences (1) • Assessment & Evaluation in Higher Education (1) • European Journal of Engineering Education (1) • Journal of Engineering Education (14) • Journal of Higher Education (4) • Journal of Process Mechanical Engineering (1) • Review of Educational Research (1) • The Academy of Mangement Journal (1) • Books (2)

The overt symptoms, specific skills, educational causes and remedies are summarized in Table 2 but will be presented for each of each of six identified broad symptoms in more detail in following.

Skills Gap I – Teamwork

Engineering has always been about teamwork, but in this era of globalization it is becoming ever more important. The Boeing Company relied on a network of 50 tier 1 supplier which were engaged in risk sharing partnerships to develop their latest model, the 787. Based on this approach major sections were manufactured in: Japan, Korea, Italy, Australia, Washington, Kansas, South Carolina, and Oklahoma among others before being assembled in Everett, WA. [31] This required engineers to work on global teams, which provides an additional level of complexity when compared to operating in a co-located team environment. This trend is replicated throughout the United States, where trade in goods and services has increased 95% between 2003 and 2012 [32]. While the use of social networking has increased dramatically over the last decade, especially for those that would currently be enrolled in higher education, the 18-29 year olds [33], there has not yet been a clear way to harness this experience to advance teamwork in academia or industry.

Overt Symptom

The National Center for Improving Science Education notes that "Collaboration in SMET courses and programs is aimed at enhancing the preparation of students for collaboration in SMET professions and at giving all students a better sense of how scientists and engineers work." [34] Since student preparation for a later career should be in the interest of the universities, a criterion with regards to this is also found in the general Accreditation Board for Engineering and Technology (ABET) criteria for Baccalaureate engineering programs under student outcome d). [35] An American Management Association (AMA) Survey found that 72.6% of managers and executives agree or strongly agree that collaboration is a competency that has "priorities for employee development, talent management, and succession planning in the next one to three years." [13] Furthermore 60.2% of respondents agreed or strongly agreed that they are assessing competencies in the area of collaboration prior to making hiring decisions. [13] Casner-Lotto and Barrington in a survey of 409 employers found that teamwork and collaboration was ranked as very important by a staggering 94.4%. [14] The Center on Education and the Workforce proposes that this is a natural transition as automation simplifies or takes over many tasks and "workers are left to perform more general, non-repetitive functions like quality control and innovation that require heightened interaction with other workers across intellectual disciplines and occupations." [8] They further posit that "the growth in overlapping assignments and performance goals increases the need for cross-training and soft skills like communications and teamwork." [8]

Skill

Having identified a significant overarching objective in improving collaboration skills, it is important to further stratify what the exact skills are that contribute to successful collaboration. What does it actually mean to be a team player or a collaborator?

Schrage identifies teamwork as a "process of shared creation" [36] indicating that teamwork should always have a final product that benefitted of the contributions of all team members. Furthermore, his mention of the process indicates that he does not simply believe that it should be a collection of contributions from various team members, but rather that they must actually interact with each other to create a final product. This requires that collaborators have "social perceptiveness" [8] which Carnevale et al. define as recognizing and understanding the reactions of others. [8] This skill is clearly required to fulfill the Department of Labor's call that one should "choose behaviors and/or actions that best support the team" as defined in the advanced manufacturing competency model. [37]

This requires that team workers possess "active listening" skills where they "give full attention to what other people are saying, taking time to understand the points being made, asking questions as appropriate, and not interrupting at inappropriate times." [8] A Georgetown University study found that this is the most highly valued skills for high-wage, high-growth, high-demand jobs one of which they consider engineering to fall under. [8]

This alone however will not be sufficient for successful collaboration. One of the benefits of working on teams is, that there are members with various backgrounds and opinions. In addition to listening, collaborators also have to be able to "persuasively present thoughts and ideas," [37] or per Lafer's definition have the "capacity to teach others." [30] Since not all team members can do so successfully all the time, the ensuing differences need to be reconciled from time to time to again bring the team together, therefor negotiation is a critical skill. [8] An ability to "build towards consensus" [37] will be invaluable in such a case.

While there are certainly various kinds of leadership models [38] and one could argue about the advantages and disadvantageous of each, there seems to be a consensus that regardless of the leadership style, some leadership is nonetheless required. This is supported by Lafer [30] as well as the Conference Board, which states that 81.8% of industry respondent s view leadership skills as very important. [14]

Educational Cause

While there are some laudable attempts to include teamwork and collaboration in the engineering classroom [39-41] there are hindrances and institutional barriers preventing its widespread implementation. First and foremost Lejk et al. [42] and Almond [43] point out that in an environment where an individual is attempting to obtain his or her individual diploma, which is dependent on individual performance in various courses, it is difficult to create a motivational structure in which an individual is rewarded for collaborating with others.

The Association for the Advancement of Sciences points out that his leads to a competition which "distorts what ought to be the prime motive for studying science: to find things out." [44] This competition may "result in many of them developing a dislike of science and losing their confidence in their ability to learn science." [44] Johnson and Johnson describe it as a "competitive goal structure in which students are expected to outperform their peers" [45] In a competitive environment such as this, where having the best grades determines who will receive scholarships, internships, or jobs, collaboration will be difficult to achieve and require special application of educational theory. Kezar identifies the ultimate culprit, when he states that "one cannot impose collaboration within a context designed to support individualistic work." [46]

Even when professors encourage collaboration in courses, what role models do students have? The very institutions that ABET accredits to instill "an ability to function on multidisciplinary teams" [35] operate in "departmental silos and within bureaucratic/hierarchical administrative structures." [46] If "institutions are not structured to support collaborative approaches to learning, research, and organizational functioning," [46] then surely in their current form it will be very difficult for them to effectively teach collaboration. The entire situation is further complicated by extensive student codes of conduct issued by universities that specifically prohibit collaboration unless explicitly authorized. [47] In order to fully address this, a true paradigm shift in engineering education is necessary, an environment in which interdepartmental collaboration is the norm rather than the exception will have to be created that allows faculty as well as students to work together without fear of repercussions.

Educational Remedy

Solutions to address the lack of collaboration in engineering education are various, some applicable at the individual professor level, while others will require significant support from Deans and university Presidents. Prior to any discussion on the details of these improvements it is important to note that the effects of teaching on collaborative setting are much more far reaching than simply teach better teaming skills.

Piaget [48] and Vygotsky [49] both agreed that student's cognitive development could best be supported by having them work in small group settings on problems that are open-ended, ill-structured and have multiple possible solutions. Doing so would expose them to potential flaws in their mental model which could be remedied by other class members sharing their insights. Furthermore "cooperation has favorable effects on achievement and productivity, psychological health and self-esteem, intergroup attitudes, and attitudes toward learning." [34]

In spirit of the call to action by the Society of Manufacturing Engineers, to present data on the evaluation of proposed solutions, [24] some data will be presented here to support the previous claims regarding small group work. A study by the National

Center for Improving Science Education at the University of Wisconsin [34] found that student achievement is greatest with medium group time (d = 0.73), rather than high or low group time (d = 0.52 for both). The researchers also found that students attitudes were best when group work was high (d = 0.77). They conclude that "small-group learning has significant and positive effects on undergraduates in SMET courses and programs." [34]

This model is effective, because students are working in a cooperative environment, where "each group member (is) accountable for learning," [34] a concept that has been successfully implemented in M.B.A. program. [50] In order for this model to succeed, it requires that students "share responsibility for learning with each other." [44] Springer et al. [34] as well as the American Society for the Advancement of Science [44] both propose that this may be achieved by assessing student teams not only on the outcomes, but also on their learning. Only a team that has a favorable outcome, in addition to proving learning took place for all team members, can obtain highest marks.

A similar approach is proposed by Lejk who proposes that student's individual assessment should be "based directly on the material used in the group activity" [42] Johnson and Johnson agree, that "a cooperative goal structure results in higher achievement than does a competitive goal structure," [45] but it does require changed instructional roles where professors should "facilitate more frequent and less constrained interaction among students." [34]

It has been proposed by Gibbs and Habeshaw [51] as well as Mu and Gnyawali [52] that group work is most effective when ground rules are set. These ground rules enable all team members to thrive in a collaborative environment. It may be helpful to have some ground rules set by the instructor to which teams can then add their own rules. It is important that ground rules are agreed upon by all team members, otherwise they may indeed have a negative impact on team performance. Mu and Gnyawali [52] also propose that it can be helpful for cognitive development to have groups work on the same problem simultaneously.

In addition to learning new skills to succeed in a cooperative learning environment, which according to Springer et al includes “communicating a common goal to group members, offering rewards to group members for achieving their group’s goal, assigning interrelated and complementary roles and tasks to individuals within each group, holding each individual in each group accountable for his or her learning, providing team-building activities or elaborating on the social skills needed for effective group work, and discussing ways in which each group’s work could be accomplished more effectively,” [34] students also need to “unlearn non-collaborative skills.” [46] Regardless of the specific considerations to improve teamwork it has been found that “the effects of small-group learning on achievement were significantly greater when measured with exams or grades (d = 0.59) than with the standardized instruments (d = 0.33).” [34] While this statement is not intended to provide a judgment for or against the use of standardized instruments in the classroom, it should be noted for future research regarding the evaluation of small-group learning.

Deans and Presidents who are concerned with diversity in engineering at their institutions should consider that “small-group learning may have particularly large effects on the academic achievement of members of underrepresented groups.” [34] Whether or not viewed under this pretense, it will require their assistance in order to prepare students for teamwork in industry as only they have the power to change “the organizational context features that need to be redesigned.” [46] Some examples of this are appointments of cross-disciplinary faculty [46] or enabling multidisciplinary teams across higher education. [52]

In addition to these very fundamental changes to engineering programs, there are also opportunities to take advantage of new technologies. Social technologies have made “significant contributions to raising the productivity of high-skill workers, improving coordination and collaboration with partners, and accelerating innovation through co-creation.” [53] Yet these advances have not found very many implementations in the traditional educational settings, in fact the National Academy of Engineering sees advanced personalized learning as one of only fourteen grand challenges they have issued. [54] While distance learning has been a part of many large research institutions for quite a while, teaching in itself has not adapted to these new opportunities, rather the mode of delivery has been changed. Where previous students relied on recordings stored on VHS, students now can access videos via the internet from anywhere in the world. While this is certainly commendable, the implementation of technology like this leaves much to be desired.

Instead of traditional accredited university programs embracing technology, it has been a new development, the Massive, Open, Online, Course (MOOC) that has laid claim to first use of many of these social features in the classroom. While many large research institutions now offer some courses in a MOOC format [55], implementations of full degree programs taking advantage of this new online social structure like the online Masters of Computer Science at Georgia Tech [56] are very rare. As these social media tools are developed further and find more widespread implementation in the traditional classroom, they will be “enablers of future learning styles by facilitating the formation of learning communities, fostering student engagement and reflection, and enhancing the overall student learning experience in synchronous and asynchronous learning environments.” [53]

The effectiveness of these social media tools will be further expanded as collaborative Computer Aided Design [57] and analysis tools [58] are matured and integrated with current social media tools. Initial applications of these technologies in education have taken place [39, 59] and continue to be under evaluation to evaluate how they assist in advancing collaboration in higher education.

Skills Gap II – Problem Solving Skills

An additional area often mentioned as lacking in recent graduates is problem solving. As will be discussed in this section, the focus here is not on the lack of knowledge for particular types of problems (i.e. lack of ability to solve manufacturing problems), which will be addressed later, but rather that of a lack of systematic processes to solve an unknown, ill-defined problem to an acceptable level of engineering accuracy within company risk profiles. The lack of these processes is more fundamental than that of specific knowledge needed to solve them.

Overt Symptom

Problems solving is the essence of engineering work, as Nathan Dougherty, former Dean of the University of Tennessee, famously postulated in 1955: “The ideal engineer is a composite ... He is not a scientist, he is not a mathematician, he is not a sociologist or a writer; but he may use the knowledge and techniques of any or all of these disciplines in solving engineering problems." [60]

Given this recognition and importance, it is surprising to see that the Manpower Group reports that a lack of problem solving skills is a problem for companies globally, the lack of "ability to deal with ambiguity or complexity" further magnifying this problem. A study by Casner-Lotto and Barrington found that 92.1% of industry responses see problems solving as very important, yet only just over a quarter (27.6%) of four-year college graduates receive excellent marks for this very same measure. [14]

A study by Georgetown University supports these findings, in their survey complex problem solving is identified by 80% of responded as having medium or high importance for high-wage, high-growth, high-demand jobs. [8] The Organization for Economic Co-operations and Development (OECD) supports that lacking problem solving skills are a global problem, acknowledging that typically more skilled worked have "higher order problem solving skills" [61] pointing to a lack of ability in less experienced employees.

A survey of manufacturing companies in the US by Deloitte found that 52% of respondents (n = 1123) found inadequate problem-solving skills to be "the most serious skill deficiency in current employers," which earned it the top spot, almost ten percentage points before the next entry. [62] They determined that "the national curriculum may be discretely addressing certain skills, (but) there continues to be a lack of broader problem solving abilities." [62] They conclude by assessing the impact on innovation, 80% responded that it had an impact on new manufacturing process, 64% expressed that it influenced product development. For a manufacturing company both areas are at the very core of their business, they can only survive by continuously offering better products either through new development or new processes. For both, problem solving is an essential skill since at the core, each is addressing an engineering problem.

Toner finds that "an increased rate of technical change introduces greater 'uncertainty' for firms, which, in turn, demands an increased capacity for adaptability and more widely distributed problem solving skills." [61] The American Society of Engineering Education (ASEE) found in a survey that 40% of respondents believed the responsibility to teach the "ability to identify, formulate, and solve engineering problems" rested squarely on the shoulders of academia with an additional 51% believing responsibility was shared between academia and parents (26%) or academia and industry (25%). [63]

Skill

The Department of Labor defines problem solving as a "workplace competency" [37] in their advanced manufacturing competency model and thus differ from the opinions presented previously; nevertheless, their model correctly identifies problem recognition and definition as a required first step in problem solving. The importance of proper problem identification is similarly reported in a study by Carnevale et al. [23] who also report that problem sensitivity is critical. They define this as the ability to "recognize when something is wrong or likely to go wrong," [8] in essence identifying a problem before its existence makes itself known.

In order to properly do this engineers are often required to engage in "information ordering." [8] Modern engineering artifacts, be they machines, buildings, or something else often generate lots of data on their own through integrated sensors, are monitored on occasion, or are analyzed using computational tools. The amount of this data is always growing so that now is often commonly referred to as “big data” [64] and it needs to be sorted “in a certain order or pattern.” [8] While some patterns may be so complex that humans cannot effectively recognize them, [64] they still need to have “information literacy” [37] in order to enable them to determine where and how they can find the information required to define and solve a problem. This includes the ability to critically evaluate information and recognition of gaps in existing data. [37]

Engineers have to be able to transfer knowledge from various contexts and apply it in new situations, this may require an engineer to “recall previously learned (relevant) information” [37] or work as part of a team to “identify potential causes of the problem.” [37] This particular example should serve as an example to show how intertwined many of the skills gaps are. In order to enable successful transfer and application in new contexts engineers need to be adaptable. [61]

All of the previously identified skills culminate in perhaps the most important one, critical thinking. A Georgetown University study finds that “96% of all occupations rank critical thinking as either very important or extremely important to that job.” [8] A finding that is corroborated by the American Management Association which found that 71.9% of organizations agree or strongly agree that critical thinking is a skill with importance to their organization. [13] This importance is mirrored in a variety of other studies [14, 23, 37] so much so, that the author considered designating critical thinking as a gap of its own, however it was felt that it fits better in the broader context of problems solving where it is an essential building block.

As part of the problem solving process students will have to use both inductive reasoning, “combining pieces of information to form general rules or conclusions” [8] or “finding a relationship between seemingly unrelated events” [8] and deductive reasoning, “applying general rules to specific problems.” [8] Both are considered to be among the top ten abilities most highly valued throughout the economy. [8]

While problem solving skills improve with experience, they can be taught. This however should not distract from the basic principle of improving skills through lifelong learning [14], in order to successfully solve problems engineers need to constantly understand advances made in their own as well as related fields, this can only be achieved through a process of lifelong learning.

Educational Cause

Although the Grinter Report called for “the instructional goal of engineering education (to) include helping the student to learn to deal with new situations in terms of fundamental principles” [65] in 1955, this goal has not yet been fully realized. This may be due to the recommendation given in the same report that engineers be educated in a variety of topics, which requires addition of classes on new emerging developments while maintaining focus on the fundamental scientific skills. The committee realized that “there is considerable doubt as to whether there is any margin of student time left” [65] however looking at engineering education today one wonders if perhaps too much emphasis has been placed on including new scientific discoveries in the program at the expense of emphasizing transfer between various subjects.

The Grinter report proposes various possible solutions to this conflict of interest regarding how students should spend their limited time in higher education, however it appears that now almost sixty years after the original report we are little closer if not further away from the vision of the committee. Currently nearly 60% of first-year college students have to take remedial classes, [66] pointing towards a failure in providing a "more adequate high school preparation." [65] While "higher selectivity" [65] is certainly an option to increase the likelihood of students completing an engineering degree, it does so at the expense of reducing a pipeline of students which is already unable to satisfy industry demand. While there have been calls to change engineering education to a model similar to practices in medicine in law (with extended education) [67] these efforts so far have failed to produce sufficient traction to influence change. That leaves the options of "increasing the effectiveness of instruction" [65] and elimination of "material now in the curriculum." [65] The latter options appears to not find widespread implementations, rather engineering curricula are stovepiped, ever increased subject matter resulting in a "lack of transference of skills from one unit to another," [68] leaving the former as the only alternative.

Blair reports that "the effectiveness of the lecture is dependent on the quality of the delivery and the quality of the presentation." [69] At large research universities in particular the preparation required to achieve such quality may suffer as young faculty are struggling to obtain sufficient research funding to secure a tenured position and tenured faculty struggle to maintain their extensive contracts network the established. It is up to the Department Chairs and Deans to ensure that faculty do not have a conflict of interest between maintaining research relations and student teaching. They could further assist by hiring faculty from a diverse background, including researchers as well as practiced engineers so that students can solve "workplace problems" [70] which can best be provided in the appropriate context by engineers who were able to experience them.

While there is certainly room for improvement from policy makers and university leadership, students also contribute to the lack of problem solving skills. Many courses for various reasons rely on problems that "possess knowable, correct solutions that are achieved by applying preferred solution methods." [70] Students thus "apply a limited number of regular rules and principles that are organized in a predictive and prescriptive arrangement" [70] Whether because of the form of assessment, the personal choices of the students, or a combination of both, this leads to "students relying heavily on memory". [71] Similarly, when given the opportunity, students "often depend heavily on the textbook during their problem solving rather than using it as a resource to complement their knowledge." [72] This overreliance on textbooks and standard, memorized solution approaches leads to a degradation in problem solving skills rather than improving them. Jonassen notes that "problem solving, as an activity, is more complex than the sum of its component parts… it engages a variety of cognitive components." [73] Students must be engaged in all these various cognitive components.

Educational Remedy

Hargreaves notes that "topics covered in an engineering degree are related and even though units are separated (and assessed separately), both content of individual units and the process of learning must be integrated across the complete engineering curriculum." [68] This integration could be improved, current curricula, while relying on a broad engineering curriculum, often do so by sending students outside of their departmental silo with little or no interaction among faculty of the various departments in the university. In order to educate engineers successfully, "both content of individual units and the process of learning must be integrated across the complete engineering curriculum." [68]

While some attempts have been made to integrate units across the curriculum, most notably at the Massachusetts Institute of Technology (MIT) with its unified engineering courses, [74] widespread adoption of these principles is not found. Furthermore even this exemplary program, integrating fundamentals from the areas of thermodynamics, propulsion, fluid mechanics, structures, dynamics, and linear systems in one course, is currently only in place for Sophomores attending MIT.

The American Society of Engineering Education proposes that this integration may be "cultivated through multiple iterations of design throughout the curriculum." [63] The definition of structural engineering provided by Dr. Dykes, it "is the art of modeling materials we do not wholly understand into shapes we cannot precisely analyze so as to withstand forces we cannot properly assess in such a way that the public at large has no reason to suspect the extent of our ignorance," [75] certainly confirms that the findings of the ASEE study, that design should be taught in iterations so that students can get a better understanding of the limitations of even the most sophisticated problem solving approaches. Student problem solving skills could be further improved by utilizing multidisciplinary student teams to solve these various iterations of design problems. [52]

When designing problems for students to solve, whether on multi-disciplinary teams or not, it can be of benefit to consider Vygotstky's "zone of proximal development." [49] He proposes that in this zone students are unable to solve a posed problem independently, but they are able to do so with guidance. This guidance can come from the instructor, other students in a cooperative learning setting, especially when working on multidisciplinary teams, or other resources available to the students. The report on Transforming Undergraduate Engineering Education (TUEE) views “aiming problem-solving instruction slightly beyond what students can do alone but within the boundaries of what they can do with assistance from others” [63] as vital to the teaching of problem solving skills.

The oft found “formula of one answer path per problem places boundaries on problem solving,” [63] that are not acceptable or representative of engineering problems where usually multiple feasible solutions exist within a variety of constraints. The approach of a singular solution approach, while perhaps easier for the instructor from the perspective of preparation, does not provide students a true opportunity to experience failure. Failure here would be in the form of being unable to apply certain principles to a specific application, rather than from understanding the technical underlying of proposed design that was found to be infeasible upon evaluation. The former having a degrading effect on student motivation, while the latter provides encouragement that fundamentals learned allow for evaluation of complex engineering systems. Unfortunately “struggle through failure is not admonished as positive” [63] by many within engineering education.

In order for students to work though these struggles, it is vital that they understand the subject matter at hand, discussions in a lecture environment are a means for instructors to validate, through formative assessments, that students are grasping the main concepts. [51] A simple first step in this dialogue may be to have students review and summarize the problem statement, [76] verification of successful understanding will be a first step in ensuring successful problem solving. This could later on be supplemented by "self-explanation strategy," [71] as proposed by Litzinger et al., supporting the common notion that you do not really understand something until you can explain it to somebody else.

Instructors can further enhance the student's problem solving skills by being aware of the differences in problem solving approaches between novices and experts. A study by Atman et al. [77] found that experts have much greater "information literacy" [8] than students, spending significantly more time on reviewing information from many more domains. It was also determined that experts usually create significantly more model components and are able to successfully connect them into one single solution. [77, 78] Instructors should use findings like these to alter the instructional methods and allow students to emulate successful expert practices in problem solving.

Skills Gap III – Knowledge Gaps

Although the previously listed skills may often be referred to as "soft skills" they are nonetheless very valuable to industry. The skills gap however manifests itself not only in soft skills, but also in the hard skills. Industry is realizing that too many applicants don't possess the technical skills required to fulfill job responsibilities.

Overt Symptom

The problem of lack of technical expertise is of particular concern for the "mid-skilled" that possess on the job training in manufacturing, but do not hold a college degree. As the role of manufacturing changes towards more automated processes, these individuals do not have the skills to work on the machines that now take over tasks they previously completed. [5]

A study Manpower Group shows that 33% of respondents indicated that “lack of technical competencies (hard skills)” [18] was the culprit of their difficulty in filling jobs and in fact stratifying these results by industry revealed that for engineering in particular the business impact was usually high. This study is supported by findings of the American Society for Training and Development which in a survey of 377 employers found that 26% of respondents indicated a lack of basic skills as a problem their company is currently facing.

Deloitte reports in a study on the state of manufacturing that shortages of skilled labor “are taking their toll on manufacturers’ ability to expand operations, drive innovation, and improve productivity.” [62] The study goes on to say that 43% identified “lack of basic technical training (degree, industry certification or vocational training” as “the most serious skill deficiency.” [62] In addition 30% identified a lack of mathematical skills. And 29% perceive a lack of reading and writing abilities. [62] A Georgetown University study finds that hiring in manufacturing in the decade from 2010 – 2020 will likely have to be around 3.5 Million to satisfy economic growth and fill positions of retirees [8], this goal can only be met if educational programs provide graduates with the skills desired by industry.

Skill

Some of the previously mentioned studies already further detailed the lack of basic skills by identifying mathematics and language as specific skills perceived as lacking. While the lack of these specific skills may be most often of concern for those workers with no post-secondary education, mathematics are still identified by 70% of respondents as being in required knowledge domain for high-wage, high-growth, high-demand jobs. [8] Additionally 30% found production and processing to be important with mathematics and science being ranked among those skills most highly valued in the same job category. [8]

The Society of Manufacturing Engineers identified that outside of manufacturing engineering or technology education “manufacturing in other disciplines continues to fracture and wane.” [24] They posit that that “many manufacturing employees do not have formal education for aspects of their work” [24] but that organizations such as SME can assists in sharing their extensive knowledge regarding manufacturing with others that will require it as part of their training for employment.

With manufacturing forecasted to maintain its position as leading industry when evaluating economic output, [8] this lack of manufacturing and materials knowledge of STEM workers will pose a problem. While manufacturing engineers may always be the last stop to review manufacturing plans in large companies, waiting to consider manufacturing until the end in a linear product development cycle will lead to tremendous cost. Furthermore small and medium business, which produce 40% of the manufacturing economic output and employ 60% of the manufacturing workforce [79], often have engineers that have to fulfill the role of design and manufacturing engineer as one. For these companies it is vital that academia prepares graduates not only in the sciences, but also in manufacturing and the application of science principles therein. This preparation can only be achieved in manufacturing and other subject matter is linked enabling a knowledge transfer across subjects.

Educational Cause

Perhaps one of the biggest reasons why manufacturing is not more widely taught as part of a general engineering curriculum, is that by nature it requires a hands-on experience, tools, learning space, and materials, all of which compete for funds with other parts of department budgets. With equipment and space typically requiring large sums of initial capital, these investments are difficult for institutions to make. While engineering education traditionally included many of the elements of craftsman education, e.g. machine tool training [65], this has given way to more science focused classes.

A significant number of engineering programs have lab classes integrated with lectures, these teach students some manufacturing methods (e.g. manufacturing of wind tunnel models), many principles that will be important in manufacturing (e.g. taking appropriate measurements) and could be further modified to emphasize manufacturing with very little loss of focus on the original lab topic (e.g. more problem based instructional design that focuses on letting students develop a lab). While these labs are oftentimes integrated with lectures, Gibbs and Habeshaw warn that "simply alternating theory and practice does not guarantee that they will be linked in a way which will enhance learning." [51] Special care has to be taken that lectures and labs are aligned and have appropriate instructional design so that students knowledge from one domain will transfer into the other.

This particular gap, not just for manufacturing and materials, but also for fundamental skills, is one that is actually assessed through student grades. While this would lead one to believe that approaches to close this gap can be easily evaluated since a metric has already been determined by course grades, this may not actually be the case. Pollio and Beck state that "the notion that grades provide accurate indices of how well a student is doing in college and how well he or she will do in a future career is not supported by the empirical literature." [80] This provides a major problem for employers who have typically used transcripts of academic performance as a key indicator of an individual's ability to succeed. It also provides students with a false sense security or insecurity as grades are one of the few metrics available during the academic education that allow them to evaluate how successful they may later be in the workplace. A situation that is further complicated by the fact that "students to not always hold a realistic evaluation of their own learning." [81]

Educational Remedy

The obvious solution to address the assessment portion of the previously discussed educational cause is proposed by Meier et al.: "Unique evaluation tools need to be developed to determine student proficiency of the essential concepts and competencies." [82] In order to be useful, they rightfully state that these evaluation tools need to "be designed by teams of educators, community representatives, and business and industry leaders to achieve acceptance." [82] Without this broad participation and acceptance these new evaluations would either not be accepted or valued, furthermore these evaluations should not be static, but rather evolve as industry requirements change.

These new assessments would best be supplemented by "practical experiential learning activities" [82] which would take place in an interactive learning environment. [83] As computational capabilities increase, virtual simulations may prove to be a more economical substitute for some of these practical experiences. These virtual problems should still “engage students in individual and collaborative problem-solving, analysis, synthesis, critical thinking, reasoning, and reflections to real-world situation.” [82]

If “training engineering students to become critical readers and users of information” [72] can be successful, this would enable better knowledge transfer across the engineering curriculum and faculty collaboration in curriculum design could be even more successful. [84] Furthermore integrating “business/ industry leaders with expertise in the multiple areas” [82] into existing curricula “and providing students with practical experiential learning activities” [82] would enable much inclusion of manufacturing in the student’s education.

Skills Gap IV – Job Readiness Gaps

While all the aforementioned skills qualify as a job readiness gap, this section will focus on some of those skills that perhaps don’t directly align to the others. As such, references to the overt symptom are few, but examples of specific skills are many. It was felt by the author that it was important to capture these additional skills and group them into a larger category.

Overt Symptom

The American Society for Training and Development finds that executives think that “enhanced soft skills are important to support business expansion.” [5] These enhanced soft skills describe a variety of skills as will be seen in following. The manpower group finds that “emerging trends put unprecedented value on talent.” [18] What talent exactly? They determined that lack of talent in the form of experience or in the form of employment skills is given by 24% and 18% of managers respectively when asked why they had difficulty filling jobs. [18] An additional breakdown of these employment skills will be presented in the next section.

Deloitte and the Manufacturing Institute actually found that the situation is a little more dire, finding that 40% of respondents indicated that basic employability skills are the most serious skill deficiency. [62] As mentioned previously, these employability skills are seldom addressed as a group, rather individual skills are evaluated separately. In following is a more detailed description of the type of skills falling in this category.

Skill

Employability in the most basic sense begins with timeliness and attendance, both of these skills are identified by Deloitte as lacking 40% of current employees. [62] Casner-Lotto and Barrington go as far as stating that "Employment 101" should be taught at all educational levels, especially considering that 93.8% respondents from industry value professionalism and work ethic as most important skill in graduates from four-year programs. [14] This trend is similarly seen for graduates of 2-year programs and High Schools, however the impact seen is significantly lower, 83.4% and 80.3% respectively. Georgetown University in fact says that time management is one of the most highly valued skills further detailing, that employers value not only that employers begin on time, but that they also know how to make the most of the time available to them while at work. [8] The Department of Labor views professionalism as part of the personal effectiveness competencies comprising the base of its advanced manufacturing competency model, they go as far as to include "rules and standards of dress and hygiene" [37] under this category.

In addition to basic timeliness, graduates also often do not yet know appropriate software tools when entering the workforce, although this is ranked as important by 81% of employers. [14] The Society of Manufacturing Engineers singles out that the use of statistical software deserved further emphasis in higher education. [24] They also maintain that software training in particular is often considered to be specific skills training that may be conducted outside of formal education settings and instead could be handled by third party providers, but maintain that software training should be included in the classroom where applicable. [24] The Department of Labor goes as far as to say that successful employees should “identify sources of information concerning state-of-the-art … technologies” [37] implying that not only should one learn the appropriate tools, but also stay current with newest versions.

By far the most often cited skills gap within this category is in communication. Carnevale et al. report that “five of the top 12 skills most valued in the economy are communicative in nature.” [8] They are specifically “active listening, speaking, reading comprehension, critical thinking, and writing“ [8] and are of tremendous value to employers. The careful reader will not that some of these have already been referenced in previous sections, this highlights the highly integrated role that communication takes. Lack of the ability to communicate well with others very well may make bridging the skills gap impossible, e.g. any increase in manufacturing knowledge in graduates will have no measurable impact if an engineer cannot communicate his proposed changes to a technologist or worker actually implementing them. This is emphasized by the fact that 3 out of the top 4 most highly valued skills for high-wage, high-growth, high-demand jobs are communicative in nature, taking two top positions. [8]

A study by Warner finds that 76% of employers in Washington State report that they have difficulty finding applicants with appropriate communication skills, a problem that can actually be traced back as far as Kindergarten and is more persistent in High School graduates where 81% of employers reported lacking communication skills. [10] The study further finds that the economic recovery will in fact accelerate this skills gap noting that communication "will become even more important in the next three to five years because of global competition and the pace of change in the business environment." [10]

A study by the American Management Association reveals that three quarters of employers agree or strongly agree that communication skills are a priority when hiring, with only 8.5% of respondents disagreeing. Casner-Lotto and Barrington find that the top deficiencies for college graduates are writing in English and written communication. [14] They further find that reading comprehension, English language, and writing in English are the top 3 ranked skills desired by employers for high school, two-year, and 4-year graduates. [14] It is interesting to note, that the communicative skills become more important the higher the degree is, importance in fact increases between 24.5 and 40.3 percentage points between high school graduates and 4-year graduates. [14] It is also curious, that for high school graduates and two-year graduates reading comprehension is ranked higher than writing comprehension by 13.1% and 6.7% respectively, while for 4-year graduates writing is ranked higher than reading comprehension, but by less than 3%. [14] This may be explained by the fact that 4-year graduates are more likely to be in a supervisory capacity where they have to give instructions.

The Department of Labor sees communication as a core academic competency, which includes listening as well as speaking, listing in particular, that for manufacturing it is important that technical concepts can be explained to non-technical audiences. [37] This becomes particularly important when put in the context of project management, where engineers may interface with a variety of individuals from various backgrounds and it will be important that they can articulate their concerns or constraints of the processes they are describing. While project management is not ranked as the first priority it has a firm hold on the top three specific skills currently perceived as lacking as found by a survey of the American Society for Training and Development. [5]

Educational Cause

The causes for this gap are many, however particularly often seems to be cause by traditions within engineering education. While many institutions, especially large research universities, often times take advantage of the educational offerings provided by engineering software companies, the use of their software is not always widespread within the undergraduate curriculum. Often times the advanced software tools, which are the same ones used in industry, are only used in the research groups of the various faculty. Researchers on those groups that know the software are oftentimes not instructors for undergraduate courses and even when they are, have little influence over the material taught. Professors on the other hand may have the authority to change the course content to utilize software, but they neither know the software nor are they given the time to work on extensive curriculum realignments.

While the work ethic and motivation of graduates may be a primary concern to employers, a recent workshop by the American Society of Engineering Education found that most representatives (92%) believed that responsibility to change this was with students, parents, or students and parents. [63] The same study also found that 96% of respondents believe that responsibility to teach project management skills lies with academia (21%), industry (29%), or both (46%). [63] How can these skills be taught in academia if professors continue to rely on individual assignments? While project management principles can certainly be addressed on the personal level, project management typically involves an inherent element of collaboration.

While many universities require graduates to take a communications course in accordance to ABET criteria [85], they are not always integrated within the technical context of student's studies where the taught skills will have be applied. Furthermore a lack of common communications requirements for coursework within a department complicates the learning process for students. A problem that is in part caused by student's lack of understanding "that written communication pervades all aspects of engineering," [68] which may similarly affect some faculty.

Educational Remedy

Within the engineering community there are various standards for communication, these are often times standardized by the various professional societies, e.g. the American Institute of Aeronautics and Astronautics (AIAA) or the American Society of Mechanical Engineers (ASME). While these standards likely would prevent college-wide adoption of a single communications standard, they should serve as a guide for inner-department communications guidelines. If students follow the same template for projects in all their classes this should be a significant step towards improving the mechanics of written communication within their area of study.

Shuman et al. suggest that these skills are best learned in “situational learning” [86] opportunities, where students are immersed in a problem space. This space can be enhanced by the use of design studies [86] or even more so by using “capstone projects with real-world application.” [87] These project often times are done in teams [88, 89], but the word capstone could be eliminated from the previous statement without any loss of accuracy. Team-based, problem-based learning throughout the engineering curriculum provides the opportunity for students to learn these professional skills in context. Without appropriate work ethic, timeliness, communication skills, project and time management these project cannot be successfully completed if structured appropriately. Not all students will necessarily obtain all skills on their own, faculty will likely have to support the learning process through adequate interventions.

These projects could be much improved if universities partner with local business to determine the problem spaces students should address, or investigate opportunities to have students work as interns or cooperative students within these local companies. [46] A collaboration like this could be further enhances when industry and academia come together to jointly develop curriculum that fulfills the requirements both place on graduates. [87] Chairs and Dean of engineering programs could also encourage that “faculty … seek practical experience” [90] as part of professional development or could go as far as requiring prior industrial work experience. [87] This would ensure that faculty know the requirements placed on graduates in industry and they could thus better fulfill their role of preparing them for life after graduation.

Skills Gap V - Creative Thinking

If one were to ask a random person to identify professions that require creativity, one would likely not hear engineering very often, perhaps instead the responses may oftentimes be linked to occupations requiring a liberal arts background. Creative thinking however is a required element of engineering. How else could engineers envision, design, and build novel items never seen before? One might argue that creativity cannot be learned and one either has it or doesn't, however it is the opinion of the author, that at the very least it can be enhanced through appropriate techniques.

Overt Symptom

Warner finds that employers think of creativity as "just as important as the hard skills. " [10] A finding that is supported by the American Management Association which lists creativity as "one of the four C's" [13] critical to business performance and found that 91.6% of employers believe creativity is somewhat or most important in growing their organization. Their analysis reveals that employers believe 61.0% of their employees are at or below average, which leads to only 13.4% saying that creativity is not of importance to their organization. [13]

While Casner-Lotto and Barrington do not identify creativity to be among the top five skills desired by industry at any educational level, their survey indicates that 81.0% of respondents indicated that it is very important for four-year graduates. [14] It is interesting to note that for two-year and high school graduates this number is significantly lower, 54.2% and 36.3% respectively [14], which likely is related to the particular responsibilities each holds within the company.

A McKinsey report shows that creative thinking is not a natural result of a good education systems, citing South Korea as an example of a country with tremendous scores on academic achievement tests, but nevertheless a lack of creative thinking in graduates. [17] All of these studies show the value placed on creativity by employers even in more technical fields such as engineering. They also find that creativity can be influenced by education, either positively or negatively. Academia should focus on finding ways to encourage creativity in students rather than support the students unlearning what they may have obtained in previous capacities.

Skill

Lafer suggests that creativity should support problem solving. [30] While problem solving as a skills gap was discussed in detail in a previous section, it should again be addressed here to qualify the previous statement. While many problem may be solved using critical thinking, information literacy, and reasoning, there are some problems that will require novel solution approaches that are not purely based on previous methods. Creative problem solving in particular will support the functions of adaptability and transfer knowledge. In this capacity, it will help "place new ideas into practice." [91]

This idea is supported by Thompson and Lordan [92], who agree that a T-shaped learning experience is only helpful if it contributes to a student's performance in the core area of study. This should express itself by means of novel application of techniques and processes found in other disciplines which do not have to be limited to engineering, but should also include the sciences, economics or other liberal arts. As Cheryton and Merrill find, this should result in "work that is novel and appropriate." [91] Findings that are echoed by Weisberg [93], and will result in increased value to employers.

Educational Cause

There are two main reasons preventing the teaching of creativity in engineering education: first and foremost, as has been previously established, the engineering curriculum already occupies more credit hours than required by most states for a baccalaureate degree. Suggesting that creativity should be taught will automatically trigger a response asking what should be cut from the curriculum. Current emphasis of the curriculum favors basic sciences over creativity. [94]

In addition many view creativity as not essential because they view design through the prism of "equipment of standard design." [92] While the notion to use commercial off the shelf (COTS) components is certainly laudable and can have great benefits for companies resulting in reduced complexity, lower cost, and better business performance, these COTS components still need to be arranged in a new manner to create a new product. The fact that create and creativity share the same root is not by accident.

Both of these concerns highlight the fact that solutions that can address creativity in the context of other engineering courses are likely to have the largest impact on the student population.

Educational Remedy

The benefits of problem based learning have been identified in many of the previous sections. Creative thinking no differently can be improved as part of project work, especially when instructors encourage divergent thinking. [92] Divergent thinking requires that students "move beyond traditional and expected boundaries," [95] a process that is improved when they seek stimulations from different points of view. [96]

Students will benefit from the T-shaped education they receive which expose them to a large variety of fields. They will be instructed in principles from various technical and non-technical subjects, it is up the instructor to encourage the cross-application of these theories. This must include, that students are allowed to explore approaches or design choices which may seem unnatural to even the instructor. Innovation is born out of these new applications, in fact the IPPD methodology used for this thesis was born out of the combination of statistical quality control methods that were originally used in agriculture, then applied to manufacturing processes, and finally are part of an engineering design procedure.

Skills Gap VI – Business Impact

Last but certainly not least there are a variety of skills that similarly to job readiness gaps are not really categorized into an overarching classification, but have been found by the author to relate to the impact on business.

Overt Symptom

Although engineering students are exposed to a variety of subjects they are oftentimes not required to take a course on business, cost analysis or similar topics. This is surprising since almost 40% of scientists and engineers work for companies with fewer than one hundred employees, with only 30% working in companies with over five thousand employees. [7] When viewing this data at a more granular level it shows that around 20% (depending on degree level) of science and engineering graduates are actually employed in companies that have fewer than ten employees. At companies this size, chances are that every one of those employees fulfills dual if not more roles. Issues that may be typically addressed by somebody with a background in accounting or business administration will now be the responsibility of an engineer or scientist. A staggering one fifth of the workforce will have to address issues at work they most certainly will not have been exposed to as part of the engineering curriculum.

Skill

A study by Carnevale et al. finds that a "knowledge of economic and accounting principles and practices, financial markets, banking, and analysis and reporting of financial data" [8] is desired for high-wage, high-growth jobs. A skill which should be supplemented by legal and financial knowledge, including compliance with "the spirit of applicable laws as well as the letter" [37] as well as an understanding of privacy, confidentiality, and intellectual property laws. [37]

In today's world of globalization no company, regardless of size, will control the entire supply chain of a product. At some point they will rely on other companies to provide raw materials or sub-assemblies, or their product will in fact be a sub-assembly in another company's product. Take for example the Rolls Royce and the Trent 1000 engine it produces, on its own the engine consists of more than 18,000 parts manufactured by Rolls Royce from a variety of raw materials and sub-assemblies at various tiers of suppliers. [97] When a pair of engines is delivered to Boeing to be mounted on a 787 they becomes two, albeit big ones, of 2.3 Million parts that make up the aircraft. [98] The 787 in general serves as a great case study for the importance of knowledge regarding supply chains, Boeing and its various tiers of suppliers are manufacturing parts for the 787 all over the world prior to final assembly in Everett, WA and Charleston, SC. A core understanding of supply chains, as indicated by the

Department of Labor [37] as well the Society of Manufacturing Engineers, [24] is essential in order for engineers to succeed in this globally connected workforce.

Especially in this global context employees have a charge to be aware of social responsibility, sustainability, and ethics. [8, 14, 23, 24, 37] Ethics in this context not relating to work ethic as previously described, but rather to an ethical completion of one's engineering duties as outlined in the National Society of Professional Engineers (NSPE) Code of Ethics for Engineers. [99] As Hargreaves notes "increasing awareness of environmental issues and the impact of technology in a global context demand that engineers be aware of, and able to predict and plan for, problems arising from a far wider field than the purely technological." [68]

While every engineer has a responsibility to follow these guidelines, leaders and managers have a special responsibility to do so and to encourage all to do the same. Doing so successfully requires leadership skills found by the American Society for Training and Development to be the top gap currently existing. [5] A Georgetown report also identifies leadership skills as important and defines them specifically as "Knowledge of business and management principles involved in strategic planning, resource allocation, human resources modeling, leadership technique, production methods, and coordination of people and resources." [8] These skills are found to be very important by 81.9% in a study by Casner-Lotto and Barrington. [14]

It should be noted that these skills are not yet very well stratified to a large extent. While some overarching skills have been identified they are far from the granularity seen in other areas of the skills gaps, e.g. teamwork, and their exact application in the workplace by new engineers is far from defined. As will be shown later, this leads to limitations in the number of educational remedies since the exact problem is not yet fully defined.

Educational Cause

It should be clear to the reader that there is a recurring theme when it comes to the educational causes of these gaps: a lack of time in the curriculum to cover additional areas. For ethics in particular, in depth studies by Colby and Sullivan [100] as well as Drake et al. [101] show that packed engineering curricula leave little room for non-technical subjects.

Furthermore the complexity of these issues can easily be overwhelming. After all, how do you teach students the intricacies of a supply chain that tracks 2.3 Million parts for each of the over 1,000 final aircraft ordered? How do you instill in students a basic understanding of what it takes to manage a company with over 170,000 employees as in the case of Boeing? As noted previously, many will not work on projects of this scope, but the abstraction of basic principles from these complex processes can make it difficult to provide active learning experiences to students. [100]

Educational Remedy

Hargreaves postulates that educators have a responsibility to “broaden the commonly perceived narrow view of engineering” [68] and suggests that “engineering needs to enter the area of real-world debate and controversy.” [68] This may best be achieved through active engagement in simplified hypothetical case studies in context. [100, 101]

This approach has been successfully implemented by Chapman and Martin [102] in the development of a business simulation. A similar approach is followed by Shuman et al. who suggest that ethics could be taught as part of design studies, in particular when evaluating past product and their development. [86]

In accordance with the findings of the Grinter report, [65] Hargreaves suggests that engineers should have “an awareness of the global social, political, and cultural arena in which they work” [68] in addition to their education in science and engineering. A survey by the American Society of Engineering Education however reveals that 66% of respondents believe the students and parents or parents only are responsible for teaching this awareness. [63]

Tao proposes that knowledge about these skills can be gained by co-class instruction, where students of various levels are instructed as part of the same lecture with varying assignments for each. [103] Similarly instruction could also rely on professors as well as industry representatives that can share their experience in the workplace. These skills, like all skills in engineering will require a student commitment to lifelong learning. [68]

Table 2. Symptoms, Skills, Causes, and Remedies for the Skills Gap

Overt Symptom	Skill	Educational Cause	Educational Remedy
Teamwork ability/Collaboration [5, 8, 10, 13, 14, 18]	1. "Process of shared creation" [36] 2. Respectful interaction with others [8, 37] 3. Reporting [8] 4. "Active Listening"[8] 5. Negotiation [8] 6. Leadership [14, 30] 7. "Capacity to teach others" [30]	1. Individual marks for group assessments [42, 43] 2. Competition for grades [44, 45] 3. "Institutions are not structured to support collaborative approaches to learning, research, and organizational functioning" [46] 4. "higher education institutions work in departmental silos and within bureaucratic/hierarchical administrative structures" [46] 5. "one cannot impose collaboration within a context designed to support individualistic work" [46]	1. "Individual assessment …based directly on the material used in the group activity" [42] 2. Syndicate groups with same problem simultaneously [51] 3. Ground Rules [51, 52] 4. "a cooperative goal structure results in higher achievement than does a competitive goal structure" [45] 5. Assess learning of the group, rather than just outcomes [34, 44] 6. Instructor as facilitator [34] 7. Cross-disciplinary faculty [46] 8. "The organizational context features that need to be redesigned to enable collaboration

Table 2 continued:

Overt Symptom	Skill	Education Cause	Educational Remedy
			include structure, processes, people, and rewards" [46] 9. "unlearning noncollaborative skills" [46] 10. Cooperative learning [50] 11. Multidisciplinary teams [52]
Problem solving skills [8, 14, 18, 30, 61, 62]	1. Transfer Knowledge 2. Critical Thinking [8, 10, 13, 14, 23, 37] 3. "Information Literacy" [37] 4. Problem Identification [23, 37] 5. Adaptability [61] 6. Lifelong Learning [14]	1. Stovepiping 2. Assessments not aligned to course material 3. "The lack of transference of skills from one unit to another." [68] 4. "The effectiveness of the lecture is dependent on the quality of the delivery and the quality of the preparation" [69] 5. "Workplace problems" [70] 6. "Students rely heavily on memory" [71]	1. "Discussion is vital if students are to understand their subject." [51] 2. "both content of individual units and the process of learning must be integrated across the complete engineering curriculum" [68] 3. Multidisciplinary teams [52] 4. "Self-explanation strategy" [71]

Table 2 continued:

Overt Symptom	Skill	Educational Cause	Educational Remedy
		7. "They often depended heavily on the textbook during their problem solving rather than using it as a resource to complement their knowledge" [72]	5. Review and summarize the problem statement [76]
Knowledge gaps [5, 18, 62]	1. Materials and Manufacturing [8, 23, 24] 2. Fundamental Knowledge [8, 14, 23] 3. Lack of knowledge transfer	1. "Simply alternating theory and practice does not guarantee that they will be linked in a way which will enhance learning" [51] 2. "Students do not always hold a realistic evaluation of their own learning" [81] 3. "The notion that grades provide accurate indices of how well a student is doing in college and how well he or she will do in a future career is not supported by the empirical literature" [80]	1. Faculty collaboration in curriculum design [84] 2. "Practical experiential learning activities" [82] 3. "Unique evaluation tools need to be developed to determine student proficiency of the essential concepts and competencies" [82] 4. Interactive learning environment [83] 5. "training engineering students to become critical readers and users of information" [72]
Job readiness gaps [5, 18, 62]	1. Appropriate Software [14, 24, 37]	1. Lack of time for appropriate communications training	1. Partner with local businesses [46]

Table 2 continued:

Overt Symptom	Skill	Educational Cause	Educational Remedy
Job readiness gaps [5, 18, 62]	2. Employability (Timeliness, Work Ethic) [14, 37] 3. Communication [8, 10, 13, 14, 30, 37] 4. Project Management [5] 5. Time Management [8]	2. Lack of understanding "that written communication pervades all aspects of engineering" [68] 3. Lack of applicability of concepts in coursework	2. "Faculty …to seek practical experience" [90] 3. "Capstone Projects with real-world application" [87] 4. Require industrial work experience prior to teaching [87] 5. Develop curriculum jointly with local industry [87] 6. "Situational Learning" [86]
Creative Thinking [10, 13, 14, 17]	1. Creative Problem Solving [30] 2. "Work that is novel and appropriate" [91, 93] 3. "Place new ideas into practice" [91, 92]	1. Creativity is seen as not essential when design consists of "equipment of standard design" [92] 2. Emphasis of basic sciences over creativity [94]	1. Open ended projects in which instructors encourage divergent thinking [92] 2. Encouragement "to move beyond traditional and expected boundaries" [95]

Table 2 continued:

Overt Symptom	**Skill**	**Educational Cause**	**Educational Remedy**
			3. Seeking stimulations from different points of view [96]
Business Impact	1. Economic Impact [8, 14, 37] 2. Social Responsibility, Sustainability, Ethics [8, 14, 23, 24, 37] 3. Supply chain considerations [24, 37] 4. Leadership/Management Skills [5, 8, 14] 5. Judgment and decision-making [8]	1. Engineering curricula that leave little room for non-technical subjects [100, 101] 2. Complexity of subjects makes active learning experiences difficult [100]	1. "Broaden the commonly perceived narrow view of engineering" [68] 2. Business simulations [102] 3. Active engagement in simplified hypothetical case studies in context [100, 101] 4. Co-class instruction [103] 5. Use of design studies to also study ethics [86]

CHAPTER IV

ESTABLISH VALUE

The next step of the IPPD methodology is to establish value, this is not an easy proposition even when considering an actual physical system, but much more difficult when considering something like education. While businesses commonly use a measure known as return of investment (ROI), this is very difficult to establish for learning. [104] For physical products there is a clear financial trail that can be followed, for learning establishing rigor in the information required to establish a value proposition requires longitudinal studies that evaluate the learning curves and impact of learning. While these studies can be carried out for individual courses [105] evaluating the same for engineering education as a whole would be beyond the scope of this thesis.

While a specific quantifiable ROI may not be determined, there are other measures that are more readily evaluated and can serve as a substitute for a fiscal return on investment. While previously much time was spent regarding the quality of engineering education, important implications of the insufficient quantity of engineering graduates were also mentioned. It is hypothesized that to some extent that lack of graduates in engineering is caused by instructional methods lacking in quality, which contributes to the 35% of STEM students who change majors after their first year, [9] or to the two thirds of STEM degree holders who decide not to work in STEM.

A model developed by Raytheon and consequently turned over to the Business-Higher Education Forum (BHEF) models the flow of students from kindergarten through employment. [9] It was further enhanced by contributions from The Boeing Company, the ACT Group, and various academic members. The model was developed in response to a challenge to double the number of STEM graduates in the decade from 2005 to 2015.

While a full decade has not yet elapsed since the self-declared challenge, we are near the end of the decade and progress so far should be reviewed. In order to provide historical context data regarding STEM graduates two prior decades were also evaluated based on data available in the National Science Foundation's Science and Engineering Indicators from 2002 [106] and 2012 [20]. Due to the limitations in the available data graduations from 1983, 1993, 2002, and 2011 were evaluated.

In the nine years from 2002 to 2011 the number of annual college graduates overall has risen by 1.1 Million. This sharp increase in college graduates had a significant influence on the number of STEM graduates, which increased by over 230,000. Figure 2 shows that a large majority of this increase came from Bachelor degrees, which already increased by almost 100,000 in the two decades prior to 2002.

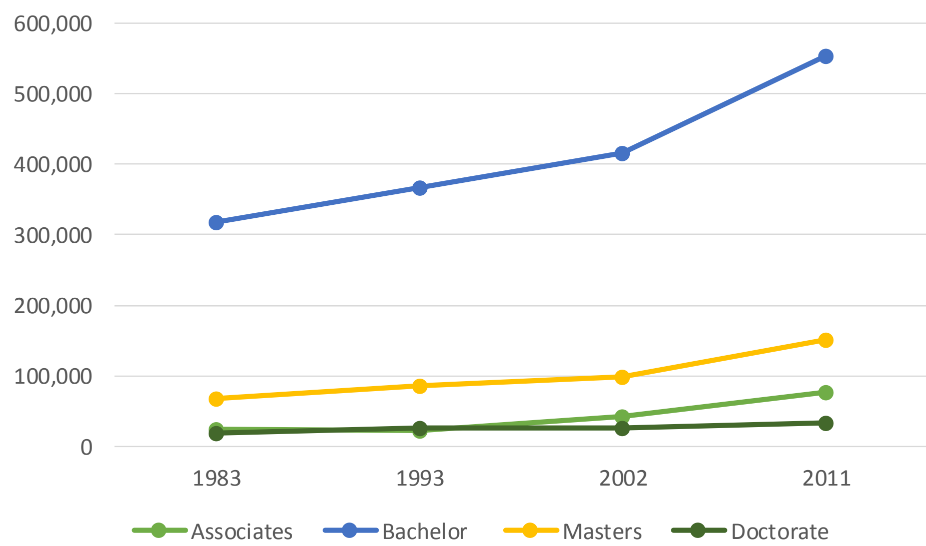

Figure 2. STEM Graduates - Total Quantity [20, 106]

The trend in these graduation numbers is very positive. Across all degree types total graduates increased significantly: Associates (80.14%), Bachelors (33.39%), Masters (51.91%), and Doctorates (30.42%). This results in an overall growth of 39.79% of STEM graduates across all degrees. While this is a significant increase, it falls well short of BHEF's goal of doubling the number of engineering graduates. It should be noted here again that the statistics used to evaluate the objectives are not from the exact same year range.

While overall numbers have increased, the fractional distribution of STEM graduates compared to all graduations has been constant at best or even decreasing, see Figure 3. In the years from 2002 to 2011 the percentage of STEM graduates as a fraction of all graduates only increased for Associate and Bachelor degrees, both by less than half a percentage point, while the percentage for Masters and Doctorates actually decreases resulting in a drop from 24.5% of all graduations in 2002 to 23.42% in 2011.

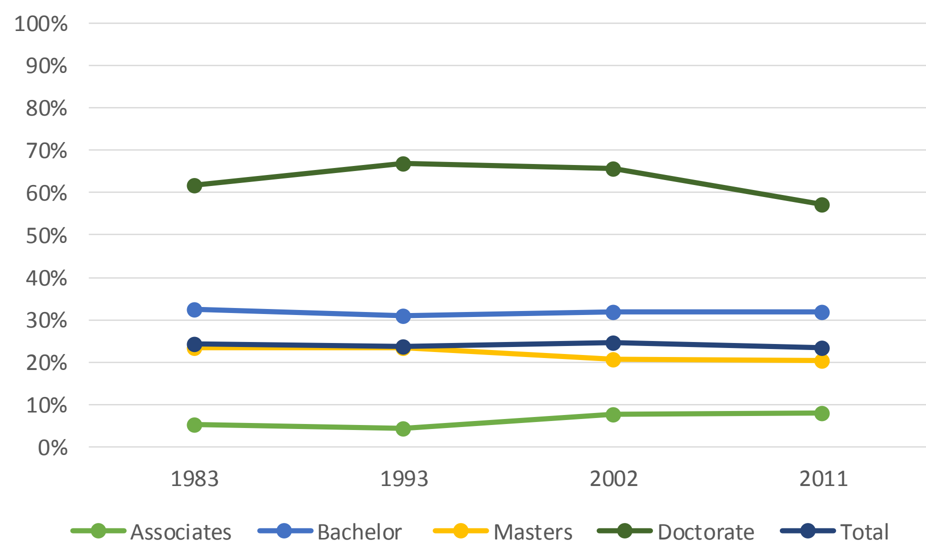

Figure 3. STEM Graduates - Percentage of overall Graduations [20, 106]

The Business-Higher Education Forum found, that not only do more students need to go to college, but also that a larger share of them need to pursue a degree in a STEM field. [9] Clearly any efforts to increase the fraction of STEM degrees have failed. This may be in part due to the fact, that there is a limited supply of students that are adequately prepared to enter STEM majors in college. A study of 12th graders by ACT found that only 17.3% of all students have a sufficient proficiency in math and in interest to pursue a STEM career. [9] There an additional 25.4% of students that have sufficient proficiency but are not interested in STEM. [9] These are the students that could help raise the percentage of STEM degrees awarded, new ways have to be found to spark their interest.

The model developed by Raytheon and BHEF is built on the premise, that the education can be simulated using system dynamic modeling techniques. The model contains multiple macro-models which are interconnected to form the model of the entire education system. These sub-models are: K-12 Grades, College, Professional, Career Selection, and US population. Each sub-model relies on a variety of data tables, states, and multivariate transition functions.

While this model provides ability to evaluate a very large number of scenarios only a select few are evaluated here to provide an idea for the value that can be provided by the various learning interventions described previously. The model construction allows for the evaluation of various, simultaneous changes to any number of input parameters, this study focuses on main effects for a few select variables. This approach was taken since the BHEF model is focused on the quantitative aspects of STEM pipeline while this thesis focuses on the quality, therefor any links to the model variables are subject to fuzzy relations. The model was built using an original investigative period of 2003 to 2025, since significant historical data is included at each sub-module it was determined that it would be best for model integrity if the time period was kept the same rather than attempting to update all historical information.

Due to the fact that many of the previously mentioned interventions can most easily be applied to capstone courses, one variable on interest was the number of graduates after 4 years that are interested in working in a STEM career. In addition to the baseline value of approximately 91,000 graduates per year, cases with 95,000 and 100,000 graduates were considered. It was assumed that better instruction would lead to reduced frustration in students which, when coupled with closer collaboration between industry and academia, should result in a better learning experience for the student and thus should increase their desire to work in a STEM field. Figure 4 shows these respective changes.

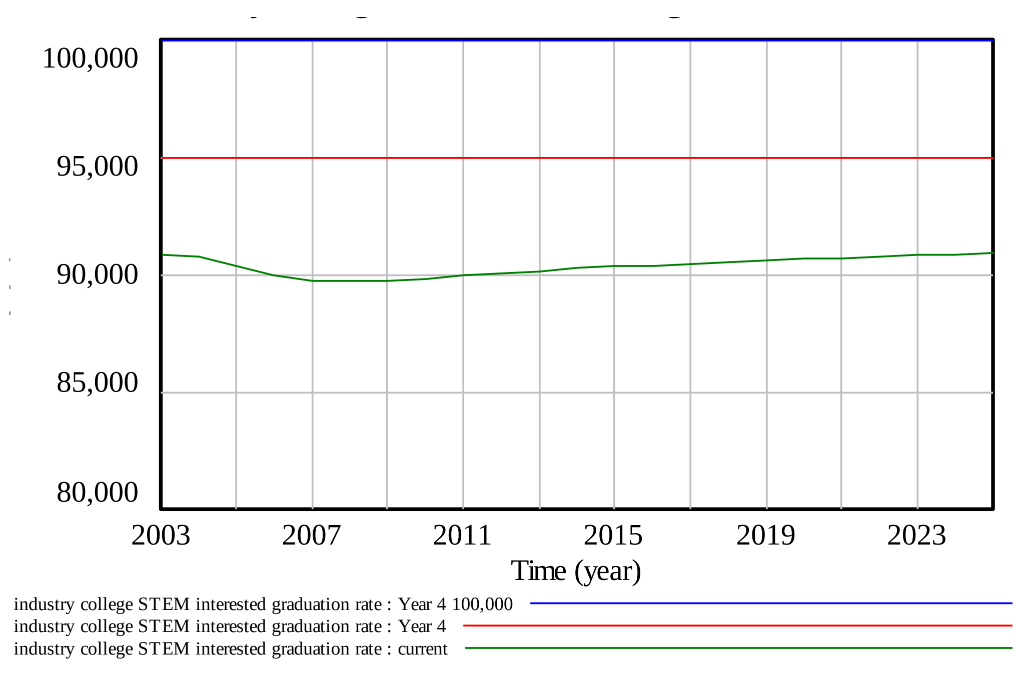

Figure 4. STEM Interested Graduates after 4-years

As can be seen in Figure 5 this increase naturally has a very immediate impact on the number of STEM industry college graduates, naturally this impact is larger when the graduation rate in increased 100,000 rather than 95,000. The long term assimilation of the industry graduates is due to the underlying population increase and college population increase which was not taken into account in the one factor variation shown here.

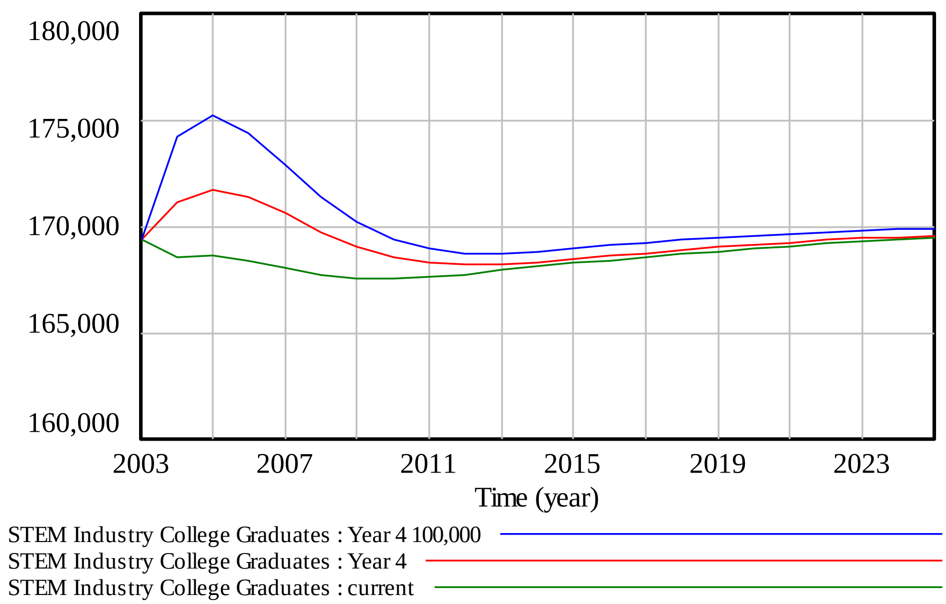

Figure 5. STEM Industry Graduates

In order to more realistically visualize the effects of this program a ramp input was provided for the 4-year STEM interested graduation rate beginning at 93,000 in model year 2003 and ending at 110,000 graduates in 2025. The effects on the input variable can be seen in Figure 6, it is assumed this gradual change in total graduations is more likely as implementations of the heretofore proposed solutions will take time to be adopted. The constant case of 100,000 graduates is shown for reference.

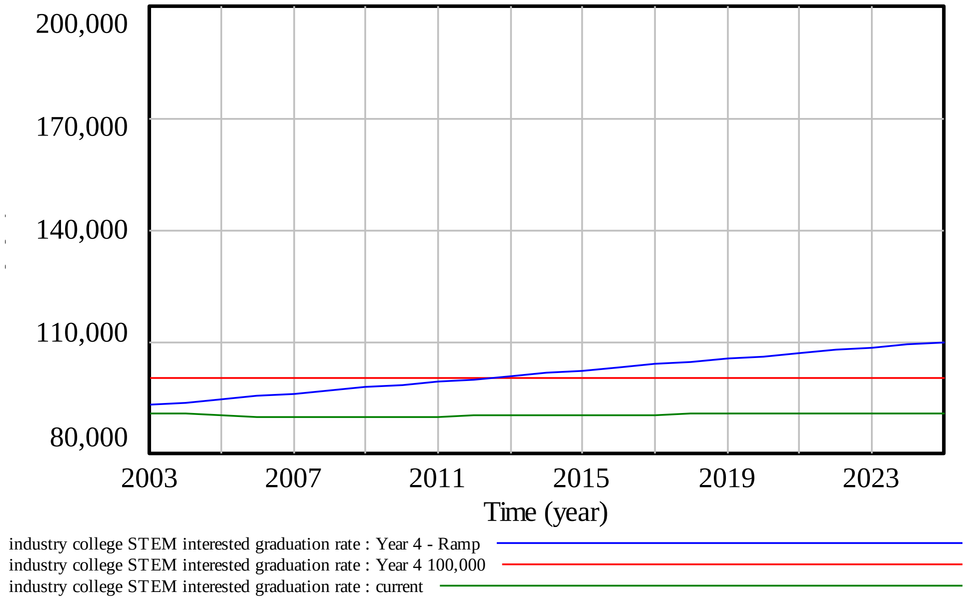

Figure 6. Interested Graduates after 4-years - Ramp Input

When compared to the to the constant graduation case, the initial impact of this change is naturally less, see Figure 7.Long term however the ramp input better reflects the underlying population dynamics, resulting in a consistently better performance when compared to either the baseline or the constant 100,000 graduate cases.

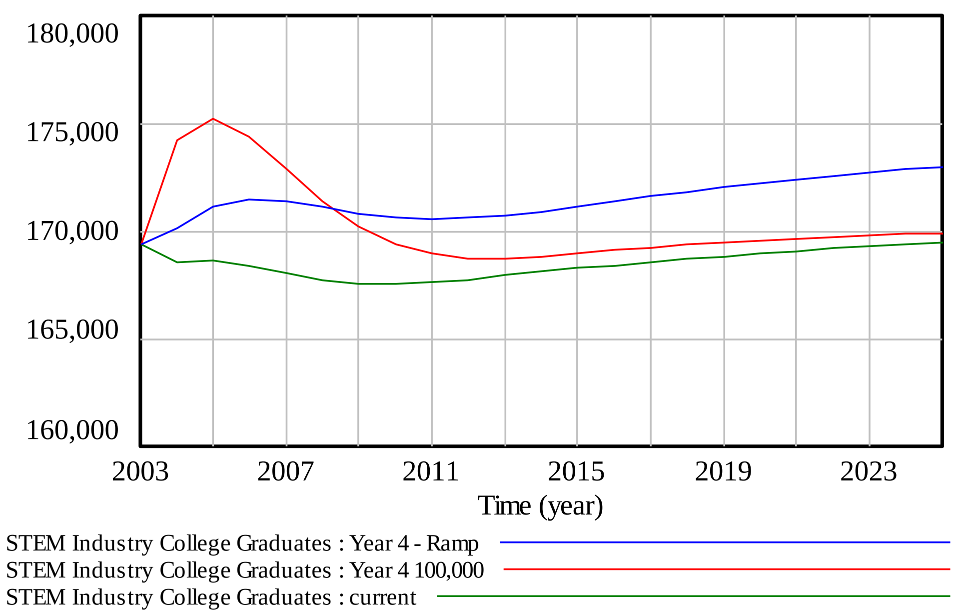

Figure 7. STEM Industry Graduates - Ramp Input

In addition to student motivation, closing the skills gap should result in a larger qualified candidate pool for industry. If more students possess the desired skills, industry should be able to hire a larger number of them for positions in their companies. In order to capture the effect of this the fraction of STEM graduates hired by industry was changed to 0.525 from 0.470. This change in the variable can be seen in Figure 8.

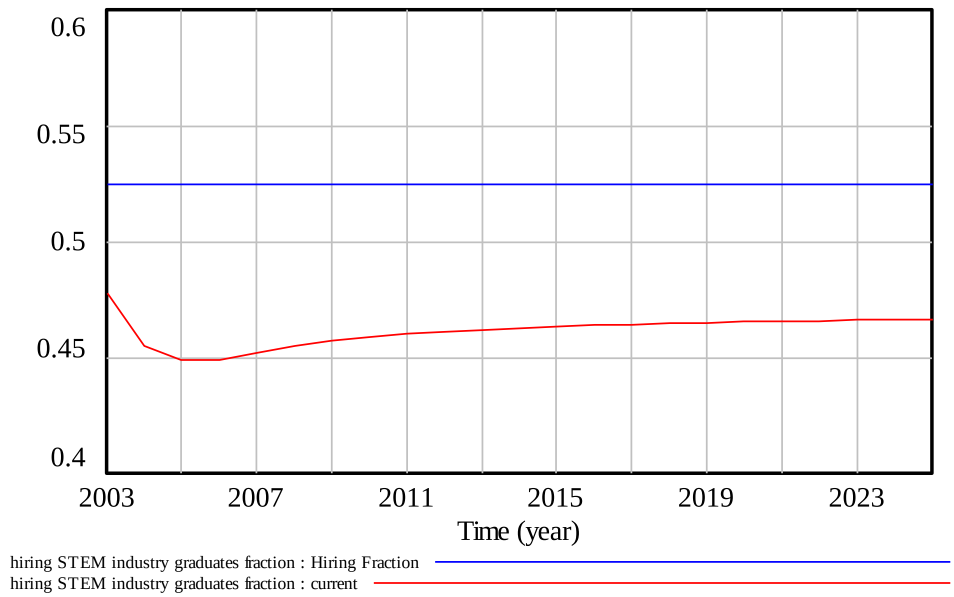

Figure 8. Industry hiring STEM graduates fraction

As expected this has an immediate positive effect on the number of people employed in industry as can be seen in Figure 9. This substantial increase is also sustained over the long term.

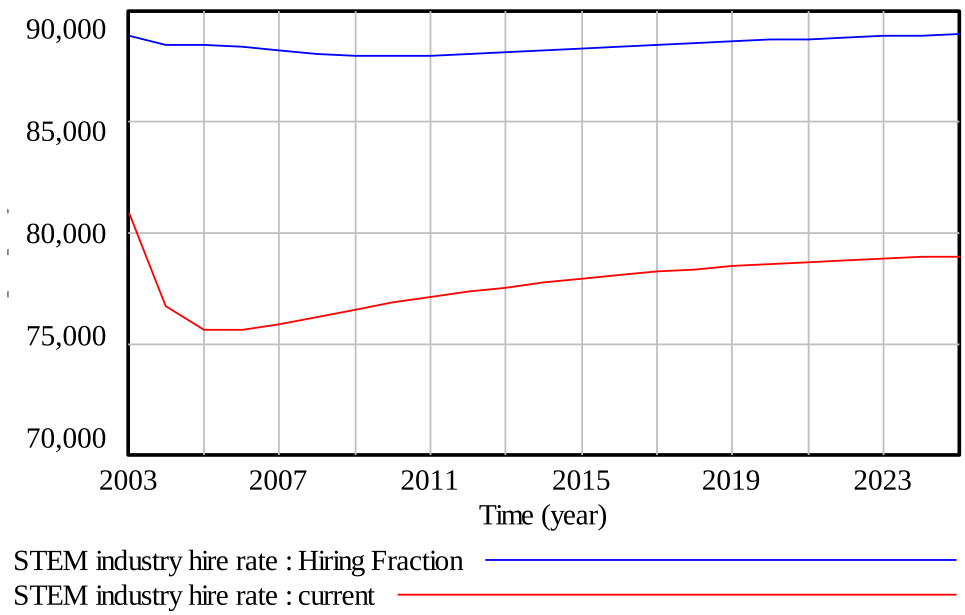

Figure 9. STEM industry hirings

BHEF finds that doubling the STEM graduates cannot occur by only changing any one of the sub-models, their guidance to policy makers is that it takes a comprehensive approach considering improvements to K-12 and higher education as well as teacher quality. [9] While this model shows that changes early on in education can have significant impact on the number of overall graduate students, these improvements are not considered here. [9] Changes to early childhood education are difficult to implement by individual teachers, but rather have to be supported by school boards and state accreditation agencies. In addition, some research indicates that early childhood interventions are only successful if sustained throughout a number of years. [107]

While no direct financial value is determined as part of this analysis, it is clear that educational improvements provide various leverage points that allow for an increase in STEM graduates. Some were presented previously, the focus on interventions late in the stage of engineering education will be continued in the next section.

CHAPTER V

GENERATE FEASIBLE ALTERNATIVE

As part of defining the problem a variety of feasible alternatives were developed and to some extent evaluated. A variety of authors proposed various activities, this chapter will present an implementation of some of these concepts such as: assessment of group learning [34], organizational context enabling collaboration [46], multidisciplinary teams [52], having students operate in their zone of proximal development [63], real-world problems encouraging divergent thinking [82, 87, 92], and co-development of curriculum with industry [87] after reviewing some more general alternatives.

The heretofore mentioned solutions can work in the current educational framework, however a big question arises whether or not there truly exists a culture at many universities to fully implement these changes. Just as old as the discussion of the skills gap are academia’s attempts to close it. Analysis of data appears to indicate though, that even though many universities strive to teach these overt symptoms, their interventions have in large part been unsuccessful. Simply adding group assignments to the curriculum will not result in students learning proper teamwork on their own, these skills actually need to be taught. In following a few ideas shall be described that would represent a true paradigm shift in engineering education, non are perfect, however the author’s intent is to jog the creative mind of individuals interested in solving the problem of the skills gap.

A major recurring theme throughout has been that engineering education in large parts is constrained by the total academic time available. The health and law profession already rely on professional degrees which are obtained after completing a Bachelor degree, why should engineering be any different? The reasoning for this extended education for medical doctors it that they are directly responsible for the health of those people that seek their help, but doesn't the same apply to engineers? One could argue that in fact the impact of an engineer on public safety is much higher than that of a medical doctor. Civil engineers construct bridges that are traversed by hundreds of thousands of cars a day, build dams that hold massive amounts of water near very populated areas, aerospace engineers design vehicles that carry hundreds of passengers through the air, chemical engineers design plants in which thousands of tons of flammable material are refined.

Considering this responsibility it seems only appropriate to extend an engineer's education to be however long it takes to obtain all the required skills to ensure public safety. This extended curriculum should specifically be able to close the knowledge gap, but would also present an opportunity to teach specific classes on creativity or teamwork. These professional degrees would be different from current "scientific" doctorate degrees offered in engineering which usually address issues in the underlying sciences of engineering problems. The professional doctorate would simply prepare engineers with all the professional skills, whether hard skills or soft skills, required to be a successful engineer.

While this solution certainly presents a possibility to dramatically increase the quality of graduated engineers, there are also some concerns. Engineering curricula are already considered to be very challenging technically, increasing the time required in school prior to employment would likely reduce the already slow flow of students into engineering disciplines. Economic incentives would likely also have to be altered, additional schooling would result in additional debt for a majority of students. Whether or not students are going to be willing and able to take on this additional debt will in large part depend on their future compensation. Industry would have to change their compensation model. Another possibility would be for industry to actually sponsor students for the post-baccalaureate part of their education. Similar to residencies or fellowships in the medical field, engineering students would complete rotations in industry. Were this to be started as part of the undergraduate education (as many students currently do), it would allow companies to see students in action and make a decision on whether or not to support a student based on his performance in the workplace. This would lighten the burden on employers on assessing skill based on grades, give students an opportunity to learn in context, and provide a means for further engineering education for students where cost is shared with their future employer. In order for industry to justify this financial commitment, they would want to be closely integrated into the curriculum design and instructional process to ensure there is a return of investment for them. As indicated previously, this infusion of industry knowledge in the educational process is highly desirable. Further consideration would have to be given to the future role of baccalaureate only degree holders and engineering technology degree holders. Should there be an engineering baccalaureate only degree, and would holders of this degree take positions taken currently by engineering technologists? Again, the medical field with it scaffolded approach to licensure may be an example: A doctor is always supplemented by a team of nurses, which may be LN's, CRN's, RN's, or MSN's. A similar model could be applied in engineering.

Another problem highlighted is that of assessment. Not only are there problems appropriately assessing hard skills, but especially soft skills are very difficult to measure with current instruments. One possible alternative to this would be to have students create a portfolio as part of the academic courses. Rather than their great point average, it could serve to demonstrate fluency in various technical subjects as well as providing examples of successful teamwork, problem solving skills, or business applications. This approach also is used quite frequently in more artistic disciplines, musicians may have a collection of recordings of their music, dancers videos of their performances, and artists images of their work. In engineering, just like in these disciplines, artifacts are created. Why shouldn't these serve as exemplars for once achievements? These portfolios could very well be in a digital format so they can include simulations or other computational work that was carried out. Assessing deep technical skill as part of this method would require a nuanced approach, but similar to a sculptor's technical talent being visible in his final product, so a student's technical knowledge can be revealed in their portfolio.

Thinking about the previously proposed alternatives, there is also a much more radical change that could be performed. So far this discussion has focused on competencies required for work in industry, this research describes many of the non-traditional competencies in addition to the already well defined technical content for engineering disciplines. What if engineers were accredited simply based on their demonstrated competencies? Considering the various educational backgrounds of freshman engineering student's, the heterogeneity in the time they spend in school for various reasons, and their differing learning styles, why not simply test students competencies? Very gifted and well prepared students may be able to show competency after only two years, perhaps even less, of formal post-secondary education. Some may choose to not enroll in such a post-secondary institution at all, but rather learn on their own and pass the test. As discussed previously, engineers have significant responsibilities for public safety, what do we gain by mandating that students complete a certain number of credit hours prior to being able to work, especially considering that the grades they obtain may not accurately reflect their knowledge and ability to work?

Obviously creating assessments to measure competency would be a significant undertaking, but perhaps hybrid approaches of applied knowledge testing, such as part of medical residency, and traditional testing, already found in engineering licensure exams such as the fundamentals of engineering exam, could be a solution. Standards for these assessments would have to be developed jointly by industry, academia, and government to ensure that they are acceptable to all stakeholders.

Another possibility to address the capability gap may be for institutions to require students to complete a co-op or internship prior to graduation. Similarly, universities could require that students commit a certain number of hours for non for profits, such as engineers without borders, to expose them to the social responsibilities of engineers or that they serve in a leadership capacity in at least one of the many student organizations found on the campuses of most universities. This approaches would present opportunities for students to learn in informal as well as formal settings.

The previously presented approaches represent radical shifts in engineering education, they will not be achieved over night. Rather it will be a slow evolution, initially relying on the foundational findings established earlier in this research. In following one such initiative will be described which makes large strides towards a renewed engineering education, but still operates within the boundaries of traditional engineering education.

AerosPACE

Capstone courses offer an ideal vehicle to implement many of the proposed remedies identified previously. Capstone courses often allow instructors significantly more flexibility in construction of the course and its contents, and are typically the keystone to any engineering curriculum requiring application of many of the skills learned previously in a variety of classes.

In response to the challenges to its workforce pipeline The Boeing Company engaged in a unique project that could serve as a test bed for new approaches to engineering education and thus serve as an exemplar for the types of interventions that enhance students critical knowledge, skills, and abilities by bringing together domain experts of collaborative mechanical design, digital design and manufacturing, and aerospace design fundamentals to bring about a paradigm shift in engineering education.

Warner et al. note that “technology allows project teams to be located in different time zones and in different locales,” [10] a process that is already underway at Boeing, which has engineering centers around the world, but is constrained by the single user paradigm found in all Computer Aided Engineering (CAE) applications. In order to address this underlying problem as part of a capstone, Boeing partnered with the center for E-design at Brigham Young University, a NSF funded Industry University Cooperative Research Center, to further develop a software engine based on Massive Multiplayer Online Role Playing Games (MMORPG) [57, 108], that would enable multiple users of commercial Computer Aided Design (CAD) software to work on the same part simultaneously.

An initial study consisted of ten students, four from Brigham Young University, three from Georgia Tech, and three from the University of Puerto Rico at Mayaguez that worked together on a design challenge utilizing these new collaborative tools. Students were undergraduates with backgrounds in mechanical or aerospace engineering who participated in this study as part of research activity carried out at the institutions. Participation was not for credit but rather provided students with an informal learning environment in which they had the opportunity to work with cutting edge software as well as have direct contact with a variety of Boeing subject matter experts, managers, and directors. Students were provided with three lecture sets: 1) Integrated Product and Process Design 2) Advanced Composite Materials and 3) Collaborative Design. These lectures were provided by instructors from the various schools or Boeing subject matter experts. Richey et al. [59] describe the activity in detail, but it was found that students from all backgrounds were able to work in teams across space and time, collaborate using novel CAD software, learn and apply knowledge from diverse backgrounds to a common design project based around the redesign of the F-86, a Korean War fighter jet.

The program was such a success that it was determined that in the following year it should be offered as an alternative to the capstone course taught at the participating universities. This transition enabled a more realistic evaluation of the interventions and their applicability to general engineering classrooms. Zender et al. [39] describe how nineteen students from four institutions, BYU, Georgia Tech, Purdue University, and the University of Washington, worked collaboratively to redesign an aircraft based on

Common Research Model (CRM) [109] which is similar to the Boeing 777. The curriculum was designed with the goal that all students, mechanical, manufacturing, or aerospace engineering, could participate in and complete all lectures. Overarching topics were 1) integrated product and process design 2) aircraft systems design 3) general design 4) simulation & testing 5) composites design 6) manufacturing and 7) entrepreneurship concepts. Student learning was evaluated through assessments and was generally high. Some lectures however were found to be difficult to be taught adequately to an audience as broad as this one, e.g. aeroelasticity. Students concluded the project by jointly designing a scale model of their design which was printed using additive manufacturing and tested in the wind tunnel at Purdue. Even though students indicated that some lectures could be improved, overall none of the students said they would not recommend participation in the program to a friend.

In the current year, 2013-2014, the program was again expanded now including Embry-Riddle Aeronautical University in Prescott, AZ. In addition it now also include undergraduates and graduates, in line with the proposal of co-instruction as proposed by Tao. [103] This year's course relies on fewer instructional sessions which are focused on the basics design criteria and processes required to complete the distributed manufacturing of an Unmanned Aerial Vehicle (UAV) which will be flown at the completion of both semesters. Rather than teach the students everything, the course took advantage of the knowledge of the participants, requiring students to teach other members of their team or course. Since the course is still underway no final findings can be presented, but the use of a social learning platform, CorpU, allows for unobtrusive data mining. This data can be evaluated for knowledge transfer among and across team members allowing a tracking of the distributed cognition of the course participants. Zender et al. [110] describe a general framework for constructing an industry-academia collaborative project such as this. Furthermore Gorrell et al. [111] provide insights into some of the outcomes of the students as well as into the specific methodology used to assign students into teams.

Overall this program has enabled multidisciplinary teams to work amongst a group of Boeing coaches and faculty utilizing social media as well as collaborative CAD software that placed them in an environment where collaboration is required and essential yet easily available and implemented. Students at various levels are able to operate in their zone of proximal development, undergraduate students are able to fully design, build, and fly a vehicle with the help of graduate students and coaches. Graduate students, while already technically experienced, are given an opportunity to improve their leadership skills under the guidance of faculty mentors. Mechanisms for assessments of group learning are in place and will be evaluated. Students are working on a problem that addresses one of the National Academy of Engineering' Grand Challenges under close direction from industry, which was involved in the development of the curriculum. The project as a whole has been a success, with about 60% of graduates pursuing a career in industry while 40% pursue advanced degrees. In the last iteration half of the people seeking full time employment were able to be employed by Boeing.

While the program has had much success, much more work is required. Students in the current cohort appear to learn well, especially when instructed by their peers, but course design is still a challenge. In particular, in the initial weeks of the course teachings of technical material compete with time for the teaming process. Students, not familiar with a majority of their peers, need to form teams, establish acceptable norms for interaction and decision making processes all while beginning the design process for an aerospace vehicle with requirements new to them. An early start with technical material is required in order to be able to complete the task in the time frame provided by the academic calendar, but can one really afford to wait to establish team norms? Friction is likely to occur as a very heterogeneous group of students learns to come together as a team, while in itself this is part of the teaming process, this friction must be constructive.

An evaluation of student feedback also reveals that while it is technologically possible to have an instructor present to students at various locations throughout the US in a synchronous and asynchronous manner, this may result in lecture not fully satisfactory to any of the students involved. Further research is required how this may be achieved best. A possible solution may lie in an unrelated field, that of network analysis. In network analysis, nodes that share many connections cluster together, what if skills could be arranged as such, skill nodes organically aligning across topical boundaries in a matter that is easily accessible to students and observable by instructors? If students could learn skills in this fashion in a chunked manner, being able to select between various levels of desired competencies for narrowly defined skills it would ease the instruction of this vary heterogeneous group of students. Furthermore the networked structure of these skills would enable a seamless transition between various skills, e.g. from structure to composite manufacturing. Online platforms appear to be suited to support this kind of course design and it may be the next paradigm shift in education. It would be a transition from MOOC's where one set of course materials is made available to large numbers of learners simultaneously, to course material instead being personalized for each individual.

CHAPTER VI

FUTURE WORK

This research presented a foundational analysis of the skills required of engineers and potential means to close the capability gap. Future work by ASEE as part of their ongoing program "Transforming Undergraduate Engineering Education" [63] should be closely monitored as it has some similar aims, identifying through the inclusion of various stakeholders what the desired knowledge, skills, and abilities are and who may best be able to teach these to learners. Some of their initial findings have been referenced heretofore. Some of the steps of the IPPD methodology were applied to this problem, however analysis revealed that especially the value definition needs to be further refined. The author sees two primary paths for further work 1) detailed redesign and analysis of an engineering course using the heretofore mentioned methods, and 2) detailed analysis of the system dynamics comprising the skills gap. Detailed proposals for both shall be presented in the following.

AerosPACE provides a framework to carry out much of the work that is proposed regarding a more thorough evaluation of varying instructional and assessment methodologies. AerosPACE research is quasi experimental, relying on both qualitative and quantitative measures. Future work in this area should apply lessons learned in an experimental group of students as well as a control group to validate the findings. Furthermore, significant work remains to fully map skills and competencies to lectures and labs in AerosPACE. While student learning is measured through pre and post assessments, further work remains to fully link learning objectives to assessments. Future work should evaluate student learning using more thorough instruments, think aloud protocols may be appropriate to evaluate if the students underlying problem solving approach changed. Think aloud protocols and observations of group interactions will also facilitate a better understanding of the underlying socio-technical decisions processes. Additional work will also have to address measures of adaptability and transferability to further evaluate the scalability of the program.

The second approach focuses on engineering a solution to the problems in engineering education. While the BHEF system dynamics model was utilized as part of this research, some significant shortcomings were identified. First and foremost, the model must be expanded to include quality measures, quantity is not an adequate surrogate for quality measures. If a means is established to include quality, the model could be used to engineer a solution to the problems seen in engineering education. Analysis of this model would also not be an easy undertaking, due to its already complex sub-system behavior. Varying parts of the model operate on very different time scales, while the influence of higher wages may have a very immediate feedback on graduates selection of STEM vs. non-STEM careers, incentive structures to recruit STEM graduates as teachers in K-12 will take much longer to materialize as a benefit. This presents a challenge for traditional optimization algorithms, which is only magnified by the number of feedback loops contained in the system and its inherent nonlinear behavior which was visible when evaluating the effect of changing the number of 4^{th} year graduates interested in STEM. In summary the complexity of the model stems from the multi-dimensional agent and organizational constraints as well as the sub-system interaction patterns.

In order to engineer a solution to this complex problem levers of opportunity must be identified. A design of experiment approach may be useful to evaluate the behavior of the system based on various inputs. Due to the inherent unknowns in the system, it would be important to consider various initial conditions for the model, this would increase the robustness of potential solution approaches, as this evaluation of starting conditions would minimize the possibility of observing negative Lorentz effects.

Following a standard system dynamics process with the following steps: 1) bound the problem space, 2) generate dynamic hypothesis, 3) model formulation, 4) testing and evaluation, and 5) policy evaluation and measures would be helpful for this problem approach. The current model already bound the problem space in a manner aligned to the scope of the problem. Some hypothesis were created as part of this research, but for this purpose an initial design of experiments should be considered exploratory, so that all possible interactions are tested, rather than those deemed likely by the researchers. This may result in the discovery of novel solution approaches. The current model may serve as a baseline for future work, but as mentioned before, would require some modifications. Testing and evaluation would have to be significant in order to ensure that time scales and nonlinear behaviors are captured. Lastly, it will be non-trivial to identify policies that can create the positive changes identified in the preceding analysis, but even more difficult to implement them.

CHAPTER VII

CONCLUSION

In the IPPD methodology the next steps are to evaluate alternatives and to make a decision. While some evaluations have been presented as part of the problem definition and obviously decisions have already been made in the exemplar programs detailed in the previous section, closing the skills gap at the national level will require industry, academia, and government to come together to define what solution will be implemented.

As Heckman details, “early interventions promote economic efficiency and reduce lifetime inequality.” [112] Governments and that national, state, and local level should be interested in working together to implement these early interventions, however they should not forget that “focusing on improvements to preschool through high school or to higher education alone will not result in sufficiently large increase” [9] for the nation’s workforce needs. Indeed the Business-Higher Education Forum found that “improving persistence and student success in STEM undergraduate education can produce significant returns in the near term.” [9]

This thesis detailed some methods available to bring about near term change. Indeed the program described previously follows an approach outlined by Carnevale et al. by “developing curricula that put academic competencies into applied career and technical pedagogies and link them to postsecondary programs in the same career clusters.” [23] This linkage seldom occurs, because “we are too focused on preparing students for the next level,” [23] rather than providing a holistic approach to engineering education. Indeed it can be said that "we haven't even scratched the surface of creating a link between K through 12, community colleges, and industry." [21]

This misalignment of the entire education system and its slow moving transformation can in part be attributed to "a lack of industry-based knowledge and funding to pay for equipment that supports emerging technologies" [21] in academia. Industry however is feeling the impact of the capability gap now and they are looking "for innovative ways to meet the workforce demands today for jobs that are available right now." [21] Indeed the American Management Association found that 74.6% of managers found that "these skills and competencies will become more important to their organizations in the next three to five years." [13] They furthermore found that it is much easier to instill these skills in students rather than experienced workers, validating the approach to teach these skills as part of a capstone experience. A study by Lang et al. defined some of the most important attributes of engineering programs to be: 1) Engineering courses with application 2) ability to structure , solve, and report on solutions in the engineering specialty 3) demonstrated ability in data analysis and interpretation 4) team experience 5) demonstrated understanding of honesty and the code of ethics 6) interpersonal skills 7) computer literacy in analysis and design tools and 8) understanding that skill training is an employee's responsibility and a part of lifelong learning. [113]

Some of these abilities may best be taught in small groups, "which can reduce attrition in SMET courses and programs substantially." [53] Most importantly though it was highlighted previously that "skills and abilities are best learned and used in the context of particular knowledge-domains and fields of practice." [8] When taught and learned appropriately knowledge of these skills will be “both transferable and useful in contexts across occupations.” [8]

A critical role in these transferable learning experiences may be played by “social tools (that) enable students to create self-paced, customized ‘learning paths’ that draw on interactive, social, and self-publishing media tools.” [81] Indeed technology is underutilized in education, the capstone program described previously aims to answer some of these challenges issued as part of the National Academy of Engineering’s Grand Challenge to advance personalized learning.

This thesis highlighted the specific capability gaps in engineering education, defined skills that make up that more fully define each gap, discussed educational causes and remedies to address each gap. Findings from this research have been integrated into a collaborative, multidisciplinary capstone course with participants from multiple universities throughout the United States developed in collaboration with The Boeing Company. Some modeling has been completed to simulate the impact of the proposed educational remedies, however it only addressed the quantitative aspects of the workforce pipeline. Future work should expand on the work done by the Business-Higher Education Forum and include measures of quality in their system dynamics model regarding the STEM workforce pipeline.

REFERENCES

[1] Yashchin, A. *Redefining Education to Close the Workforce Skills Gap*. 2014 [cited 2014 2/22/2014]; Available from: http://www.huffingtonpost.com/avi-yashchin/redefining-education-to-c_b_4676818.html.

[2] Porter, E., *Stubborn Skills Gap in America's Work Force*, in *New York Times*. 2013: New York.

[3] Harrison, J.D., *No shortage? New STEM data could derail entrepreneurs push for immigration changes*, in *Washington Post*. 2013: Washington D.C.

[4] Dale, R., *THINKING AHEAD : U.S. Schools Fail to Fill the Skills Gap*, in *New York Times*. 1998: New York, NY.

[5] Development, A.S.f.T., *Bridging the Skills Gap - Help Wanted, Skills Lacking: Why the Mismatch in Today's Economy?* 2012.

[6] Innovation, N.N.f.M. *U.S Manufacturing In Context*. 2014 [cited 2014 2/22/2014]; Available from: http://manufacturing.gov/mfg_in_context.html.

[7] Board, N.S., *2014 Science & Engineering Indicators*. 2014, National Science Foundation: Arlington, VA.

[8] Carnevale, A.P., N. Smith, and J. Strohl, *Recovery - Job Growth and Education Requirements through 2020*. 2013, Georgetown University - Center on Education and the Workforce.

[9] Forum, B.-H.E., *Increasing the Number of STEM Graduates: Insights from te U.S. STEM Education & Modeling Project*. 2010.

[10] Warner, L., et al., *The Skills Gap - Reversing Washington's Lack of Skilled Workers Through Early Learning*. 2011, America's Edge.

[11] Steigleder, S. and L. Soares, *Let's Get Serious About Our Nation's Human Capital - A Plan to Reform the U.S. Workforce Training System*. 2012, Center for American Progress.

[12] Schrage, D. *Technology for Rotorcraft Affordability Through Integrated Product/Process Development (IPPD)*. in *55th National Forum of the American Helicopter Society*. 1999. Montreal, Quebec, Canada.

[13] Association, A.M., *AMA 2012 Cirtical Skills Survey*. 2012.

[14] Casner-Lotto, J. and L. Barrington, *Are They Really Ready to Work - Employers' Perspectives on the Basic Knowledge and Applied Skills of New Entrants to the 21st Centruy Workforce*. 2006, The Conference Board.

[15] Marx, W.J., D.N. Mavris, and D.P. Schrage, *Integrating Design and Manufacturing for a High Speed Civil Transport Wing*, in *19th ICAS/AIAA Aircraft Systems Conference*. 1994: Anaheim, CA.

[16] Technology), O.o.t.U.S.o.D.A.a., *DoD Integrated Product and Process Development Handbook*. 1998, Department of Defense: Washngton, DC.

[17] McKinsey&Company, *The world at work: Jobs, pay, and skills for 3.5 billion people*. 2012.

[18] Group, M., *2012 Talent Shortage Survey Research Results*. 2012.

[19] Carnevale, A.P., J. Strohl, and M. Melton, *What's it Worth? - The Economic Value of College Majors*. 2011, Georgetown University - Center on Education and the Workforce.

[20] Board, N.S., *Science and Engineering Indicators 2012*. 2012, National Science Foundation.

[21] Cooperation, A., *The Mid-Skills Gap in Middle America*. 2011.

[22] Carnevale, A.P. and B. Cheah, *Hard Times College Majors, Unemployment and Earnings*. 2013.

[23] Carnevale, A.P., N. Smith, and M. Melton, *STEM*. 2011, Georgetown University - Center on Education and the Workforce.

[24] Jack, H., et al., *Curriculum 2015 A Four Year Strategic Plan for Manufacturing Education*. 2011.

[25] Hedden, C.R., *Aviation Week Workforce Study 2012*, in *Aviation Week*. 2012.

[26] Seng, J.M. and P.E. Flattau, *Assessment of the DoD Laboratory Civilian Science and Engineering Workforce*. 2009, Institute for Defense Analysis: Alexandria, VA.

[27] *Hearing on Threats to U.S. Competitiveness in Aviation*, in *Senate Commerce Subcommittee on Aviation Operations, Safety, and Security*. 2012: Washington, DC.

[28] Montgomery, D., *Retiree flood waits in aerospace wings*, in *The Seattle Times*. 2008, The Seattle Times Company: Seattle, WA.

[29] Association, A.I., *Launching the 21st Century American Aerospace Workforce*. 2008: Arlington, VA.

[30] Lafer, G., *The Jobs Training Charade*. 2002, Ithaca and London: Cornell University Press.

[31] Tang, C.S. and J.D. Zimmerman, *Managing New Product Development and Supply Chain Risks: The Boeing 787 Case.* Supply Chain Forum, 2009. **10**(2): p. 74-86.

[32] Administration, I.T., *U.S. Trade Overview 2012*. 2012, Department of Commerce: Washington, DC.

[33] Center, P.R. *Social Networking Use*. 2013 [cited 2014 3/7/2014]; Available from: http://www.pewresearch.org/data-trend/media-and-technology/social-networking-use/.

[34] Springer, L., M.E. Stanne, and S.S. Donovan, *Effects of Small-Group Learning on Undergraduates in Science, Mathematics, Engineering, and Technology: A Meta-Analysis*. 1997, University of Wisconsin - National Center for Improving Science Education.

[35] Technology, A.B.f.E.a., *Criteria for Accrediting Engineering Programs*. 2014: Baltimore, MD.

[36] Schrage, M., *Shared minds : the new technologies of collaboration*. 1990, New York: Random House. xxv, 227 p.

[37] *Advanced Manufacturing Competency Model*, U.S.D.o. Labor and E.a.T. Administration, Editors. 2010.

[38] MacKinnon, C., *Team Leadership*. Sage Publication. p. 340-365.

[39] Zender, F., et al., *Wing Design as a Symphony of Geographically Dispersed, Multi-disciplinary, Undergraduate Students*, in *54th AIAA Structures, Structural Dynamics, and Materials Conference*. 2013: Boston, MA.

[40] Lamancusa, J.S., et al., *The Learning Factory: Industry-Partnered Active Learning*. Journal of Engineering Education, 2008. **97**(1): p. 5-11.

[41] Stanfill, R.K., et al., *Lessons Learned in Integrated Product and Process Design Education*, in *American Society of Engineering Education Southeast Section Conference*. 2002: Gainesville, FL.

[42] Lejk, M., M. Wyvill, and S. Farrow, *Group Assessment in Systems Analysis and Design: a comparison of the performance of streamed and mixed-ability groups.* Assessment & Evaluation in Higher Education, 1999. **24**(1): p. 5.

[43] Almond, R.J., *Group assessment: comparing group and individual undergraduate module marks.* Assessment & Evaluation in Higher Education, 2009. **34**(2): p. 141-148.

[44] Science, A.A.f.t.A.o., *Science for all Americans: Project 2061*. 1989: New York.

[45] Johnson, D.W. and R.T. Johnson, *Instructional Goal Structure: Cooperative, Competitive, or Individualistic.* Review of Educational Research, 1974. **44**(2): p. 213-240.

[46] Kezar, A., *Redesigning for Collaboration in Learning Initiatives: An Examination of Four Highly Collaborative Campuses.* Journal of Higher Education, 2006. **77**(5): p. 34.

[47] Technology, G.I.o., *XIX Student Code of Conduct*, in *Prohibited Academic Conduct*. 2012.

[48] Piaget, J., *The language and thought of the child*. 1926, New York, NY: Harcourt Brace.

[49] Vygotsky, L.S., *Mind in society: The development of higher psychological processes*, ed. M.C.e. al. 1978, Cambridge, MA: Harvard University Press.

[50] Baldwin, T.T., M.D. Bedell, and J.L. Johnson, *The Social Fabric of a Team-Based M.B.A. Program: Network Effects on Student Satisfaction and Performance.* The Academy of Management Journal, 1997. **40**(6): p. 1369-1397.

[51] Gibbs, G. and T. Habeshaw, *Preparing to Teach*. 1st Edition ed. 1989: Technical and Educational Services Limited.

[52] Mu, S. and D.R. Gnyawali, *Developing Synergistic Knowledge in Student Groups.* Journal of Higher Education, 2003. **74**(6): p. 21.

[53] McKinsey&Company, *The social economy: Unlocking value and productivity through social technologies.* 2012.

[54] Engineering, N.A.o. *Grand Challenges*. 2014 [cited 2014 3/9/2014]; Available from: http://www.engineeringchallenges.org/cms/8996.aspx.

[55] Milheim, W.D., *Massive Open Online Courses (MOOCs): Current Applications and Future Potential.* Educational Technology, 2013(May-June): p. 38-42.

[56] Lewin, T., *Master's Degree Is New Frontier of Study Online*, in *New York Times*. 2013: New York, NY.

[57] Winn, J.D., et al. *Applying Massive Multiplayer Online Role Playing Games Architecture for Collaborative Multi-User CAx Applications*. in *Tools and Methods of Competitive Engineering*. 2012. Karlsruhe, Germany.

[58] Weerakoon, P., et al., *A Networking Architecture for a Mutli-User FEA Pre-Processor*. Computer Aided Design and Applications, 2011.

[59] Richey, M., et al., *An Innovative Approach to an Integrated Design and Manufacturing Multi-Site "Cloud-based" Capstone Project*, in *ASEE International Forum*. 2012: San Antonio, TX.

[60] *From The Dean*. 2010 [cited 2014 3/9/2014]; Available from: https://engineering.purdue.edu/Engr/AboutUs/News/Publications/EngineeringImpact/2010_2/COE.

[61] Toner, P., *Workforce Skills and Innovation: An Overview of Major Themes in the Literature*. 2011, Organisation for Economic Co-operation and Development - Directorate for Science, Technology and Industry - Centre for Education Research and Innovation.

[62] Deloitte and M. Institute, *Boiling Point? The skills gap in U.S. manufacturing*. 2013.

[63] *Transforming Undergraduate Education in Engineering*. 2013, American Society for Engineering Education: Arlington, VA.

[64] Manyika, J., et al., *Big data: The next frontier for innovation, competition, and productivity*. 2011, McKinsey Global Institute.

[65] Education, A.S.o.E., *Summary of the Report on Evaluation of Engineering Education*. Journal of Engineering Education, 1994: p. 74-95.

[66] *Beyond the Rhetoric Improving College Readiness Through Coherent State Policy*. 2010, The National Center for Public Polic and Higher Education and Southern Regional Education Board.

[67] Galloway, P.D., *The 21st-Century Engineer*. 2007, Reston, VA: ASCE Press.

[68] Hargreaves, D.J., *Addressing the transition to tertiary education in*. European Journal of Engineering Education, 1998. **23**(1): p. 79.

[69] Blair, E., *Student Evaluations of Teaching: Are They Related to What Students Learn? A Meta-Analysis and Review of the Literature*. Enhancing the Learner Experience in Higher Education, 2013. **5**(1): p. 16.

[70] Jonassen, D., J. Strobel, and C.B. Lee, *Everyday Problem Solving in Engineering: Lessons for Engineering Educators*. Journal of Engineering Education, 2006. **95**(2): p. 139-151.

[71] Litzinger, T.A., et al., *A Cognitive Study of Problem Solving in Statics*. Journal of Engineering Education, 2010. **99**(4): p. 337-353.

[72] Lee, C.S., et al., *Indispensable Resource? A Phenomenological Study of Textbook Use in Engineering Problem Solving*. Journal of Engineering Education, 2013. **102**(2): p. 269-288.

[73] Jonassen, D., *Instructional design models for well-structured and III-structured problem-solving learning outcomes*. Educational Technology Research and Development, 1997. **45**(1): p. 65-94.

[74] Hollister, W.M., E.F. Crawley, and A.R. Amir, *Unified Engineering: A Twenty Year Experiment in Sophomore Aerospace Education at MIT*. Journal of Engineering Education, 1995. **84**(1): p. 1-7.

[75] Schmidt, J.A., *The defintion of Structural Engineering*, in *STRUCTURE*. 2009. p. 9.

[76] Crismond, D.P. and R.S. Adams, *The Informed Design Teaching and Learning Matrix*. Journal of Engineering Education, 2012. **101**(4): p. 738-797.

[77] Atman, C.J., et al., *Engineering Design Processes: A Comparison of Students and Expert Practitioners*. Journal of Engineering Education, 2007. **96**(4): p. 359-379.

[78] Sherrett, B.U., et al., *An Expert Solution to Assess an Industrially Situated, Computer-Enabled Design Project*. Journal of Engineering Education, 2013. **102**(4): p. 541-576.

[79] Institute, T.M. and R. McGladrey, *The Future Success of Small and Medium Manufacturers: Challenges and Policy Issues*. 2006, National Association of Manufacturers: Washington, DC.

[80] Pollio, H.R. and H.P. Beck, *When the Tail Wags the Dog: Perceptions of Learning and Grade Orientation in, and by, Contemporary College Students and Faculty*. The Journal of Higher Education, 2000. **71**(1): p. 84-102.

[81] Clayson, D.E., *Student Evaluations of Teaching: Are They Related to What Students Learn?: A Meta-Analysis and Review of the Literature*. Journal of Marketing Education, 2009. **31**(1): p. 16-30.

[82] Meier, R.L., M.R. Williams, and M.A. Humphreys, *Refocusing Our Efforts: Assessing Non-Technical Competency Gaps*. Journal of Engineering Education, 2000. **89**(3): p. 377-385.

[83] Menekse, M., et al., *Differentiated Overt Learning Activities for Effective Instruction in Engineering Classrooms*. Journal of Engineering Education, 2013. **102**(3): p. 346-374.

[84] Briggs, C., *Curriculum Collaboration: A Key to Continuous Program Renewal*. Journal of Higher Education, 2007. **78**(6): p. 676-711.

[85] *Criteria for Accrediting Engineering Programs*, I. Accreditation Board for Engineering and Technology and E.A. Commission, Editors. 2012: Baltimore, MD.

[86] Shuman, L.J., M. Besterfield-Sacre, and J. McGourty, *The ABET "Professional Skills" — Can They Be Taught? Can They Be Assessed?* Journal of Engineering Education, 2005. **94**(1): p. 41-55.

[87] Downing, C.G., *Essential Non-Technical Skills for Teaming*. Journal of Engineering Education, 2001. **90**(1): p. 113-117.

[88] Todd, R.H., et al., *A Survey of Capstone Engineering Courses in North America*. Journal of Engineering Education, 1995. **84**(2): p. 165--175.

[89] Howe, S. and J. Wilbarger, *2005 National Survey of Engineering Capstone Design Courses*, in *ASEE Annual Forum*. 2006: Chicago, IL.

[90] Swearengen, J.C., et al., *Globalization and the Undergraduate Manufacturing Engineering Curriculum*. Journal of Engineering Education, 2002. **91**(2): p. 255-261.

[91] Charyton, C. and J.A. Merrill, *Assessing General Creativity and Creative Engineering Design in First Year Engineering Students*. Journal of Engineering Education, 2009. **98**(2): p. 145-156.

[92] Thompson, G. and M. Lordan, *A review of creativity principles applied to engineering design*. Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 1999. **213**(1): p. 17-31.

[93] Weisberg, R., *Creativity: Genius and Other Myths*. 1986, New York: W.H. Freeman/Times Books/ Henry Holt & Co.

[94] Charyton, C., et al., *Assessing Creativity Specific to Engineering with the Revised Creative Engineering Design Assessment*. Journal of Engineering Education, 2011. **100**(4): p. 778-799.

[95] Blashki, K., et al., *'The future is old': immersive learning with generation Y engineering students*. European Journal of Engineering Education, 2007. **32**(4): p. 409-420.

[96] Klukken, P.G., J.R. Parsons, and P.J. Columbus, *The Creative Experience in Engineering Practice: Implications for Engineering Education*. Journal of Engineering Education, 1997. **86**(2): p. 133-138.

[97] Geer, A., et al., *Rolls-Royce: Trent engines*, in *Innovation Now*. The Royal Academy of Engineering.

[98] Company, T.B. *World Class Supplier Quality*. 2014 [cited 2014 3/15/2014]; Available from: http://787updates.newairplane.com/787-Suppliers/World-Class-Supplier-Quality.

[99] Engineers, N.S.o.P., *Code of Ethics for Engineers*. 2007: Alexandria, VA.

[100] Colby, A. and W.M. Sullivan, *Ethics Teaching in Undergraduate Engineering Education*. Journal of Engineering Education, 2008. **97**(3): p. 327-338.

[101] Drake, M.J., et al., *Engineering Ethical Curricula: Assessment and Comparison of Two Approaches*. Journal of Engineering Education, 2005. **94**(2): p. 223-231.

[102] Chapman, G.M. and J. Martin, *Developing Business Awareness and Team Skills: The Use of a Computerized Business Game*. Journal of Engineering Education, 1996. **85**(2): p. 103-106.

[103] Tao, B.Y., *Senior/Sophomore Co-Class Instruction: Teaching Interpersonal Management Skills in Engineering*. Journal of Engineering Education, 1993. **82**(2): p. 126-129.

[104] Gale, S.F., *Measuring the ROI of E-Learning*. Workforce, 2002. **81**(8): p. 74.

[105] Richey, M., K. Lin, and M. Mohaghegh. *A Blended Academia–Industry Learning Model for Aircraft Composite Structures Education*. in *48th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*. 2007. Honululu, HI.

[106] Board, N.S., *Science and Engineering Indicators 2002*. 2002: Arlington, VA.

[107] Knudsen, E.I., et al., *Economic, neurobiological, and behavioral perspectives on building America's future workforce.* Proceedings of the National Academy of Sciences, 2006. **103**(27): p. 10155-10162.

[108] Red, E., et al., *Emerging Design Methods and Tools in Collaborative Product Development*. Journal of Computing and Information Science in Engineering, 2013. **13**.

[109] Vassberg, J.C., et al., *Development of a Common Research Model for Applied CFD Validation Studies*, in *26th AIAA Applied Aerodynamics Conference*. 2006: Honolulu Hawaii.

[110] Zender, F., et al. *Aerospace Partners for the Advancement of Collaborative Engineering (AerosPACE) - Connecting Industry and Academia through a Novel Capstone Course*. in *International Conference on E-Learning in the Workplace*. 2014. New York, NY.

[111] Gorrell, S., et al. *Aerospace Partners for the Advancement of Collaborative Engineering (AerosPACE).* in *ASEE Annual Forum*. 2014. Indiananpolis, IN.

[112] Heckman, J.J., *Schools, Skills, Synapses*. 2008, Institute for the Stufy of Labor: Bonn, Germany.

[113] Lang, J.D., et al., *Industry Expectations of New Engineers: A Survey to Assist Curriculum Designers*. Journal of Engineering Education, 1999: p. 43-51.