Individual Development in Systems Engineering

Mark Lauritz Espeland
23 March 2008

Systems Engineering Creative Component
Dr. Gemmill, Dr. Jackman, Dr. Rectanus
2019 Black Engineering
Iowa State University
Ames, IA 50011

Table of Contents

1 Introduction

Systems engineering is a relatively new engineering discipline. Its popularity is increasing both within education and industry. Systems engineering encompasses a broad range of applications, and this is reflected in the diversity of systems engineering degree programs offered.

While there are already papers written on the topic of systems engineering education [Sage, 2000; Frank and Elata, 2005; Frank, 2006], a comprehensive look at the development of a systems engineer encompassing both formal education and industry experience is needed. This goal of this paper is to facilitate discussion in two areas: 1) how systems engineering degree programs can better serve the needs of industry, and 2) how industry can improve the development of systems engineers. In short, this paper will provide suggestions and approaches for the development of successful systems engineers.

I will set the context with a brief summary of globalization and its effects on systems engineering, then proceed to a discussion on systems engineering education. Regarding education, the scope of this paper will be limited to undergraduate and graduate systems engineering degree programs, which have much more depth than, say, certificate programs, although many concepts will apply to those as well. I will continue on to discuss the development of a systems engineer in industry, including hiring, organizational integration, and practice.

1.1 Globalization

A major force changing and shaping the world today is globalization. Globalization can be defined as “the expanding scale, growing magnitude, speeding up and deepening impact of interregional flows and patters of social interaction. It refers to a shift of transformation in the scale of human organization that links distant communities and expands the reach of power relations across the world’s major regions and continents” [Reader, 2006]. Globalization is certainly not new – the concept has existed for quite some time. Reader reminds us that “…much of what we talk about under this heading was around before the First World War in the guise of mapping, exploration, travel, and … the influence of missionary activity” [2006]. However, most experts would agree that the rate of globalization has been increasing, especially in the last twenty-five years.

Thomas Friedman, an author and columnist for the New York Times, divides globalization into three eras, each with a different driving force. The first era, which he calls Globalization 1.0, is roughly from 1492 (Columbus) until 1800. Countries and governments, often motivated by imperialism or religion, led the way in breaking down walls. Globalization 2.0 lasted from 1800 to 2000, and was led by multi-national companies. Falling transportation costs in the first half, and falling communication costs in the second half, powered global integration. Globalization 3.0 is the era that we are now in, according to Friedman. This era is defined by the new ability of individuals to collaborate and compete globally [Friedman, 2007].

For the purposes of this paper, I will briefly address three aspects of globalization that I believe are important in setting the context for a discussion on systems engineering: accelerating change, increasing competition, and outsourcing/collaboration.

1.1.1 Accelerating Change

The pace of change continues to increase. The digital revolution has led to a death of distance, the merging of telecommunications technology and computer technology into information technology, and networked individuals and organizations; a major characteristic of this change is great speed [Sage, 2000]. New processes, capabilities, and products are continually being introduced. In order to compete and thrive in this environment, companies must be able to effectively deal with change.

Increasing change has a direct impact on individuals working in this setting. Reader states that "greater degrees of uncertainty, inbuilt instability and shorter term projects and agreements become the norm for staff in this environment…The New Economy demands flexibility and the capacity to shift from one set of skills to another at almost a moment's notice, whatever the personal costs" [Reader, 2006]. Flexibility is required, and in order for an individual to continue to be able to provide high value to an enterprise, continual learning takes on an increasing importance. In addition, education programs themselves will need to keep pace with the rapid changes in industry in order to remain relevant.

1.1.2 Increasing Competition and Specialization

Globalization is generating a rise in specialization. As competition on a global scale increases, individuals and companies are differentiating their products and services by offering customized solutions to satisfy the specific needs of their customers.

Robert Reich wrote a prescient and influential book in 1991 titled The Work of Nations, in which he described *inter alia* how globalization is shaping the structure of corporations, the relationship between corporation and nation, and the relationship between company and employee. He contends that throughout the 20th century, the focus has been changing from high volume to high value. "These [high value] businesses are profitable both because customers are willing to pay a premium for good or services that exactly meet their needs and because these high-value businesses cannot easily be duplicated by high-volume competitors around the world" [Reich, 1992]. Systems engineers are directly involved in weighing tradeoffs and providing custom solutions to diverse customers.

The focus on high-value, customized solutions creates challenges. In his paper on future trends and implications for systems engineering processes, Barry Boehm states that "…the biggest challenges will be the increasing rates of change and decreasing half-lives of product line architectures, and the increasing proliferation of product line variabilities caused by globalization" [2006]. Systems engineers will be faced with demands for increasing specialization, which pose a challenge to maintaining commonality in product lines used by multiple customers. However, if, as Reich states above, customers are willing to pay a premium for products that exactly meet their needs, systems engineering will be in high demand.

1.1.3 Outsourcing and Collaboration

Globalization is driving collaboration across national and cultural boundaries. This provides new opportunities for sourcing work. The global economy provided by the Internet provides major economies of scale that drive both an organization's product and process strategies [Boehm, 2006]. The ability to work with other cultures and nationalities is vital.

Knowledge and information are key drivers of value today. The alignment of industry is changing from command and control to collaborate and connect [Friedman, 2007]. Companies are collaborating with other organizations that have a given expertise rather than spending the money and effort to gain it themselves. They focus on developing their core competencies. Whether it be co-workers, customers, or sub-contractors, it is safe to assume that many systems engineers will be working with individuals from different cultures, nationalities, backgrounds, and perspectives.

2 Formal Education in Systems Engineering

Because systems engineering is relatively new discipline, formal education in this area is growing and changing. The number of programs continues to increase, and with it, the diversity of programs available increases. Graduate programs have been available for some time, and now undergraduate programs are becoming more common. This section will address some advantages and disadvantages of these two types of formal systems engineering education, and discuss some topics that should be addressed in the education of a systems engineer.

The topic of systems engineering certificate programs is outside of the scope of this paper. With the limited amount of classes required for certificate programs when compared to full degree programs, there is little to no room to incorporate much more than fundamentals classes into the curricula. In addition, Petee and Componation conclude that when ranked against an overview, topic course, crash course, or graduate course in the areas of accessibility, depth, relevance, and educational development, the certification approach had the lowest score [2002]. In order to limit the scope of this paper, the focus on education will be restricted to formal undergraduate and graduate degree programs.

2.1 Graduate versus Undergraduate

Systems engineering education continues to grow. The website of the International Council on Systems Engineering (INCOSE) lists 103 institutions that provide systems engineering education, including both certificate and degree programs [2007]. Sixty-four of these are in the United States, which suggests that the U.S. continues to lead in the development and deployment of systems engineering. China follows with eleven institutions, England with seven, Canada with six, and France and Germany with two each. Among these organizations, there is a wide variation in content and core audience of their programs. There are many opinions on what should be taught in systems engineering, and how much can actually be learned through formal training methods [Petee and Componation, 2002]. I will attempt to explore some of these opinions and provide my own suggestions and conclusions.

As part of writing this paper, I conducted an admittedly limited survey of systems engineering degree programs in the U.S. I emailed a list of questions about the school's systems engineering program and systems engineering education in general. A table was also included for the school to rate how well its curriculum addresses certain topics. An example questionnaire is provided in Appendix A. I sent seventeen requests and received five responses. I will include some insightful comments from the responses in the following discussion on formal systems engineering education.

2.1.1 Graduate

Systems engineering has traditionally taken place at the graduate level. It is commonly suggested that systems engineers should first have a foundation in a traditional engineering discipline. The systems engineer must understand the principles of the natural and mathematical sciences in order to know how to use these to support the definition, development, and deployment of cost effective and trustworthy systems [Sage, 2000]. Multiple survey responses indicated that systems engineers should have a traditional or focused engineering background, such as mechanical or electrical engineering. Frank states that "successful systems engineers…are expert in at least one main field" [2006]. A background in a traditional engineering field provides a systems engineer with knowledge of the impact of decisions, levels of technical difficulty, and issues commonly faced during component design, implementation, and integration. It also enables the systems engineer to communicate more efficiently and effectively with individuals performing the engineering work.

Another advantage of the graduate-level program is that experience is beneficial to the learning of systems engineering. Graduate programs are commonly pursued by individuals who are already in industry. It is widely accepted that capacity for systems thinking is a skill that is primarily developed through experience [Frank and Elata, 2005]. One survey response stated that admission criteria for their systems engineering program included at least three years experience working in a technical environment. Another suggested that in order to get the most from a systems engineering program, students should have from three to five years work experience as a discipline engineer. This seems logical because experience provides real situations to apply educational concepts to. Applications can be made from first hand knowledge, and therefore concepts can be comprehended more rapidly.

2.1.2 Undergraduate

While graduate level systems engineering has its advantages, undergraduate level education is becoming increasingly common. There are both advantages and disadvantages to this approach. The biggest disadvantage is the lack of discipline knowledge. This can be alleviated somewhat by including technical engineering classes in the undergraduate curricula. One of the survey respondents stated that their undergraduate systems engineering program included four mechanical engineering courses, two electrical engineering courses, and mathematics courses through differential equations. However, it is evident that compared to a mechanical or electrical degree, the number of engineering courses in the curriculum will be substantially curtailed. Another disadvantage listed by survey respondents was that it may be difficult for a younger individual lacking in experience to find a job, since systems engineering is typically a more senior position.

There are also advantages to studying systems engineering at the undergraduate level. First of all, it gives them a head start in developing the concepts of systems engineering. They are able to look at the whole design process and what it entails from the very beginning. However, one respondent indicated that this could be accomplished by installing systems engineering content in the existing courses of a discipline-based program. This is true, but only to a point. Students could be introduced to some systems engineering concepts, but due to the limited hours in the curriculum, depth would necessarily be lacking in order to not interfere with discipline-based courses.

Another advantage of undergraduate systems engineering programs is that they may attract students that otherwise would choose a topic of study outside of engineering. The skills and character traits that make good systems engineers are not always that same as those that make good electrical or mechanical engineers. Figure 1 shows behavioral competences of successful systems engineers, according to a study by Frank.

Rank	Behavioral Competency/Individual Trait	Frequency	% (of 77)
1	Management Skills	66	86
	Team Leader		
	Building and Controlling the Work Plan		
	Defining Boundaries		
	Taking into Consideration Non-Engineering Factors		
	Additional Management Skills		
2	Good Human Relations; Team Player; Good Communication Skills; Good Interpersonal Skills	40	52
3	Autonomous and Independent Learner; Strong Learning Skills	38	49
4	Willing to Deal with Systems	34	44
5	Curious, Innovator, Initiator, Promoter, Originator	28	36
6	Ask Good Questions	26	34

Figure 1 – Behavioral Competences of Successful Systems Engineers [Frank, 2006]

It is evident that some of these traits, notably the first two, are not stereotypically found in traditional discipline-based engineers. Frank also notes that successful systems engineers are aware that sometimes when preparing proposals, one must bear in mind non-engineering considerations such as business, ecological/environmental, marketing, political, organizational, economic, and personal issues, personality styles, business, re-use opportunities, and different viewpoint considerations [2006]. Systems engineering as an undergraduate discipline provides an opportunity to attract students that are also interested in these aspects. Systems engineering requires collaboration and interaction with individuals outside of engineering. One survey respondent asserts that studying systems engineering at the undergraduate level would help prepare students for entry into a business world where knowledge of systems engineering principles is increasingly being seen as a vital part of the overall engineering process. Providing an undergraduate systems engineering program is an opportunity to expand the reach of science and engineering.

2.1.3 Systems Engineering Program Survey Results

The survey responses also provided interesting ideas for improving systems engineering program curricula. Figure 2 shows a compilation of the ratings that the respondents provided for their own programs. The rating criteria are as follows:

5 – Emphasized in a required course

4 – Briefly covered in a required course, or emphasized in multiple elective courses.

3 – Emphasized in an elective course

2 – Briefly covered in an elective course

1 – Not explicitly covered

Emphasis Area	**5**	**4**	**3**	**2**	**1**
Globalization – The context in which systems engineers will be working, including increased global competition, outsourcing, cross-cultural collaboration, changing political pressures, etc.	X	XX	XX		
Management/Leadership – Systems Engineering involves tradeoff decisions and interdisciplinary collaboration. Systems Engineers should know how to lead, make decisions, communicate effectively and efficiently, and understand the motivations of the other functional groups.	XX XX	X			
Character – Building character traits that can enhance systems thinking, such as: creativity, comfort with ambiguity, good decision-maker, motivated, curious, life-long learner, etc.	XX	X		XX	
Software Development – Software plays an increasingly important part as systems become more complex. Differences in software development throughout the Systems Engineering process based on criticality of the system.		XX	X	XX	
Business Environment – The System Engineer's role in business development, economic impact of decisions, different business environments and contract types in industry.		XXX		X	X
Human Aspect – How to elicit requirements from customers, importance of solutions that apply across cultural boundaries, the human aspect of every system, usability of software and human interfaces.	X	XX XX			
Modeling – Systems modeling and simulation.	XXX	X		X	

Figure 2 – Survey Results: Topic Areas Addressed In Systems Engineering Curricula

Character and business environment are the two emphasis areas that have the widest variation in coverage among the respondents. Globalization, management, and the human aspect seem to be consistently addressed. One respondent observes that there is a need to understand the business requirements and drivers in any program. His school promotes a combined MSE/MBA program to address this. Another respondent states "I would like to see the introduction of courses on the philosophy of engineering and science, and argumentation and rhetoric. It has been my experience that many of our students do not know how to apply critical thought to what constitutes proper engineering and science practices, and how to convey those thoughts to an audience." This is obviously an important skill for a systems engineer who must make decisions and defend them to multiple stakeholders. In the next section of this paper, I will attempt to build on these responses as well as other research in this area to suggest certain topics areas that should be addressed in a formal systems engineering education.

2.2 Systems Engineering Focus Areas

Systems engineering is a diverse discipline that has a very broad range of applications. Degree programs in this field are accordingly diverse, but there are common threads that apply throughout the field. Educational programs in systems engineering need to be especially concerned with the emergence of systems engineers who can cope with the challenges of finding integrated solutions to issues that are of large scale and scope [Sage, 2000]. Any degree program is necessarily limited in scope to due time constraints, so the inclusion of new topics may result in the exclusion or limitation of others. With this in mind, I believe that the formal education of systems engineers could be improved by addressing six relevant topics in the systems engineering curricula:

1. the global context of systems engineering,
2. management, leadership, and team structure,
3. character development,
4. business environment,

5. the human aspect of every system,
6. and requirements.

These topics could be addressed either in required courses, electives, or a combination of the two. It is up to each education provider to determine how best to improve the education of their core audience. Providing an overview or an in-depth study of these topics would prepare students for work in industry, help them understand their work environment, and enable them to successfully execute their tasks.

2.2.1 Global Context of Systems Engineering

The world is constantly changing; that much is given. As globalization continues apace, systems engineers will find that the world they work in can be unpredictable and volatile. An introduction to the transformation that globalization is bringing will provide students with a framework in which to make sense of and adapt to changing processes and realities. In other words, it will set the context for the environment in which the systems engineer will be working.

Systems engineers will be working in an environment of global access and competition. It is likely that at some point they will be working with or for customers or stakeholders in other cultures. Collaborative activities will require stronger human systems and software engineering process and skill support, not only across application domains but also across different cultures [Boehm, 2006]. Different cultures have different ways of doing business, different processes, and different expectations. It will be important to know how to adapt to and work in other cultural environments.

Systems engineers will also need to be able to manage and work with diverse groups. Differential salaries provide opportunities for cost savings through outsourcing, although lack of careful preparation can easily turn the savings into overruns [Boehm, 2006]. Outsourcing is just one of the drivers of cultural interaction. Another is the shortage of engineers coming from the U.S. Asian countries are producing eight times as many bachelor's degrees in engineering as the U.S. [Friedman, 2007]. As engineering grows around the globe, systems engineers in the U.S. will increasingly be working across national and cultural boundaries, whether as customer, contractor, sub-contractor, or collaborator.

A systems engineering education should address the challenges associated with working for and collaborating with individuals from different cultures and nationalities. It should incorporate social, cultural, and ethical issues, a sense of economic and organizational realities, and a sense of globalization of engineering efforts [Sage, 2000]. This perspective will prepare the systems engineer to be effective in a changing and diverse workplace.

2.2.2 Management, Leadership, and Team Structure

The systems engineering process is collaborative. It is a management technology which involves the interactions of science, the organization, and the environment, and the information and knowledge base that supports each [Sage, 2000].

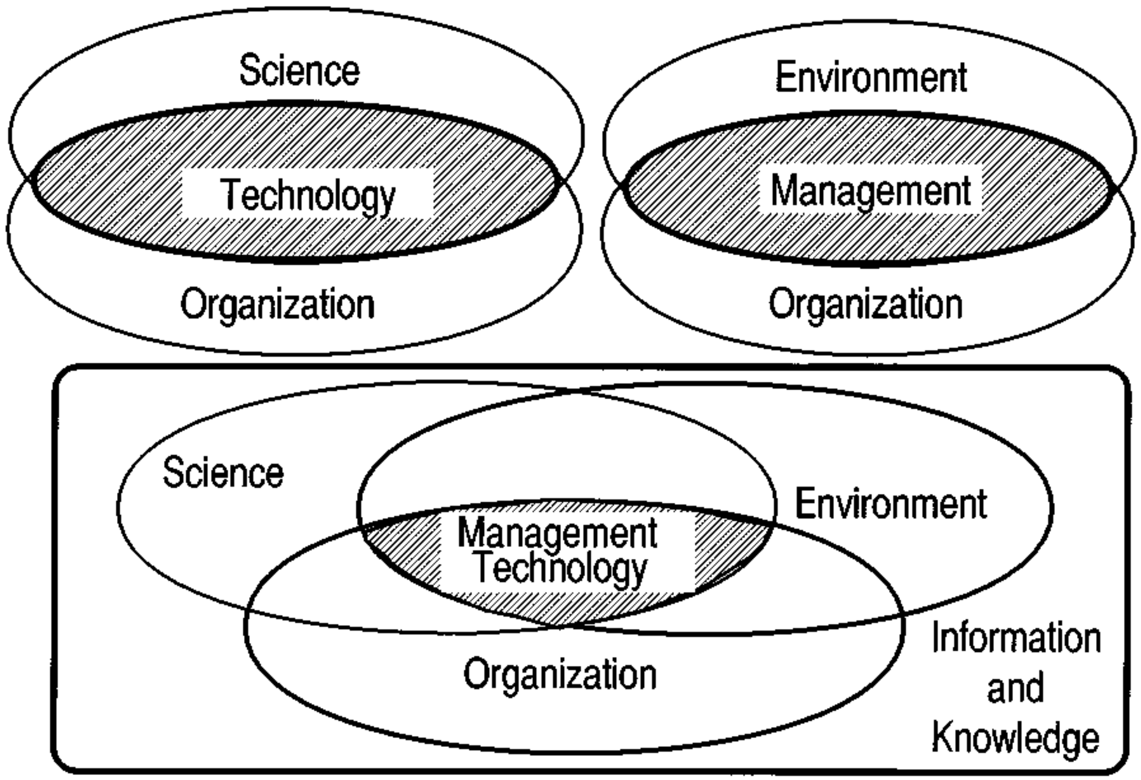

Figure 3 – Systems Engineering as a Management Technology [Sage, 2000]

As systems become more complex, the roles involved in developing and managing such systems also become more complex [Davidz and Nightingale, 2007]. Introducing systems engineers to the importance of management, leadership, and team work is essential. The main aim of systems engineering is to optimally integrate individual components into a whole system that will meet specific system-level requirements. This process of optimal integration must be performed with full consideration of various limitations such as schedule, available resources, performance, and cost [Frank and Elata, 2005]. All of these constraints must be balanced and managed.

Appropriate information management and knowledge management are each necessary for high quality systems engineering and management [Sage, 2000]. Systems engineers work in an environment of change where management of information is critical. Collaboration across many different functional areas is a routine part of systems engineering, and effective management is necessary to coordinate groups with different priorities and philosophies.

Decision making, leadership, and planning are all critical skills in systems engineering. Large projects generally have many stakeholders, all with different priorities and concerns. Systems engineers often must mitigate between conflicting considerations of cost, time, and performance, while considering tradeoffs and engineering constraints of different alternative solutions [Frank and Elata, 2005]. The systems engineer needs to have an understanding of the motivations and concerns of the different parties involved and be able to successfully mediate between them. Successful systems engineers are able to bring engineers from different disciplines together into cooperative professional activity [Frank, 2006].

Systems engineering requires communication between collaborating groups and individuals. Without proper management and coordination, necessary communication will not always take place. Learning to collaborate, communicate abstract concepts, and achieve a consensus are not usually emphasized in formal education [Reich, 1992]. These are skills that are especially applicable to systems engineering. Systems engineers often take on management roles associated both with identification of appropriate processes and with technical direction of implementation efforts and associated overall configuration control [Sage, 2000]. Even if a systems engineer plans to remain on the technical side rather than entering leadership areas such as lead project engineer, he should be familiar with the importance of management, and should have an idea of what information is valuable to individuals in lead positions.

The importance of management in the systems engineering process cannot be understated. A systems engineering curriculum should cover the various aspects of management and leadership. In addition, a course on project management would be very beneficial to systems engineers. Even though most will not start out managing or leading projects, having the background to understand how and why decisions are made will help the systems engineer be more effective in his role.

2.2.3 Character Development

Various character traits are evident in proficient systems engineers. While many of these traits are exhibited by successful individuals in general, they are especially important for the systems engineer. A formal systems engineering education program should seek to develop students that are creative, curious, good decision makers, comfortable with ambiguity, motivated and proactive, and life-long learners, as well as students that have solid interpersonal skills and the ability to remain objective.

Creativity and curiosity are obvious traits that would support systems engineering thinking. Systems engineers need to be able to contribute to brain-storming discussions, offer workable innovative solutions, and transform creative concepts into realizable ideas [Frank, 2006]. They should also constantly question the information that they are given [Frank, 2006]. Systems engineers should constantly be looking for better solutions, whether solution- or process-oriented. In a paper entitled “Systems Thinking in the Development of Senior Systems Engineers,” Davidz and Nightingale interviewed over

200 systems engineers and experts in 10 host companies on which traits and characteristics are important for the development of systems thinking in engineers [2007]. Figure 4 shows the responses they received.

Node Category	All Participants (N=202)		Expert Panelists (N=37)		Senior Systems Engineers (N=61)		Senior Techincal Specialists (N=52)		Junior Systems Engineers (N=52)	
	Rank	Percent	Rank	Percent	Rank	Percent	Rank	Percent	Rank	Percent
Thinking broadly	1	32%	1	35%	1	25%	1	35%	1	37%
Curiosity	2	21%	1	35%	3	20%	2	23%	5	12%
Questioning	3	17%	3	22%	7	13%	3	21%	3	13%
Open-minded	4	14%	9	8%	2	21%	9	8%	2	15%
Communication	5	13%	5	14%	4	18%	9	8%	3	13%
Tolerance for uncertainty	6	11%	4	19%	5	15%	15	6%	8	8%
Strong interpersonal skills	7	11%	5	14%	11	10%	5	12%	7	10%
Thinking out-of-the-box	8	10%	9	8%	15	7%	4	17%	8	8%

Figure 4 – Individual Characteristics and Traits for the Development of Systems Thinking in Engineers [Davidz and Nightingale, 2007]

The top four responses relate to creativity and curiosity. Clearly these are important characteristics of a systems engineer.

Systems engineers need to be good decision makers. They should be comfortable with ambiguity and with working in unclear conditions and in uncertain environments. Not knowing all the details does not disturb or hinder their efforts to solve a problem [Frank, 2006]. The ability to look at the big picture without getting hung up on details is crucial. In order to make confident, informed decisions, a systems engineer must be able to see past the short term issues. A systems engineer may be tasked with capturing the value and preferences of a decision-making customer so that the decision-maker and other stakeholders will have confidence in their decisions [Smith, Son, Piattelli-Palmarini, Bahill, 2007]. Strong interpersonal skills are required to make decisions with confidence and defend them. A systems engineer often must mediate between stakeholders or co-workers with conflicting opinions.

A successful systems engineer will also be motivated and proactive. This goes hand in hand with being a life-long learner. Systems engineering efforts are, of necessity interactive. However, they transcend interactivity to include proactivity [Sage, 2000]. A hesitant, shy, or unmotivated individual will struggle in the intensely interactive and collaborative environment of systems engineering. A systems engineer is often a broker of information. He must be proactive in gathering information to make decisions and in informing stakeholders of changes – in other words, he must initiate communication. A systems engineering education should instill the knowledge of how to learn, a desire to learn, and how to adapt to changing societal needs over a successful professional career [Sage, 2000]. In an ever-changing global environment, a systems engineer needs to be constantly seeking out ways to improve processes and adapt to changing organizations.

A systems engineering program should seek to foster these qualities in its students. Schools that are more exclusive could use these traits as selection criteria for admission, while inclusive schools can emphasize their development in their students. The curriculum should reinforce teamwork, collaboration, and creativity. Rather than teach students how to solve a problem that is presented to them, they should be taught to examine why the problem arises and how it is connected to other problems [Reich, 1992].

Finally, the importance of continuing education should be continually emphasized. Concerning globalization, Friedman says that “the first, and most important, ability you can develop is the ability to ‘learn how to learn’ – to constantly absorb, and teach yourself, new ways of doing old things or new ways of doing new things” [2007].

2.2.4 Business Environment

Systems engineering is a diverse discipline in which its practitioners work in varying and diverse business environments. Most will work in multiple environments with significantly different business models throughout their careers. Systems engineering education should prepare students by exposing them to the different settings in which they will likely be functioning.

Commercial, government, defense, and aerospace are examples of different industries or structures in which systems engineers will work. These different fields can have very different processes, business models, and incentives. NASA projects, for example, have historically been difficult, large ventures with high costs [Sauser, 2006], and the aerospace sector in general is characterized by relatively low volume, expensive products for an exclusive set of customers [Guenov, Barker, Hunter, Horsfield, and Coleridge-Smith, 2006]. This contrasts starkly with consumer electronics or software, which are characterized by high volume and a priority on time to market. A systems engineer’s responsibilities and incentives depend on the environment in which he is operating.

In addition to different industries and customers, there are different contract environments that systems engineers will operate under. Some examples are fixed price, cost plus fixed fee, and design-to-cost. The incentives vary significantly under different contract approaches. It is important that the systems engineer recognize how the project is approaching the design optimization process [Gilb, 2005]. In a fixed price contract, minimizing cost maximizes profit. In a cost plus fixed fee contract, minimizing cost can reduce profit. In some projects, keeping costs down is most important. In others, schedule or functionality may be the top priority. A project's orientation impacts the decisions that a system engineer makes.

The systems engineer plays an important part in business development. Almost every decision a systems engineer makes has business implications. Systems engineers need to be taught to evaluate the economic, technical, and political impacts of each decision. They must be capable of anticipating and detailing all implications of changes in the system, both engineering and non-engineering alike, whether the changes are initiated by the contractor or required by the customer [Frank, 2006]. The organizational setting affects engineering decisions. Technical considerations must be blended with non-quantitative assessments of organizational vision, goals, culture, and values [Smith, Son, Piattelli-Palmarini, Bahill, 2007]. Systems engineers must make decisions that position their organization for future growth. In the high-value enterprise, profits derive from continuous discovery of new linkages between solutions and needs [Reich, 1992]. The systems engineer works with customers, product-line managers, engineers, and individuals in many other functional areas. This puts him in a unique position to find ways to match needs to solutions.

Software development plays an increasingly important part of the systems engineering process with respect to the business environment. Boehm states that "between now and 2025, the ability of organizations and their products, systems, and services to compete, adapt, and survive will depend increasingly on software" [2006: 1]. Coordinating software development in the systems engineering process will be crucial. Most large or complex systems are information- and software-centric [Maier, 2006]. Incremental software builds and concurrent development are common in this environment, and the spiral development process is often used in this setting. In a modern development environment, software and other disciplinary engineering will be at least partially concurrent [Maier, 2006]. In many cases, software development on a new version may be taking place while the previous version is still being tested. Good configuration management and change control are crucial in this environment.

It is evident that systems engineers will be working in many diverse business environments. In each unique setting, there are different responsibilities, incentives, and processes. A systems engineering education should familiarize its students with the different types of business environments and prepare them to function effectively in variegated settings.

2.2.5 Human Aspect of Every System

Systems engineering takes place in the domain of systems used by humans. Systems engineering is inherently associated with user organizations and humans in fulfillment of its objectives [Sage, 2000]. The purpose of systems engineering is to support individuals or organizations that desire improved performance through technology [Sage, 2000]. In today's global environment, a customer's capabilities and needs are changing rapidly. Systems engineers should be aware that the systems they design will be created for and used by imperfect and fallible human beings.

A customer's capabilities and needs are changing at an ever increasing pace. As technology continues to revolutionize how things are done, both old equipment and old ways of doing things become obsolete. Indeed, there is a need to address realities of changing requirements and customer expectations, changing technologies, and evolving standards and regulations [Verma, Farr, and Johannesen, 2003]. As capabilities and possibilities change, customers may not be aware of new options or new ways available for accomplishing an existing task. Systems engineers need to help the customer understand what options are available and what the implications are (i.e. changes to the customer's procedures or concept of operations).

There should be a focus on the long-term direction of products and solutions. As capabilities and possibilities continue to grow, a company's products need to be able to adapt to advances in technology and processes. Solutions also need to apply across cultural boundaries. Every engineering decision needs to be made in the context of the global marketplace. The optimal solution for one group of individuals will likely be very different from another's. There is a need to elevate human factor concerns from a micro-ergonomics to a macro-ergonomics focus on organization, roles, responsibilities, and group processes of collective observation, orientation, decision-making, and coordinated action [Boehm, 2006].

The human element cannot be removed from a system. The role a human plays can be reduced or minimized, but every system has human interaction. A good systems engineer recognizes that the human element is part of the system and is careful not to propose impractical designs [Frank, 2006]. It is not enough to load a product with features. “A recurring user-or-organization desire is to have technology that adapts to people rather than vice versa. This is increasingly reflected in users’ product selection activities, with evaluation criteria increasingly emphasizing product usability and value added vs. a previous heavy emphasis on product features and purchase costs. Such trends ultimately will affect producers’ product and process priorities, marketing strategies, and competitive survival” [Boehm, 2006: 3]. The user is a critical part of the system that cannot be overlooked during the design of the system.

Systems engineers design systems that interact with humans. This affects every part of the systems engineering process from the problem statement to design, development, and deployment. Systems engineers must understand the importance of designing for the human element of the system.

2.2.6 Requirements

Requirements are an integral part of systems engineering. Indeed, they are the foundation of any project [Frank and Elata, 2005]. They are the reference point where all stakeholders agree on what the system will do. “What stakeholders perceive as ‘value’ drives us to state ‘what stakeholders want’ and ‘how much stakeholders might be willing to pay for such change’: in other words, to state the requirements. Requirements, which reflect values, give us a sound basis for evaluating a design idea: a basis for deciding if we might get what we will find of ‘value’ from a potential design idea” [Gilb, 2005: 188]. Clearly the importance of requirements can not be overstated. While requirements are most likely covered at some level in every formal systems engineering education program, there are specific aspects that should be addressed.

Requirements development is an iterative process and can be difficult to control [Hari, Kasser, and Weiss, 2007]. The requirements are refined as the system is implemented and integrated. In addition, requirements changes will be driven by the customer and the stakeholders. "As you run a project or deliver to initial stakeholders, you will get new insights into which requirements are actually useful. Stakeholders, too, will learn from their early experiences using a new system, what they really want" [Gilb, 2005: 42]. For these reasons, requirements must be allowed to evolve during development. Contractually, and politically, requirements changes and refinement can be a challenging responsibility for the systems engineer. Late requirements changes driven by the customer are one of the reasons that projects go over budget or do not meet schedule. However, in order to deliver a useful end product to the customer, the systems engineer must address changing priorities and capabilities.

Complicating the requirements development process is that fact that there are hurdles to communication between the systems engineer and stakeholders. The customer deals in capabilities rather than requirements, and this leads to difficulty formulating the exact requirements [Guenov, Barker, Hunter, Horsfield, and Coleridge-Smith, 2006]. Translating capabilities into requirements is not simple. Identifying the true customer needs can be difficult because stakeholders often refer to both problem and solution domains [Smith, Son, Piattelli-Palmarini, and Bahill, 2007]. The systems engineer must be able to avoid the unnecessary limitation that comes with an assumed design or solution, even if that particular solution is initially requested by the stakeholders.

Systems engineers must learn to be effective at eliciting requirements from the customer and understand the impact of each requirement. It is helpful to communicate with and question the customer in order to determine his values and needs [Smith, Son, Piattelli-Palmarini, and Bahill, 2007]. Without this interaction, it is less likely that the final product will meet the true need. Negotiation of priorities for requirements involves not only participation from users and acquirers on each requirement's relative mission or business value, but also participation from systems engineers on each requirement's relative cost and time to develop and difficulty of implementation [Boehm, 2006]. In order to facilitate this interaction, requirements must be stated in a clear and unequivocal form such that there is one interpretation for all stakeholders. The problems due to vague requirements will inevitably arise later because of different interpretations [Gilb, 2005].

Not only will systems engineers need to know how to analyze and decompose requirements, they must be able to interpret customer needs and evaluate the relative value of each requirement. Mistakes during the requirements phase are expensive to fix later. In order to provide a high value product, a systems engineer must understand the importance of obtaining and developing accurate requirements.

2.2.7 Summary

Below is a summary table of recommended subtopics to include the curriculum in order to address these topics.

Topic Area	Recommended Course Content
Global Context of Systems Engineering	Global Economic Trends
	Cultural Interaction
Management and Leadership	Project Management
	Collaborative Team Projects
	Effective Communication
	Problem Solving / Mediation
Character Development	Decision-Making
	Process Improvement
	Continual Learning
Business Environment	Organizational Environments
	Program / Project Structures
	Business Development
Human Aspect of Every System	Focus on User / Human Factors
	Dealing with Changing Capabilities
Requirements	Requirements Elicitation
	Writing/Developing Requirements
	Stakeholder Value

Figure 5 – Recommended Course Content

3 Systems Engineering in Industry

Hiring, training, and developing its systems engineers are important tasks for a systems engineering company. An experienced systems engineer is a high-value employee. In this section, we will look at specific methods companies can use to improve their systems engineering talent, from hiring and integration to development.

3.1 Hiring and Human Resources

Each company should have a plan for hiring and integrating its systems engineers. While systems engineering education provides a conceptual foundation, experience is key to the development of a proficient systems engineer. It follows that an experienced systems engineer is a high-value employee. Care should be taken when hiring entry level systems engineers to ensure that they have a solid educational foundation, while senior systems engineers should possess applicable and appropriate experience. In addition, consideration should be given to the integration of the systems engineer into the business enterprise.

3.1.1 Acquiring Talent

Lately there has been much talk about a shortage of engineers. The number of engineering graduates in the U.S. has been declining since the 1980s [Reader, 2006]. A general theory is that the average age of practicing engineers has been increasing, and as baby boomers retire, there are not enough experienced engineers to take their places. There are conflicting opinions as to how true this is, but it is safe to assume that there will continue to be strong competition for attracting talented systems engineers. In order to attract the highest quality talent, companies should consider three primary areas on an individual basis when hiring systems engineers: education, character traits, and experience.

Education is an important piece in the development of a systems engineer. A proper education provides the foundational concepts on which experience builds. Companies should look at the quality of a prospective systems engineer's formal education and favor individuals whose education has exposed them to the six concept areas elaborated earlier in this paper. A company should develop relationships with schools that provide a high quality education that fits the company's needs. These relationships should go both directions: the company can provide input on industry trends so the school can continually update and modernize its curriculum, and the school can provide the company access to high quality graduates. A systems engineer that has been taught these key concepts will learn faster and provide more value.

Experience is usually already a key consideration when a systems engineer is hired, and there are obvious differences in the amount and type of experience required depending on what position is being filled (i.e. entry level, senior, principal, etc.). However, there are general principles that apply when considering any applicant's experience. A prominent characteristic of a skillful systems engineer is a wide, diversified, multidisciplinary, and interdisciplinary knowledge [Frank, 2006]. A systems engineer must gain a very broad base of knowledge, and that can only be accomplished through experience. Systems engineers benefit from being able to compare and draw parallels between different disciplines. They are able to learn, infer, and draw conclusions from one discipline and apply these conclusions to another [Frank, 2006]. When companies are considering an applicant's experience, they should be looking for a broad base of experience in multiple disciplines. They should also look for an appreciation of different cultures and business practices, as well as an understanding that engineering practice is now global [Sage, 2000]. Systems engineers with broad experience will have been exposed to multiple ways of doing things and can carry the best processes forward. Individuals with extensive experience in a narrow discipline may have a more narrow-minded approach because they have not been exposed to divergent practices in other fields. A systems engineer that has been exposed to many different disciplines and different ways of doing things should be more open to continually improving processes and functions.

Companies should also judge applicants on character traits. This is perhaps the most important criteria on which to assess candidates. Successful systems thinking is a mix of innate talent and acquired experience [Frank, 2006]. While systems engineering concepts can be learned through education and experience, an individual's character traits and innate talent are much harder to change or improve. As discussed earlier in this paper, there are certain character traits that enable the successful execution of systems engineering. An individual should be: creative, curious, a good decision maker, comfortable with ambiguity, motivated and proactive, and a life-long learner, and have solid interpersonal skills. He should also have broad interests going beyond the limited area of his expertise [Frank, 2006]. Hiring managers should search for clues to these qualities in an applicant's resume. A history of learning is a positive indicator. Even if the education and experience are stellar, if the candidate does not have motivation, a desire to learn, and a desire to explore new areas, he will likely under-perform.

Hiring high quality employees is a critical task in any business. A candidate's education, experience, and character provide effective insight into what kind of systems engineer he is likely to be. Companies should use these factors as criteria to hire individuals that are most likely to provide the highest value.

3.1.2 Enterprise Integration

The integration of systems engineers into an enterprise is an important process that should not be overlooked. Often newly-hired individuals with very diverse experiences and backgrounds are thrown right into a project without any training on the company's processes, business model, or expectations. The perspective they then develop is influenced by the individuals or groups that they work with, which can lead to a divergence between areas within company. Each company should have a comprehensive process to assimilate and retain its systems engineers.

Three types of training should be provided to systems engineers new to a company: a systems engineering process overview, requirements training, and business environment training. This training will provide focus and context, as well as direction. A tailored systems engineering overview will introduce the new systems engineer to the language, culture, and processes of the company. It will help him learn the company's priorities and understand key differences from other companies where he has worked. Requirements are a critical part of any system, and the company needs to ensure that all systems engineers have a firm grasp on requirements engineering. Requirements training will provide crucial expectations to inexperienced systems engineers, provide a beneficial refresher to experienced ones, and provide both with an introduction to the company's processes for requirements engineering. Finally, business environment training should be used to introduce the systems engineer to the concepts of impact estimation, budget management and cost control, earned value concepts, and where profit comes from. Ideally, this training will introduce the incentives and priorities of the company and provide the systems engineer with an understanding of the context in which he will be operating.

It is important that a company provide organization-wide metrics of how systems engineering progress and development are measured. Traditional human relations organizations and processes tend to emphasize individual and monolithic career paths which do not fit well with the team-oriented, diverse-skill needs required for success today [Boehm, 2006]. An individual's position on a team should be emphasized and initiative should be rewarded. A company should foster identified individual characteristics, provide an environment supportive to the development of systems thinking, and clearly communicate how systems thinking is evaluated and which aspects of systems thinking are being evaluated [Davidz and Nightingale, 2007]. Systems engineers need to be provided with expectations and goals for development. The benefits of this are organizational continuity and alignment. It is also important for systems engineers to know that their organizational culture really support improvements in systems engineering methods [Gilb, 2005]. When there are clear expectations and rewards, systems engineers will be able to more confidently improve their skills and effectiveness, and hence, their value to the company.

Systems engineering turnover also needs to be managed. It is expensive to replace personnel because the new individuals must be trained and assimilated into the organization. Nevertheless, it is common for an individual to change jobs multiple times in his career. One analyst attributed this increasing incidence of job change to Reagan's economic changes. "One critical consequence of [the Reagan economic] restructuring was a new compensation paradigm – one that relies on markets rather than corporate diktats, regulation, or historical norms to set pay; accepts a much higher degree of income disparity based on market-denominated performance; and expects that most people will exploit the resulting market for talent by moving from company to company many times during a career" [Manzi, 2008]. Regardless of whether or not that is the main cause, job turnover is not exclusively detrimental to systems engineering organizations. As I discussed above, a broad experience base is an important aspect of an accomplished systems engineer. A good systems engineer will draw parallels between systems in different disciplines and will be exposed to different processes and different ways of doing things. With a proper balance, turnover should provide a company with a source of new ideas and new processes that at least partially offsets the expense of hiring, training, and assimilating new personnel.

The training and assimilation of systems engineers into an enterprise is a critical function. Expectations and focus should be set early, and organization culture introduced. The resulting clarity and direction will allow systems engineers to concentrate their energy on value-added tasks sooner.

3.2 Developing Systems Engineers

Each company should have a plan for developing its systems engineers. “In a high-value enterprise, only one asset grows more valuable as it is used: the problem-solving, -identifying, and brokering skills of key people” [Reich, 1992: 108]. Development of systems engineers should be accomplished by providing experience, mentoring, and education, and emphasizing systems engineering management.

3.2.1 Experience

Systems engineers gain proficiency primarily through experience. Regarding education, there are still many opinions on what information should be taught, and how much of systems engineering can be learned through formal training methods [Petee and Componation, 2002]. Education has its limits, and experience is obviously necessary to build on the foundational concepts of education. The data show that systems thinking is developed in engineers primarily by experiential learning [Davidz and Nightingale, 2007]. Diverse experience is important in a systems engineer's development.

Companies should have a deliberate method for gaining experience for their systems engineers. This is especially important for junior systems engineers. Care should be taken to ensure that they experience a broad range of tasks over time and are not constrained to one narrow responsibility indefinitely. There are many tasks that junior systems engineers can perform, or at least contribute to, including testing, interfaces, wiring, installations, documentation, coordinating, resolving problems and troubleshooting [Frank, 2006]. It is beneficial for systems engineers to experience different stages and tasks in the systems engineering process. An obvious example is performing work on both capturing requirements and testing. Through testing, an appreciation for the importance of clear, concise and testable requirements will be gained, and through requirements development, an appreciation for the difficulty in capturing and defining the correct requirements will be acquired. Davidz and Nightingale provide suggestions on how a company should address this challenge. "First, systems training can be coordinated with job task and work environment. Second, the organization can manage schedule and cost constraints to allow time to utilize and to develop systems thinking. In addition, the organization can provide jobs and opportunities to see the systems view. Often, there are not enough jobs where a systems view is required. This is an issue of job design, and organizations can restructure tasks to foster or require systems thinking" [2007]. Companies must design tasks in such a way that fosters the development of its systems engineers.

3.2.2 Mentoring

Mentoring is a tool that should be used to develop and nurture systems thinking in systems engineers. Mentoring provides the opportunity to establish continuity and pass on knowledge learned from previous successes and mistakes. Systems engineers generally play an important role as brokers of information and knowledge, and in associated technical direction efforts, in working both with user enterprises and implementation specialists [Sage, 2000]. Senior systems engineers develop a wealth of subjective knowledge and experience over time, and pairing a junior systems engineer with a senior one is an efficient way to transfer knowledge, tips, and best practices gained through decades of experience. This is especially important in environments such as large systems projects, where the knowledge base is limited in the area of project management and systems engineering [Sauser, 2006].

Mentoring should also be used to alleviate the negative effects of turnover. It provides a vehicle to pass on knowledge that would otherwise be lost when an experienced individual leaves the company, be it through retirement, transfer, or job change. In addition, it is an effective means of introducing ideas and processes brought to the organization by new employees. Mentoring facilitates the sharing of knowledge throughout an organization and is a necessary part of developing proficient systems engineers.

3.2.3 Training and Continuing Education

Continuing training and education are important aspects in the development of valuable systems engineers. The accelerating pace of change today demands continual adaptation. When added to the trend toward emergent systems requirements, the pace of change places a high priority on systems and software engineering process agility and investments in continuous learning for both people and organizations [Boehm, 2006]. Training and continuous learning are necessary in order to stay competitive.

Companies should provide access to and encourage training and education opportunities. A successful systems engineer will have to adapt to changing societal needs over a successful professional career [Sage, 2000]. A systems engineer that is actively learning is a motivated employee. He will make sure his skills are relevant and up to date, and will be actively looking for ways to improve both his skills and the organization's processes. He will ensure that new, relevant information reaches him [Frank, 2006].

Encouraging life-long learning in employees can be done in multiple ways. Time during work can be provided for training opportunities. Tuition reimbursement can be provided for classes or formal programs. Companies that provide these opportunities will be helping their employees keep their skills up to date and relevant to today's workforce, which should breed loyalty and respect. One concern with this approach is that a company will pay for an employee's training or education only to see him leave shortly afterwards. This may happen. However, I believe that this possibility is outweighed by the increase in productivity and innovation that the company will reap from employees that are actively learning.

3.2.4 Emphasis on Systems Engineering Management

In order to create value and remain competitive, developing the management of systems engineering must be a top priority. Leadership is where most value is created, nurtured, and developed [Reich, 1992]. As discussed previously, systems engineering is management intensive and is accomplished through collaboration across different groups. There are three different primary systems engineering lifecycles for technology growth and change: system planning and marketing; research, development, test, and evaluation; and system acquisition, production, or procurement [Sage, 2000]. Each of these functions requires careful coordination and collaboration with the others. Because systems engineering relies heavily on human interaction, management is critical. Systems engineering is a management technology to assist and support policymaking, planning, decision-making, and associated resource allocation or action deployment [Sage, 2000]. Project management is where the tone of the project is set. It largely determines adherence to processes and procedures that are critical for the project's success. Appropriate information management and knowledge management are each necessary for high quality systems engineering and management [Sage, 2000]. Without proper project management, even the most qualified systems engineers will be less effective.

A properly managed project will foster a friendly environment for practicing systems engineering. A successful systems engineering product, or service, generally results only from a successful systems engineering process [Sage, 2000]. It is critical to develop and implement successful processes, and this is accomplished through management.

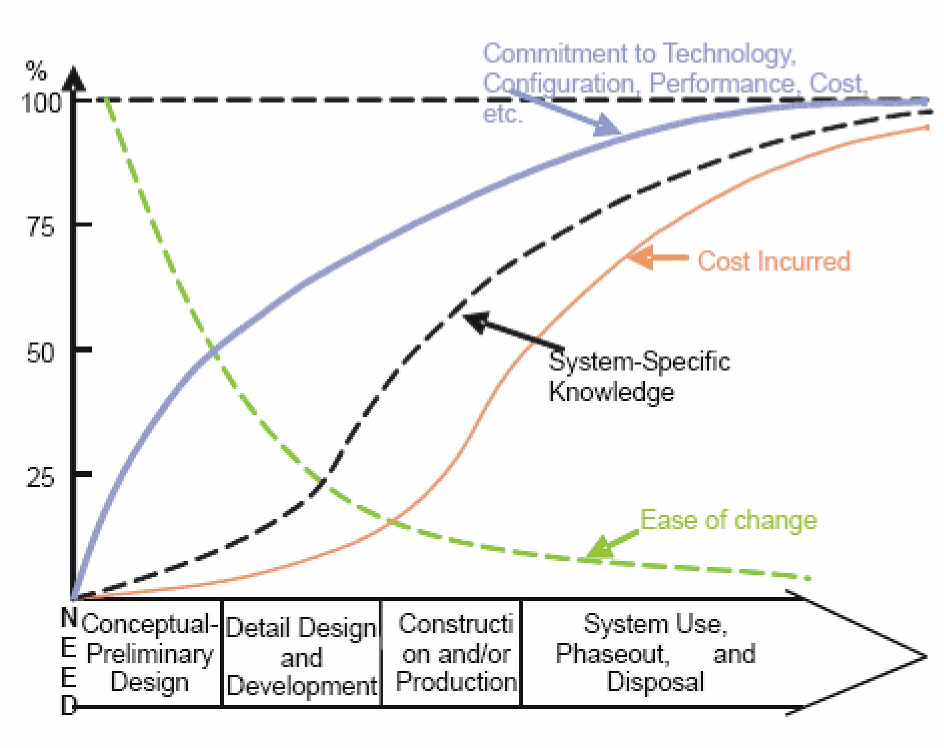

Figure 6 – Cost of change over time [Blanchard and Fabrycky, 1998]

Figure 6 shows how the cost of change increases with time throughout a project's lifecycle. A proactive management will implement good processes that will help the project eliminate mistakes early in the development cycle. Training can also be provided on where most mistakes are introduced and how best to reduce them.

Roles, responsibilities, and decision-making authority must be properly defined, assigned and understood, or there will be confusion, frustration, and inefficiency. Communication is the most important aspect that management can influence; it takes place in the context of different roles. Individuals need to know explicitly to whom they are expected to communicate what information.

In addition, systems engineering management must set the priorities in a project. Providing value is more important than narrow cost control [Gilb, 2005]. The project team needs to stay focused on the end result and not get bogged down in the details. Leadership is required to keep a team focused on the correct tasks. When there is no clear sense of direction or urgency, rework will be common.

The project management style should be tailored to the project being executed. Since almost no project is done in isolation and most organizations are involved in more than one project, organizations would benefit from developing their own organization-specific frameworks and teaching managers to adopt the right approach to the right project [Sauser, 2006]. For example, large, complex projects require a more rigorous change control process than a small project. Using unnecessarily complex and time-consuming processes on a small project can be a poor use of resources, while the opposite can lead to crippling setbacks. Each project will have a unique character that needs to be addressed through project management style. It is up to the project managers to determine which processes and procedures are worthwhile for a given project. Having processes in place for tailoring project management styles for different types of projects based on budget, complexity, and level of technological maturity would facilitate this.

Because there is so much interaction in systems engineering, it is crucial to put in place quality systems engineering management. A company should provide training in leadership and project management to its systems engineers. Systems engineers need to understand the business aspect in order to work with the program manager to provide value to the customer. They also need to be able to foster an environment of communication, collaboration, and teamwork. Training in the area of systems engineering management has the potential to provide enormous returns because the management of a project can be the difference between success and failure.

Another way companies can improve the management and practice of systems engineering is to familiarize non-systems engineers with the systems engineering process. This can be accomplished through a brief training course. Systems engineers interact with individuals from many different functional groups, and if the individuals in these groups understand the perspective and processes of the systems engineer, they can provide appropriate and helpful information more readily. This would obviously make the systems engineering process more efficient.

Project management is vital to the success of the systems engineering process. In order to foster the environment of teamwork and collaboration that is necessary for systems engineering, roles and responsibilities must be defined, processes must be put in place and enforced, and priorities must be established. Systems engineers play a large part in this process. They often take on management roles associated both with identification of appropriate processes and with technical direction of implementation efforts and associated overall configuration control [Sage, 2000]. Putting an emphasis on quality leadership and management are critical to remaining competitive and efficient.

4 Conclusion

Systems engineering is a discipline that continues to adapt to a world in which the pace of change is increasing. Systems engineers must constantly adapt to new realities. The development of a systems engineer takes place primarily through education and experience, as one would expect. I have attempted to address this development process and have proposed approaches for improvement.

Concerning formal education, there are comparative advantages and disadvantages to the studying of systems engineering at the graduate and undergraduate levels. In either case, however, I have suggested six topics that should be addressed in a systems engineering curriculum: the global context of systems engineering; management, leadership, and team structure; character development; business environment; the human aspect of every system; and requirements. These are relevant topics that will provide context to the student's work in industry. While any curriculum is limited in scope, some of these subjects could be worked into existing classes by varying the way courses are taught, or providing a greater emphasis when the topic is encountered. Ultimately it is up to each school to determine what is most beneficial for their students; this generally coincides with what industry needs. My six suggestions are intended to be a starting point for discussion on how to improve systems engineering degree programs.

While education introduces foundational concepts and processes, experience is critical to the development of systems thinking. A systems engineer is a high value employee and each company should have a strategy for the hiring, integration, and development of systems engineers. This starts with putting thought into which character traits and what types of experience should be sought after in the acquisition of systems engineers. In addition, there needs to be a plan for assimilating new systems engineers into the company in order to set expectations and provide continuity. This can be accomplished through overview or training courses. These courses can be used to introduce as well as help shape the company's systems engineering processes and organizational culture in general.

The company should put a priority on providing systems engineers with varying tasks and responsibilities over time. Encouraging mentoring and additional education or training will also aid in the development of systems engineers. Finally, systems engineering management needs to be emphasized. Because systems engineering is multi-disciplinary and collaborative, strong leadership, management, and teamwork are critical.

While these proposals are not by any means exhaustive, I hope they provide a starting point for a discussion on how to improve the quality and value of individual systems engineers.

5 Appendix: Systems Engineering Program Survey

School:
Name:
Position:

Questions regarding Systems Engineering Programs

1. What Systems Engineering degrees/programs does your school offer?

2. When did your school start offering Systems Engineering as an undergraduate degree? If it does not offer an undergraduate program, why not?

3. Are there advantages to studying Systems Engineering at the undergraduate level? Disadvantages?

4. Are there advantages to studying Systems Engineering at the graduate level? Disadvantages?

5. Do you require classes that provide a technical/engineering background as part of your undergraduate Systems Engineering curriculum?

6. Is Systems Engineering becoming a more popular degree choice for students? At the Undergraduate level, graduate level, or both?

7. Are Systems Engineering degrees becoming more popular with industry? Undergraduate level, graduate level, or both?

8. What positions in industry do typical undergraduate level Systems Engineering students take? Graduate level students?

9. What kind of additional degrees do undergraduate Systems Engineering students go on to obtain?

10. What topics, if any, do you think are not being emphasized enough in most Systems Engineering programs today?

11. What aspects differentiate your program from programs offered by other schools?

12. Does your school offer or require a Systems Engineering course as part of your traditional engineering curricula?

Survey

Please fill out the following survey regarding topics covered in your Systems Engineering curriculum by placing an 'X' in the appropriate box. In case there are significant differences between undergraduate and graduate curricula, I have provided a second table.

5 – Emphasized in a required course
4 – Briefly covered in a required course, or emphasized in multiple elective courses.
3 – Emphasized in an elective course
2 – Briefly covered in an elective course
1 – Not explicitly covered

Emphasis Area	**5**	**4**	**3**	**2**	**1**
Globalization – The context in which systems engineers will be working, including increased global competition, outsourcing, cross-cultural collaboration, changing political pressures, etc.					
Management/Leadership – Systems Engineering involves tradeoff decisions and interdisciplinary collaboration. Systems Engineers should know how to lead, make decisions, communicate effectively and efficiently, and understand the motivations of the other functional groups.					
Character – Building character traits that can enhance systems thinking, such as: creativity, comfort with ambiguity, good decision-maker, motivated, curious, life-long learner, etc.					
Software Development – Software plays an increasingly important part as systems become more complex. Differences in software development throughout the Systems Engineering process based on criticality of the system.					
Business Environment – The System Engineer's role in business development, economic impact of decisions, different business environments and contract types in industry.					
Human Aspect – How to elicit requirements from customers, importance of solutions that apply across cultural boundaries, the human aspect of every system, usability of software and human interfaces.					
Modeling – Systems modeling and simulation.					

Comments:

6 References

B.S. Blanchard and W.J. Fabrycky, Systems Engineering and Analysis, 3rd Ed, Prentice Hall, Upper Saddle River, New Jersey, 1998.

B. Boehm, Some Future Trends and Implications for Systems and Software Engineering Processes, Syst Eng 9(1) (2006), 1-19.

H.L. Davidz, and D.J. Nightingale, Enabling Systems Thinking To Accelerate the Development of Senior Systems Engineers, Wiley, New York, 2007.

M. Frank, Knowledge, Abilities, Cognitive Characteristics and Behavioral Competences of Engineers with High Capacity for Engineering Systems Thinking (CEST), Syst Eng 9(2) (2006), 91-103.

M. Frank, and D. Elata, Developing the Capacity for Engineering Systems Thinking (CEST) of Freshman Engineering Students, Syst Eng 8(2) (2005), 187-195.

T.L. Friedman, The World Is Flat: A Brief History of the Twenty-First Century, Picador / Farrar, Straus and Giroux, New York, 2007.

T. Gilb, Competitive Engineering, Elsevier Butterworth-Heinemann, New York, 2005.

M.D. Guenov, S.G. Barker, C. Hunter, I. Horsfield, and N. Coleridge-Smith, An Integrated Approach to Customer Elicitation for the Aerospace Sector, Syst Eng 9(1) (2006), 62-72.

A. Hari, J.E. Kasser, and M.P. Weiss, How Lessons Learned from Using QFD Led to the Evolution of a Process for Creating Quality Requirements for Complex Systems, Syst Eng 10(1) (2007), 45-63.

International Council on Systems Engineering website: http://www.incose.org/educationcareers/academicprogramdirectory.aspx (viewed March 2007).

M.W. Maier, System and Software Architecture Reconciliation, Syst Eng 9(2) (2006), 146-159.

J. Manzi, A More Equal Capitalism, National Review, Feb 25, 2008, 40-43.

D.A. Petee, and P.J. Componation, Development of a Systems Engineering Training Plan at the U.S. Navy's Coastal Systems Station, Syst Eng 5(2) (2002), 156-163.

J. Reader, Globalization, Engineering, and Creativity, Morgan & Claypool Publishers, 2006.

R.B. Reich, The Work of Nations, Vintage Books, New York, 1992.

A.P. Sage, Systems Engineering Education, IEEE Transactions on Systems, Man, and Cybernetics – Part C: Applications and Reviews, 30(2) (May 2000), 164-174.

B. Sauser, Toward Mission Assurance: A Framework for Systems Engineering Management, Syst Eng 9(3) (2006), 213-227.

E.D. Smith, Y.J. Son, M. Piattelli-Palmarini, and A.T. Bahill, Ameliorating Mental Mistakes in Tradeoff Studies, Syst Eng 10(3) (2007), 222-240.

D. Verma, J. Farr, and L.H. Johannesen, System Training Metrics and Measures: A Key Operational Effectiveness Imperative, Syst Eng 6(4) (2003), 238-248.