Systems Engineering Education

Andrew P. Sage, *Life Fellow, IEEE*

***Abstract*—We discuss some basic principles underlying systems engineering, and the translation of these principles to practices such as to enable the engineering of trustworthy systems of all types that meet client needs. This special issue is concerned with systems engineering education. Thus, it is inherently also concerned with systems engineering, as this provides a major component of the material that is important for systems engineering education. After setting forth some of the necessary ingredients for success in systems engineering, we devote some comments to objectives for and needs in systems engineering education.**

***Index Terms*—Engineering education, knowledge engineering, systems engineering.**

I. What is Systems Engineering?

THE PAPER is concerned with the engineering of systems, or **systems engineering**. It is also concerned with the **processes** needed to bring about trustworthy systems in an effective and efficient manner. We are also and especially concerned with strategic level systems engineering, or **systems management**, that is needed to select an appropriate process and ways to provide technical direction over this process. We begin our effort by first discussing the need for systems engineering, and then providing several definitions of systems engineering. We next present a structure describing the systems-engineering process. The result of this is a ***lifecycle model*** for systems engineering processes. This is used to motivate discussion of the functional levels, or considerations, involved in systems engineering efforts:

- systems engineering ***methods and tools***, or technologies
- a systems methodology, or ***process***, as a set of phased activities that support efforts to engineer the system, and
- ***systems management***.

Fig. 1 illustrates the natural hierarchical relationship among these levels. Systems engineers are very concerned with each of these three functional levels. Products (and services) are engineered through the use of an appropriate process, or processes. The tailoring of a process for use on a specific instance is accomplished through systems management. The drivers of systems management include the external opportunities and pressures, and the internal strengths and weaknesses of a given systems engineering organization, as well as the organizational leadership and culture associated with the organizations associated with the tasks at hand. There are a variety of tools and methods, and technologies needed at the level of product, process, and systems management. Appropriate measurements are also needed at all three levels.

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The author is with the Department of Systems Engineering and Operations Research, George Mason University, Fairfax, VA 22030-4444 USA (e-mail: asage@gmu.edu).
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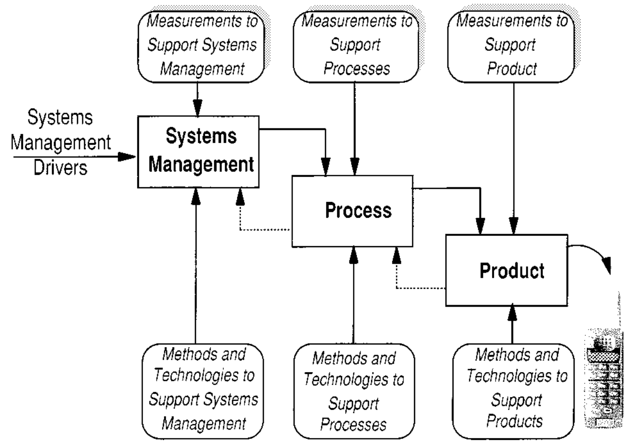

Fig. 1. Systems engineering as method, process, and management.

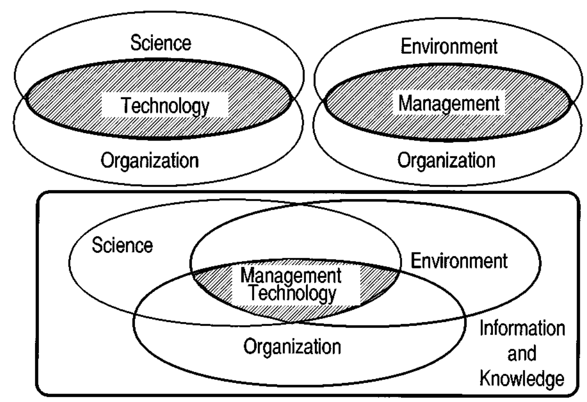

Fig. 2. Systems engineering as a management technology.

Systems engineering is a management technology—which involves the interactions of science, the organization, and the environment, and the information and knowledge base that supports each, as shown in Fig. 2. Technology is the result of, and represents the totality of, the organization, application, and delivery of scientific knowledge for the presumed enhancement of society. This is a functional definition of technology as a fundamentally human activity. Associated with this definition is the fact that a technology inherently involves a purposeful human extension of one or more natural processes. Management involves the interaction of the organization with the environment. Consequently, a management technology involves the interaction of science, the organization, and the environment. Associated with this must be the information and knowledge that enables understanding and action to effect change.

The purpose of systems engineering is to support individuals and organizations that desire improved performance through technology. This is generally obtained through the definition,

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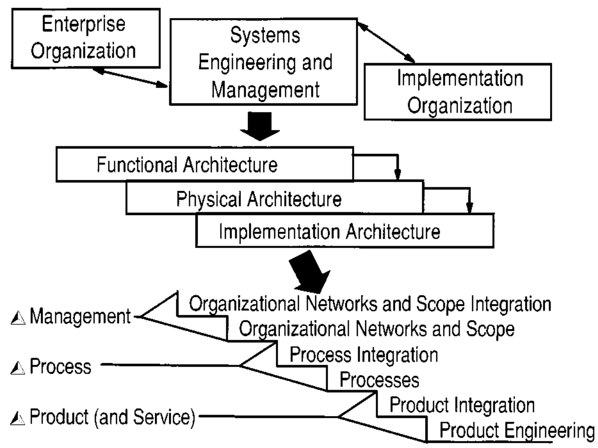

Fig. 3. Systems engineering as a broker of knowledge to enable specifications of system architecture and ultimate engineering solutions at any of six levels.

development, and deployment of technological products, services, or processes that support functional objectives and which fulfill needs. Thus, systems engineering is inherently associated with user organizations and humans in fulfillment of its objectives. The engineering of systems also involves the interaction with humans and organizations who are responsible for the physical implementation of systems. 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 who accomplish the actual realization of physical systems. Fig. 3 illustrates these conceptual interactions. The using enterprise will have various functional needs and the functional architecting and conceptual design part of a systems engineering effort is concerned with expressing these needs in the form of a functional architecture. Systems engineers are also concerned with translation of this functional architecture into a physical architecture which describes the logical breakdown of the system ultimately to be constructed in such a way that partitioning of the systems into various subsystems is then possible. Each of these subsystems should be as independent as possible and should be such that integration of them after implementation is as straightforward and feasible as possible. This physical architecture, or logical design description of the system, is next translated into an implementation architecture that provides guidance for various implementation contractors in bringing about the various subsystems, which comprise the system. This is also represented in Fig. 3, which shows the three major architectural perspectives, or views, of a system.

The products, and associated knowledge, transferred to the enterprise, or user or client, organization through the engineering of systems may represent support at three levels: product, process, or management. Within each of these three levels, new products, processes, or organizational networks and scope may be enabled. In a very large number of situations, there will be the need to integrate these within existing or legacy systems of products, processes, or management. Thus, there are six levels of support provided by systems engineering, and the role of systems integration in these is very strong, as also suggested in Fig. 3.

We can think of a physical, or more properly stated natural, science basis for systems engineering, a organizational and social science basis, and an information science and knowledge basis. The natural science basis involves primarily matter and energy processing. The organizational and social science basis involves human, behavioral, economic, and enterprise concerns. The information science and knowledge basis is often very difficult to support effectively. This is so since knowledge is not a truly fundamental quantity but one that derives from the structure and organization inherent in the natural sciences, and the organizational and social sciences. It also results from the purposeful uses to which information is to be put, and the experiential familiarity of information holders with the task at hand and the environment into which the task is imbedded such as to enable interpretation of information, within an appropriate context, as knowledge. Thus the presence of information and knowledge, as information embedded within context, in Fig. 2 is especially important. This representation stresses the major ingredients that systems engineers must necessarily deal with in their approach to the management technology that is systems engineering: the natural and physical sciences, organizations and the humans that comprise them, information and knowledge brokering, and the broad scope environment in which these are imbedded.

There are several drivers of new technologies. The natural and physical sciences provide new discoveries that can be converted into technological innovations. There must be a marketplace need for technological innovations. Knowledge perspectives enable the forecasting of the need for innovation. Innovation results when new knowledge principles are applied to produce new and different products and services, and associated knowledge practices, that fulfill a societal need. There is a need to insure sustainable development and the intergenerational and intragenerational equity considerations associated with sustainability. This leads to the notion of a technical system, an enterprise system, and a knowledge system. Management, meaning management of the environment for each of these, is needed. Thus, systems engineers often act as brokers of knowledge across the enterprises having needs for support and the various implementation specialists whose efforts results in detailed construction of innovative products and services that provide this support. Fig. 4 illustrates these interrelations. It also indicates that systems engineering knowledge is comprised of:

1) **Knowledge Perspectives**—which represent the view that is held relative to future directions in the technological area under consideration;
2) **Knowledge Principles**—which generally represent formal problem solving approaches to knowledge, generally employed in new situations and/or unstructured environments; and
3) **Knowledge Practices**—which represent the accumulated wisdom and experiences that have led to the development of standard operating policies for well-structured problems.

These interact together and are associated with learning to enable continual improvement in performance over time. It is on the basis of the appropriate use of these knowledge types

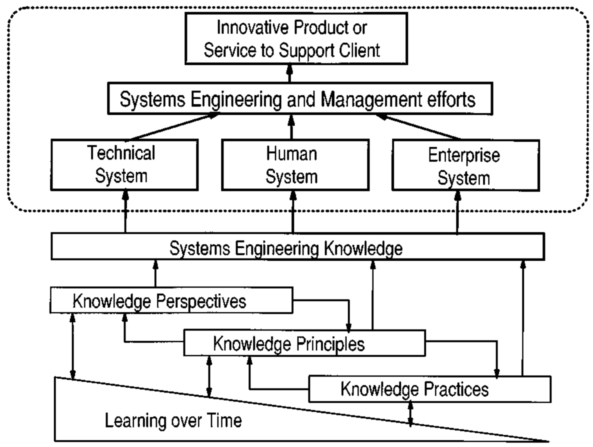

Fig. 4. Systems engineering knowledge and results of its effective use.

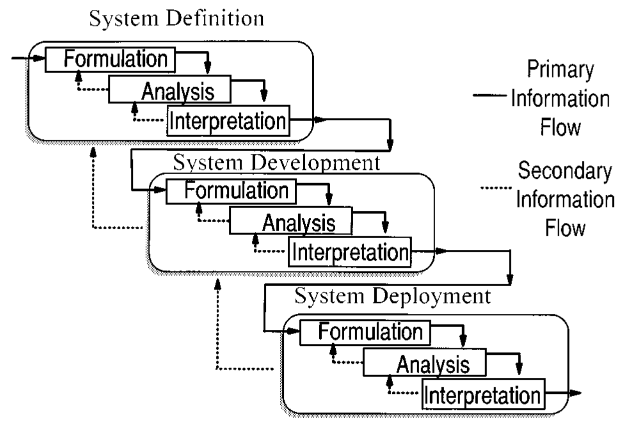

Fig. 5. A systems engineering framework comprised of three phases and three steps per phase.

that we are able to accomplish the technological system design and management system design that leads to a new innovative product or service.

We continue our discussion and definition of systems engineering by indicating one possible structural definition. Systems engineering is management technology to assist and support policymaking, planning, decision-making, and associated resource allocation or action deployment. It accomplishes this by quantitative and qualitative formulation, analysis, and interpretation of the impacts of action alternatives upon the needs perspectives, the institutional perspectives, and the value perspectives of clients to a systems engineering study. The key words in this definition are formulation, analysis, and interpretation. In fact, all of systems engineering can be thought of as consisting of formulation, analysis, and interpretation activities. We may exercise these in a formal sense, or in an as if or experientially based intuitive sense. Each of the essential phases of a systems engineering effort—definition, development, and deployment—is associated with formulation, analysis, and interpretation efforts. These enable us to define the needs for a system, develop the system, and deploy it in an operational setting and provide for maintenance over time. These are the components comprising a framework for systems engineering, as shown in Fig. 5. This framework is comprised of three phases—definition, development, and deployment—and three steps within each phase—formulation, analysis, and interpretation. This is a very aggregated representation of the systems engineering process. Generally, a more detailed representation is needed. Fig. 6, for example, represents a five phase representation of the systems engineering process. This provides a more realistic view of the efforts needed to engineer a system. It shows, for example, that one of the major activities of systems engineering is that of design. It represents the three perspectives, or views, on design and associated architecting that are taken by systems engineers:

- preliminary conceptual design and functional architecting;
- logical design or physical system architecting; and
- detailed design or implementation architecting.

A number of questions may be posed with respect to formulation, analysis, and interpretation that clearly indicate the role of values in every portion of a systems-engineering effort. Issue formulation questions of importance in this regard are the following.

- What is the problem? The needs? The constraints? The alterables?
- How do the client and the analyst bound the issue?
- What objectives are to be fulfilled?
- What alternative options are appropriate?
- How are the alternatives described?
- What alternative state of nature scenarios are relevant to the issue?

Analysis questions of importance are the following.

- How are pertinent state variables selected?
- How is the issue formulation disaggregated for analysis?
- What generic outcomes or impacts are relevant?
- How are outcomes and impacts described across various societal sectors?
- How are uncertainties described?
- How are ambiguities and other information imperfections described?
- How are questions of planning period and planning horizon dealt with?

Interpretation concerns with respect to value influence are the following.

- How are values and attributes disaggregated and structured?

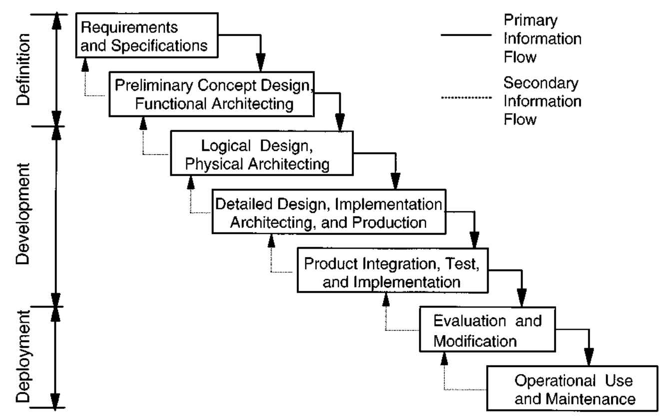

Fig. 6. One of several possible life cycle models for systems engineering.

- Does value and attribute structuring and associated formal elicitation augment or replace experience and intuitive affect?
- How are flawed judgment heuristics and cognitive information processing biases dealt with?
- Are value perspectives altered by the phase of the systems engineering effort being undertaken?

Finally, how is total issue resolution time divided between formulation, analysis, and interpretation? This is important because the allocation of resources to various systems engineering activities reflect the value perspectives of the analyst and the client. These questions associated with formulation, analysis, and interpretation need to be asked across all of the phases of systems engineering effort. This has very strong implications for the practice of systems engineering.

The efforts of some systems engineers may be primarily associated with the enterprise that ultimately is to become the client or user of the system to be engineered. They may also be associated with a systems engineering organization as an independent broker. Alternately, they may be associated with technical direction and management of the implementation system detailed design, production, and maintenance. Fig. 7 illustrates the primary involvement of these three major stakeholders in the engineering of a system. Often lifecycles are represented in a "V" fashion where the "downstroke" activities are associated with decomposition of the effort into smaller and smaller components, realization of the components at the bottom of the downstroke, and then an "upstroke" effort that is comprised of various integration efforts to form the complete system. The major efforts of the enterprise or user group is in conceptualizing the need for a system. The major efforts of an independent system engineering organization are in developing physical architectures for the system, and in taking on configuration control and management roles relative to implementation of the system. The major roles of implementation contractors include realization of the system. These roles are not mutually exclusive and they overlap over time and across the several phases of activity in engineering the system, rather than the seemingly abrupt transitions of activity shown in Fig. 7.

By adopting the management technology of systems engineering and properly applying it, we become very concerned with making sure that correct systems are engineered, and not just that the system is correct according to some potentially ill-conceived notions of what the system should do. To ensure that **correct systems are engineered** requires that considerable emphasis be placed on the front-end of the systems lifecycle. It also requires attention to various verification and validation efforts that ensure that the engineered system satisfies not only the technological specifications (verification that the system is correct) but that it performs in a manner such as to satisfy user needs (validation that it is a correct system) as well.

To support these ends, there needs to be considerable emphasis on the accurate definition of a system, what it should do, and how people should interact with it before one is produced and implemented. In turn, this requires emphasis upon conformance to system requirements specifications, and the development of standards to insure compatibility and integratibility of system products. Such areas as documentation and communication are important in all of this. Thus, we see the need for the technical direction and management technology efforts that comprise systems engineering across all phases associated with engineering a system.

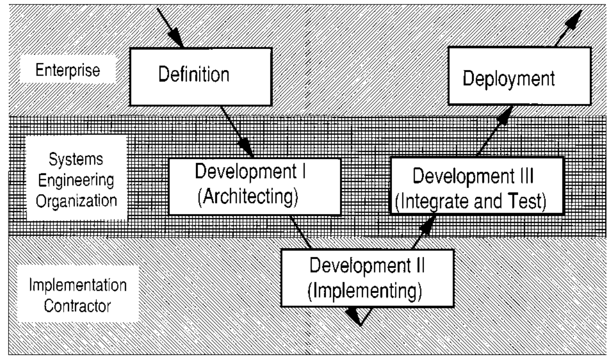

Fig. 7. "V" representation of the systems engineering process illustrating major roles for three primary stakeholders in the engineering of a system.

II. Knowledge in Systems Engineering

Clearly, one form of knowledge leads to another. Knowledge perspectives may create the incentive for research that leads to the discovery of new knowledge principles. As knowledge principles emerge and are refined, they generally become imbedded in the form of knowledge practices. Knowledge practices are generally the major influences of the systems that can be acquired or fielded. These knowledge types interact together, as suggested in Fig. 4, which illustrates how these knowledge types support one another. In a nonexclusive way, they each support one of the principle lifecycles associated with systems engineering. Knowledge practices are generally very much associated with the acquisition, or manufacturing, or production, of new systems. Knowledge principles are very much associated with the fundamental knowledge that is needed for research and development, and knowledge perspectives suggest systems planning and marketing directions. These knowledge forms flow naturally from one to the other and Fig. 4 also illustrates a number of feedback loops that are associated with learning to enable continual improvement in performance over time.

The use of the term knowledge is very purposeful here. It has long been regarded as essential in systems engineering and management to distinguish between data and information. Information is generally defined as data that is of value for decision making. For information to be successfully used in decision making, it is necessary to associate context and environment with it. The resulting information, as enhanced by context and environment, results in knowledge. Appropriate information management and knowledge management are each necessary for high quality systems engineering and management.

It is on the basis of the appropriate use of the three knowledge types depicted in Fig. 3, that we are able to accomplish the technological system planning and development and the management system planning and development, that lead to a new innovative product or service. All three types of knowledge are needed. The environment associated with this knowledge needs to be managed, and this is generally what is intended by use of the term knowledge management. Also, the learning that results from these efforts is very much needed, both on an individual and an organizational basis.

As indicated in [1]–[3], and the references contained therein, there are three different primary systems engineering lifecycles for technology growth and change:

- System Planning and Marketing
- Research, Development, Test and Evaluation (RDT&E), and
- System Acquisition, Production, or Procurement.

These are each generally needed, and each primarily involves use of one of the three types of knowledge. There are a number of needed interactions across these lifecycles for one particular realization of a system acquisition lifecycle. It is important that efforts across these three major systems engineering lifecycles be integrated. There are many illustrations of efforts that were dramatically successful efforts in RDT&E, but where the overall results represent failure because of lack of consideration of planning, or of ultimate manufacturing needs of a product while it is in RDT&E.

In our definition of systems engineering, we indicated that systems engineers are concerned with the appropriate

- **definition**,
- **development**, and
- **deployment** of systems.

These comprise a set of phases for a systems engineering lifecycle, as illustrated in Fig. 5. There are many ways to characterize the lifecycle phases of systems engineering processes, and a considerable number of them are described in [1]–[3]. Each of the lifecycle models, and those with are outgrowths of them, are comprised of these three phases. For pragmatic reasons, a typical lifecycle will contain more than three phases, as we shall soon indicate.

III. The Importance of Technical Direction and Systems Management

In order to resolve large scale and complex problems, or to manage large systems of humans and machines, we must be able to deal with important contemporary issues that involve and require:

1) many considerations and interrelations;
2) many different and perhaps controversial value judgments;
3) knowledge from several disciplines;
4) knowledge at the levels of principles, practices, and perspectives;
5) considerations involving definition, development, and deployment of systems;
6) considerations that cut across the three different lifecycles associated with systems planning and marketing, RDT&E, and system acquisition or production;
7) risks and uncertainties involving future events which are difficult to predict;
8) a fragmented decision making structure;
9) human and organizational need and value perspectives, as well as technology perspectives; and
10) resolution of issues at the level of institutions and values as well as the level of symptoms.

Those involved with the professional practice of systems engineering must use of a variety of formulation, analysis, and interpretation aids for evolution of technological systems and management systems. Clients and system developers alike need this support to enable them to cope with multifarious large-scale issues. This support must avoid several potential pitfalls. These include the following 12 deadly systems engineering transgressions.

1) There is an over-reliance upon a specific analytical method or tool, or a specific technology, that is advocated by a particular group.
2) There is a consideration of perceived problems and issues only at the level of symptoms, and the development and deployment of "solutions" that only address symptoms.
3) There is a failure to develop and apply appropriate methodologies for issue resolution that will allow identification of major pertinent issue formulation elements, a fully robust analysis of the variety of impacts on stakeholders and the associated interactions among steps of the problem solution procedure, and an interpretation of these impacts in terms of institutional and value considerations.
4) There is a failure to involve the client, to the extent necessary, in the development of problem resolution alternatives and systemic aids to problem resolution.
5) There is a failure to consider the effects of cognitive biases that result from poor information processing heuristics.
6) There is a failure to identify a sufficiently robust set of options, or alternative courses of action.
7) There is a failure to make and properly utilize reactive, interactive, and proactive measurements to guide the systems engineering efforts.
8) There is a failure to identify risks associated with the costs and benefits, or effectiveness, of the system to be acquired, produced, or otherwise fielded.
9) There is a failure to properly relate the system that is designed and implemented with the cognitive style and behavioral constraints that effect the user of the system, and an associate failure of not properly designing the system for effective user interaction.
10) There is a failure to consider the implications of strategies adopted in one of the three lifecycles (RDT&E, acquisition and production, and planning and marketing) on the other two lifecycles.
11) There is a failure to address quality issues in a comprehensive manner throughout all phases of the lifecycle, especially in terms of reliability, availability, and maintainability.
12) There is a failure to properly integrate a new system together with heritage or legacy systems that already exist and which the new system should support.

Systems engineers take on technical roles associated with the engineering of systems. They take on management roles associated both with identification of appropriate processes and with technical direction of implementation efforts and associated overall configuration control. They take on roles associated with management of the environment surrounding the engineering of systems. Failures can occur in any of these. Most of the failures are generally associated with systems management failures.

In general, we may approach issues from an inactive, reactive, interactive, or proactive perspective.

- ***Inactive***—This denotes an organization that does not worry about issues and which does not take efforts to resolve them. It is a very hopeful perspective, but generally one that will lead to issues becoming serious problems.
- ***Reactive***—This denotes an organization that will examine a potential issue only after it has developed into a real problem. It will perform an outcomes assessment and after it has detected a problem, or failure, will diagnose the cause of the problem and, often, will get rid of the symptoms that produce the problem.
- ***Interactive***—This denotes an organization that will attempt to examine issues while they are in the process of evolution such as to detect them at the earliest possible time. Issues that may cause difficulties will not only be detected, but efforts at diagnosis and correction will be implemented as soon as they have been detected. This will involve detect of problems as soon as they occur, diagnose of their causes, and correction of difficulty through recycling, feedback and retrofit to and through that portion of the lifecycle process in which the problem occurred. Thus, the term interactive is, indeed, very appropriate.
- ***Proactive***—This denotes an organization that predicts the potential for debilitating issues and which will synthesize an appropriate lifecycle process that is sufficiently mature such that the potential for issues developing is as small as possible.

It should be noted that there is much to be gained by a focus on process improvements in efforts from any of the last three perspectives. While proactive and interactive efforts are associated with greater capability and process maturity that are reactive efforts, reactive efforts are still needed [2]. Inactivity is associated with failure, in most cases.

Management of systems engineering processes, which we call ***systems management***, is very necessary for success. There are many evidences of systems engineering failures at the level of systems management. Often, one result of these failures is that the purpose, function, and structure of a new system are not identified sufficiently before the system is defined, developed, and deployed. These failures generally cause costly mistakes that could truly have been avoided. Invariably this occurs because either the formulation, the analysis, or the interpretation efforts (or all of them perhaps) are deficient. A major objective of systems engineering, at the strategic level of systems management, is to take proactive measures to avoid these difficulties. Contemporary efforts in ***systems engineering*** contain a focus on: tools and methods, and technologies for the engineering of systems, and associated metrics; systems methodology for the lifecycle process of definition, development and deployment that enables appropriate use of these tools, methods, and technologies; and systems management approaches that enables the proper imbedding of systems engineering product and process evolution approaches within organizations and environments. In this way, systems engineering and management provides very necessary support to the role of conventional and classical engineering endeavors through the implementation of various physical systems architectures as useful technological products. Fig. 1 attempts to show this conceptual model of systems engineering.

System management and integration issues are of major importance in determining the effectiveness, efficiency, and overall **functionality** of system designs. To achieve a high measure of functionality, it must be possible for a system, meaning a product or a service, to be **efficiently** and **effectively** produced, used, maintained, retrofitted, and modified throughout all phases of a lifecycle. This lifecycle begins with need conceptualization and identification, through specification of system requirements and architectures, to ultimate system installation, operational implementation or deployment, evaluation, and maintenance throughout a productive lifetime. It is important to note that a system, product or service, that is produced by one organization may well be used as a process, or to support a process, by another organization.

Virtually all studies of the engineering of systems show that the major problems associated with the production of trustworthy systems have more do with the ***organization and management of complexity*** than with direct technological concerns that affect individual subsystems and specific physical science areas. Often the major concern should be more associated with the definition, development, and use of an appropriate process, or product line, for production of a product than it is with the actual product itself, in the sense that direct attention to the product or service without appropriate attention to the process leads to the fielding of a low quality and expensive product or service.

IV. Lifecycle Methodologies, or Processes, for Systems Engineering

As we have noted, systems engineering is the creative process through which products, services, or systems that are presumed to be responsive to client needs and requirements are conceptualized or specified or defined, and ultimately developed and deployed. There are at least twelve primary assertions implied by this not uncommon definition of systems engineering, and they apply to the development of software intensive systems, as well as to hardware and physical systems.

1) Systems planning and marketing is the first strategic level effort in systems engineering. It results in the determination of whether or not a given organization should undertake the engineering of a given product or service. It also results in a, at least preliminary, determination of the amount of effort to be devoted to RDT&E and the amount to actual system acquisition or production.
2) Creation of an appropriate process or product line for RDT&E and one for acquisition is one result of system planning and marketing. The initial systems planning and marketing efforts determine the extent to which RDT&E is a need, and also determine the acquisition process characteristics that are most appropriate.

3) An appropriate planning process leads to efficient and effective RDT&E, and to the actual system acquisition which follows appropriate RDT&E.
4) The first phase of any systems engineering lifecycle effort results in the identification or definition of specifications for the product or service that is to result from the process.
5) Systems engineering is a creative process based effort.
6) Systems engineering activities are conceptual in nature at the initial phases of effort, for either of the three generic lifecycles, and become operational in later phases.
7) A successful systems engineering product or service must be of high quality and responsive to client needs and requirements.
8) A successful systems engineering product, or service, generally results only from a successful systems engineering process.
9) An appropriate systems engineering process is, generally, the result of successful systems management, and appropriate planning and marketing.
10) Appropriate systems engineering efforts need necessarily be associated with systematic measurements to insure high quality information as a basis for decision making across the three generic systems engineering lifecycles.
11) Appropriate systems engineering efforts are necessarily attuned to organizational and environmental realities as they affect both the client organization and the systems engineering organization.
12) Systems engineering efforts are, of necessity interactive. However, they transcend interactivity to include proactivity.

Good systems engineering practice requires that the systems engineer be responsive to each of these twelve ingredients for quality effort. Clearly, not all members of a systems engineering team are responsible for, and participate in, each and every systems engineering activity.

V. Evolution of Engineering and Engineering Education

Many conventional definitions of engineering suggest that it is the application of scientific principles to the optimal conversion of natural resources into products and systems for the benefit of humankind. The notion that engineering is concerned with effective and efficient use of resources for the betterment of humankind is certainly correct. There are many constraints affecting this use and engineering is much concerned with developing solutions under constraints. Initially, these resources were considered to be natural resources. Today, they are considered to be any of the four major resources or capital, as unspent resources are often now called:

- natural resources, or natural capital;
- human resources, or human capital;
- financial resources, or financial capital; and
- information and knowledge resources, or information and knowledge capital.

This enlarged concept of resources enables us to include such important contemporary knowledge intensive efforts as biotechnology and biomedical engineering. Science, on the other hand, is primarily concerned with the discovery of new knowledge. There is no inherent notion of purpose in scientific discoveries, although obviously many scientific investigations are directed at knowledge that will be of ultimate beneficial use to humanity.

Much of the world has been transformed by technology, as evidenced in an excellent work [4] that describes the history of American invention and innovation over the century from 1870–1970. While this period of time could hardly be called the information age, Beniger [5] indicates that it was actually during this period that the essence of the contemporary information age began in America. Microelectronics and integrated circuit related efforts, including digital computers and communications, became the "glamour" technologies of the 1970s and 1980s. These technologies have produced profound impacts on society and on the engineering profession. The ease of development and the power of integrated circuits have actually changed the implementation architecture for electrical circuits and the performance characteristics of the resulting systems. This has led engineers to actively search for digital solutions to problems that are not themselves inherently digital. For example, the simulation of continuous time dynamic physical systems, such as aircraft, is now accomplished almost totally digitally, even though the physical systems themselves are continuous time systems for which much analog computer technology had been developed in the 1950s and 60s. This "digital everything" trend has resulted from the major developments in semiconductors, abilities at very large scale integration of electronic circuits, the resulting microprocessor based systems, and associated major reductions in size and cost of digital computer components and systems.

The digital revolution [6] has led to a death of distance [7], the merging of telecommunications technology and computer technology into information technology, and networked individuals and organizations. Major characteristics of this change include great speed [8]. More importantly, they enable networking and communications. They also result in the major necessity for all of engineering, especially systems engineering, to be especially concerned with social choice and value conflicts issues [9] that surround strategic management of the intellectual capital [10] as a major new form of capital resource that has been in very large part brought about by the information technology revolution and the use of information technology for organizational and societal improvement. We have seen the initial focus on data in the early days of computers shift to a focus on information and information technology in the decade of the 1990s. Now we sense the imbedding of information concerns into greater concerns that affect knowledge resources and knowledge management. Transdiciplinary issues of knowledge integration need to be addressed well if we are able to address the concerns of the early part of the 21st Century. There are many influences of these innovative changes [11] [12]. These are bringing about major changes [13] and needs for engineering education to adapt programs to these changes such that the customers of engineering education, students and employers, remain satisfied with educational product quality.

Comments on the changing environment for engineering and engineering education are commonplace and issues such as the following are often cited [14].

1) Availability of a many new engineered materials, and an associated much larger "design space" from which the engineer must choose.
2) Pervasive use of information technology in the products and processes of engineering.
3) Increasing number and complexity of constraints on acceptable engineering solutions. Where cost and functionality were once the dominant concerns, ecological and natural resource concerns, sustainability, safety, and reliability and maintainability are now also major concerns.
4) Globalization of industry and the associated shift from a nationally differentiated engineering enterprise to one that is far more global.
5) Major increases in the technical depth needed in manufacturing and service sectors, both in terms of absolute specific technical knowledge and the breadth of knowledge needed.
6) Expanded role of the engineer as part of integrated product and process teams, and the broad business knowledge required.
7) Increased pace of change in which there appears to be less time to assimilate and adapt.

Each of these, individually and particularly in combination, lead to many new challenges for engineering education, especially as they relate to the technical direction and knowledge brokerage needed to bring about trustworthy systems through systems engineering.

In one notable and particularly relevant work [15], relevant, attractive, and connected engineering education is outlined as education that results from engineering programs that undertake several important action items.

1) **Establish Individual Missions for Engineering Colleges**, such that an effective planning process that enacts a clear vision supportive of excellence drives each program.
2) **Re-Examine Faculty Rewards**, such as to identify incentives that assure commitment and which support the programmatic mission.
3) **Reshape the Curriculum** to enable relevance, attractiveness, and connectivity.
4) **Ensure Lifelong Learning** of all, supported in part by new and innovative technologies for education [16].
5) **Broaden Educational Responsibility**; such that engineering programs provide support for elementary and secondary education.
6) **Accomplish Personnel Exchanges**, such that faculty are able to obtain relevant experience in industry and government, and such that industry and government experience are able to contribute their talents to programs in engineering education.
7) **Establish Across the Campus Outreach**, such that high quality and relevant courses in engineering are made available throughout the university.
8) **Encourage Research/Resource Sharing, Open Competition Based on Peer Review, and Enhanced Technology Transfer**.

The attributes associated with reshaping the curriculum are of special importance in that these are directly focused on educating students for careers as professional engineers, for research, for planning and marketing, and for the many other functions performed by engineers. The major ingredients associated with reshaping the curriculum were suggested as:

- team skills, and collaborative, active learning;
- communication skills;
- a systems perspective;
- an understanding and appreciation of diversity;
- appreciation of different cultures and business practices, and understanding that engineering practice is now global;
- integration of knowledge throughout the curriculum a multidisciplinary perspective;
- commitment to quality, timeliness, continuous improvement;
- undergraduate research and engineering work experience;
- understanding of social, economic, and environmental impact of engineering decisions;
- ethics.

Each of these is particularly important for engineering education, and especially for systems engineering education. This is especially so in light of relevant works that examine the role of technology and values in contemporary society [17] and which stress the need for engineering to become more integrated with societal and humanistic concerns, such as to enable engineers to better cope with issues and questions of economic growth and development, and sustainability and the environment [18].

VI. Objectives for Systems Engineering Education

Engineering education is a professional activity and an intellectual activity. It is necessary that the faculty responsible for this educational delivery in engineering remain at the cutting edge of relevant technologies, including emerging technologies, as technology does change rapidly over time. Research is, therefore, an absolute essential in engineering education. It is possible through relevant research, and associated knowledge principles, to develop new engineering knowledge principles and practices that are relevant to societal improvements that result from better use of information and technological innovations. Research is exceptionally important for engineering education, as it is strongly supportive of the primary educational objective of the university. It is vital to remain vigilant relative to the educational mission, and this requires that faculty remain at the cutting edge of technology in order that they are able to provide education, meaning **teaching**, at that forefront. It is because of the need to remain current in the classroom in order to deliver education for professional practice that the strong need and a mandate for faculty research in engineering necessarily emerges.

This suggests that research activities in engineering education should generally be very student oriented. It suggests that students are an inseparable and integral part of faculty research. It suggests a major role for students in development and cooperative/internship ventures with industry and government. This creates the strong need for sponsored research and internships that assure the needed industry- government-university interactions. In addition to being intimately associated with the educational process, sponsored research also provides faculty with released time from exclusively teaching efforts for scholarly pursuits necessary to retain currency in the classroom. Also needed are innovative efforts to transfer research in emerging technologies with potential marketplace success to a position where these results are useful in system acquisition. To bring this about satisfactorily requires much attention to risk management and the necessary determination of the intersections where marketing, RTD&E and acquisition can each enjoy success.

The knowledge and skills required in engineering, and in engineering education, come from all of the sciences, and from the world of professional practice. This suggests that faculty in a professional school of engineering need to keep abreast of progress in relevant sciences, both the natural sciences and the economic and social sciences, and the mathematical and engineering sciences. Taken together, these comprise knowledge principles. It suggests also that engineering educators must keep abreast of and contribute to industrial practices in relevant professional practice areas. It is for this reason that engineering schools are and must remain ***professional schools***. This is also why close ***industry-university and government–university interactions***, becomes a most desirable, and in fact essential, part of successful, high-quality engineering education programs.

Efforts in engineering must necessarily involve likely future technological developments as well, if the customers for systems engineering education are to be satisfied. Thus, we see the need for ***knowledge practices, knowledge principles***, and ***knowledge perspectives*** in engineering education. These knowledge components, and the necessary learning to enable transition and natural evolution of one form of knowledge into the other, are very important for both technology transfer and for engineering education as they relate to engineering in general and systems engineering in particular.

A number of issues relative to engineering education are discussed in [19] and the references therein. One of the major new developments in engineering education is ***Engineering Criteria 2000*** [20], which is comprised of criteria intended to emphasize quality and preparation for professional practice. The criteria retains the traditional core of engineering, math, and science requirements. However, they also place importance on formal efforts that stress teamwork, communications, and collaboration as well as global, economic, social, and environmental awareness. They are based on the premises that:

- technology has been a driver of many of the changes occurring in society over the last several years;
- it will take on an even larger role in the future;
- the engineering education accreditation process must promote innovation and continuous improvement to enable institutions to prepare professional engineers for exciting future opportunities.

These criteria are focused on insuring competence, commitment, communications, collaboration, and the courage needed for individual responsibility. These, augmenting the usual listing of competence and assumption of individual responsibility as the two traditionally accepted key characteristics of a professional, might be accepted as the new augmented attributes of a mature professional. They should truly support the definition, development, and deployment of relevant, attractive and connected (quality) engineering education that will:

- include the necessary foundations for knowledge principles, practices, and perspectives;
- integrate these fundamentals well through meaningful design, problem solving, and decision-making efforts;
- be sufficiently practice oriented to prepare students for entry into professional practice;
- emphasize teamwork and communications, as well as individual efforts;
- incorporate social, cultural, ethical, and equity issues, and a sense of economic and organizational realities—and a sense of globalization of engineering efforts;
- instill an appreciation of the values of personal responsibility for individual and group stewardship of the natural, techno-economic, and cultural environment.
- instill a knowledge of how to learn, and a desire to learn, and to adapt to changing societal needs over a successful professional career.

The unprecedented technological advances in the information technologies of computation, communication, software, and networking create numerous opportunities for enhancing: our life quality, the quality of such critical societal services such as health and education, and the productivity and effectiveness of organizations. We are witnesses to the emergence of new human activities that demand new processes and management strategies for the engineering of systems. The major need is for appropriate management of people, organizations, and technology as a social system. Systems engineering is basically concerned with finding integrated solutions to issues that are of large scale and scope. Educational programs in systems engineering need to be especially concerned with the emergence of systems engineers who can cope with these challenges. They need especially to be concerned with: the three levels of support for systems engineering efforts—methods, tools, technologies, and metrics; processes, and systems management. They need to be especially concerned with the evolution of technological innovations through life cycle processes that involve: research, development, test, and evaluation, planning and marketing; and systems acquisition, procurement, and manufacturing. They need to be concerned with efforts that are reactive to observed deficiencies, interactive to avoid errors to the extent possible; and proactive, such as to enable the determination of processes and systems management procedures based on realistic future perspectives. They must pay critical attention to integration at the level of product, processes, and systems management; and they must be aware of the need for knowledge integration itself. Also, there is much need to be concerned with the knowledge brokerage and technical directions necessary to insure success in the engineering of trustworthy and useful large-scale systems of humans, organizations, and technologies.

Much more could be said and has been said relative to these important issues as they effect engineering education in general and systems engineering education in particular [21]–[29]. The recent Electronic Industries Association Interim Standard 731, Systems Engineering Capability Model (SECM) [30] identifies 19 focus areas for systems engineering that fall into three natural groupings, or categories: Technical, Management, and Environment. These three groupings correspond closely to the notions of product, process, and systems management described here and in [1]–[3], and elsewhere. The technical focus areas support practices which are indicative of the technical aspects of systems engineering. They generally correspond well with definitions and practices contained in two important standards for Systems Engineering, EIA 632, Processes for Engineering a System [31], and IEEE STD 1220, Trial-Use Standard for Application and Management of the Systems Engineering Process [32]. The systems management focus area practices support the technical focus areas through planning, control and information management. These are attempted to incorporate and practices from systems engineering standards with industry-wide best practices such as to enhance cost-effectiveness in the engineering of systems, or systems engineering. The environment focus areas in the SECM standard represent those practices that facilitate sustained execution of systems engineering processes throughout the systems engineering organization. These are intended to ensure alignment of process and technology development with systems engineering business objectives. These practices support the technology and management focus areas. Fig. 8 represents these 19 focus areas. These comprise a very useful set of needed abilities for systems engineers. A major goal of systems engineering education should be to provide relevant courses and laboratories that support the attainment of abilities relative to each of these focus areas. There are a variety of tools and methods that support satisfactory performance in each of these focus areas and provision of support from these will allow for incorporation of the what to do delineated so well in the standard with the how to do it that is also needed for trustworthy systems engineering. This is a never ending continuous improvement effort, as also represented in Fig. 8. In a similar way, systems engineering education is a never ending lifelong process that cuts across the three major dimensions for systems engineering effort shown in Fig. 9 and which includes appropriate lifecycle processes phases and steps within each.

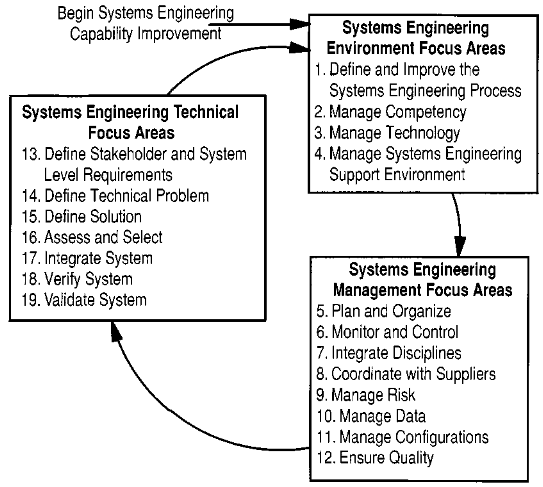

Fig. 8. Systems engineering capability model focus areas.

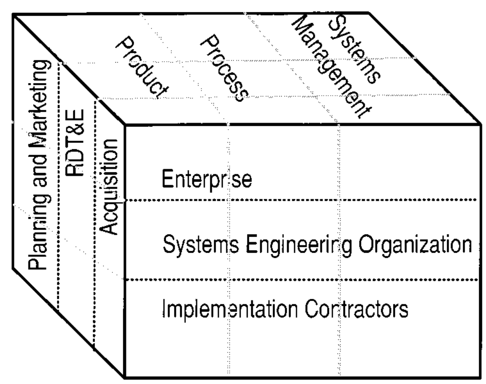

Fig. 9. One of the many possible 3-D frameworks for systems engineering.

VII. Summary

We have presented a wide scope discussion of systems engineering education. We have discussed the emergence of concerns for large systems of humans, organizations, and technologies. We have discusses some of the principles of systems engineering that need necessarily be incorporated into relevant curricula. We have stressed systems engineering education as preparation for professional practice as well as for the development of knowledge principles through research. We have focused on contemporary concerns relative to educational quality and responses to these, and educational needs and accreditation standards for the 21st Century to achieve this quality. A flow chart of interactions of systems engineering education would show a very large number of linkages across many related elements thereby indicating that engineering education itself is a system of large scale and scope. Our discussion is necessarily wide scope in that systems engineering education itself is necessarily wide scope.

A systems engineer must surely understand the principles of the natural and mathematical sciences. They must have this understanding in order know how to use these to support the definition, development, and deployment of cost effective and trustworthy systems and also to have the background necessary to retain intellectual currency throughout a lifetime of continued learning. The purpose behind the engineering of systems is the development of products, services, and processes that are successful in the marketplace through fulfillment of societal needs. Technological, organizational, and societal change are the order of the day, just as they have been throughout history. If these changes are to be truly effective and effective, over the long term especially, they must serve societal needs. This suggests that change needs necessarily to be guided by principles of social equity and justice, as well as by concerns for sustainable development and marketplace competition. There is strong evidence that this needed guidance does not always occur and that the hoped for productivity gains from technological advances may be elusive [33]–[36]. This provides the mandate for a major component of the social and behavioral sciences, and the political and policy sciences, in systems engineering education and in engineering practice as necessary ingredients for success. It also provides a mandate for major integrative knowledge components in systems engineering education and for educational accreditation standards that reflect these needs, as recognized in the reengineering efforts for education and engineering education suggested by a large number of the sources cited here. While many of these are personal references, there are a vast number of references to the excellent work of many others contained therein. These support the emergence of a multidimensional framework for systems engineering and systems engineering education, some of the many components of which have been discussed here.

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Andrew P. Sage (S'56–M'57–SM'65–F'76–LF'97) received the B.S.E.E. degree from The Citadel, Charleston, SC, the S.M.E.E. degree from MIT, Cambridge, MA, and the Ph.D. degree from Purdue University, West Lafayette, IN, the latter in 1960. He received honorary Doctor of Engineering degrees from the University of Waterloo, Waterloo, ON, Canada, in 1987 and from Dalhousie University, Halifax, NS, Canada, in 1997.

He has been a faculty member at the University of Arizona, University of Florida, and Southern Methodist University. During 1974–1984, he was Lawrence R. Quarles Professor of engineering science and systems engineering at the University of Virginia. During portions of this time, he was Associate Dean for Graduate Studies and Research, Chair of the Chemical Engineering Department, and Chair of the Systems Engineering Department. In 1984, he became First American Bank Professor of Information Technology and Engineering at George Mason University and the first Dean of the School of Information Technology and Engineering. In May 1996, he was elected as Founding Dean Emeritus of the School and also was appointed a University Professor. His initial research concerned optimization, estimation, system modeling and identification, and communications and control system design. His current interests include systems engineering and management efforts in a variety of application areas including systems integration and reengineering, software systems engineering, total quality management, cost and effectiveness assessment, and industrial ecology and sustainable development. He is the author or co-author of a number of papers in these areas as well as a number of texts that have resulted from his principal effort, which is teaching in systems engineering and management.

Dr. Sage is an elected Fellow of the American Association for the Advancement of Science, and the International Council on Systems Engineering (INCOSE). He received the Frederick Emmonds Terman Award from the American Society for Engineering Education, and an Outstanding Service Award from the International Federation of Automatic Control. He received the first Norbert Wiener Award as well as the first Joseph G. Wohl Outstanding Career Award from the IEEE Systems, Man, and Cybernetics Society. In 1994, he received the Donald G. Fink Prize from the IEEE, and a Superior Public Service Award, for his service on the CNA Corporation Board of Trustees from the U.S. Secretary of the Navy. He was Editor of the IEEE TRANSACTIONS ON SYSTEMS MAN AND CYBERNETICS for the 27 year period 1972 through 1998, and was an Editor of the IFAC Journal Automatica for the 16 year period 1981 through 1996. He is currently editor of the John Wiley textbook series on Systems Engineering, and the INCOSE Wiley journal Systems Engineering. He is also active in other scholarly editorial efforts. He was President of the IEEE Systems, Man, and Cybernetics Society for the two-year period 1984–1985. In 2000, he received the Simon Ramo Medal from the IEEE as well as a Third Millennium Medal.

6. Systems Engineering Education

Systems engineering is a professional endeavor that leads to the engineering of a system of humans, organizations and technologies through knowledge management efforts associated with bringing the perspectives of all stakeholders to the associated issues to bear. This endeavor is such as to enable the appropriate:

1. **definition** of the system to be engineered such as to achieve needed capabilities and fulfill requirements;
2. **development** of the system through appropriate architecture, design, construction to include requisition of commercial off the shelf items and manufacturing, and integration efforts; and
3. **deployment** of the system in an operational environment and associated maintenance and reengineering of it throughout a useful lifetime of trustworthy service to these stakeholders.

This definition suggests that there are a number of contemporary needs in systems engineering that act as drivers of systems engineering knowledge principles, knowledge practices, and knowledge perspectives. These have many implications for systems engineering education.

Two or more decades ago, the majority of aspiring systems engineers first learned systems engineering after they had joined the engineering workforce in a classical engineering disciplinary specialty after receiving a degree in that area. They learned systems engineering practices on the job. There are now a growing number of masters' programs and a very few bachelors and PhD programs in systems engineering. Many feel that there is limited recognition for systems thinking and little systems thinking exposure before college. However, an infusion of systems thinking and some systems engineering exposure is beginning to appear in some classical undergraduate engineering disciplinary curricula. There is still considerable divergence of views on the topic of whether systems engineering is best taught from a domain centric viewpoint or a systems engineering centric viewpoint. In this section, we wish to explore a vision for systems engineering education, beginning with its current status.

Current Status of SE Education

Over the last decade, there has been an increase in the number of systems engineering education and training programs in academia, in industry, in the several engineering societies, and in the offerings of commercial training providers. The number of universities offering graduate degrees in systems engineering has significantly increased along with the number of the degrees that have been awarded[1, 2]. A recent paper provides statistics on systems engineering education in the USA[3]. It

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[1] The INCOSE Web site, at http://www.incose.org/, provides a number of useful linkages to systems engineering education, including: certification, short courses, a job bank, careers in systems engineering, frequently asked questions, and a very useful directory of contemporary systems engineering programs throughout much of the world. It is a very useful resource.

[2] The American Society for Engineering Education (ASEE) maintains a comprehensive listing of USA based engineering education programs at http://www.asee.org/about/publications/profiles/index.cfm#Survey_of_Engineering_&_ET_Colleges

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indicates that there are (July 2005) a total of 11 BS, 27 MS, and 10 PhD programs in the USA that are exclusively systems engineering named, and 32 BS, 36 MS, and 14 PhD programs in which systems engineering is combined with some other disciplinary specialty, such as biological, computer, industrial, management, or manufacturing engineering.

As systems engineering and the classical engineering disciplines continue to evolve to meet the challenges of this new century, there are enabling changes in engineering education. And, of course, technology has the potential to be used extensively to make engineering education and research more productive.

Classical undergraduate engineering programs in a disciplinary specialty are evolving to more systems-centered disciplinary programs, often teaching approaches needed to engineer a complete system. At the graduate level we are beginning to see a continuation of this thrust as well as the evolution of innovative interdisciplinary and transdisciplinary programs. Increasingly, universities conduct capstone engineering projects with significant complexity, presenting management and technology challenges for student teams.

Distance learning and concomitant collaboration, to enable systems engineering principles and practices to become imbedded in industrial and government practices, is becoming very common. Industry and government have become more interested in systems engineering training and education. There is increasing interest in certification and certificate programs from some industry sectors.

New/Emerging Drivers and Technologies

The availability of ever-increasing computing, communicating and networking power brought about by the information technology revolution will potentially enable individuals to develop the needed information and knowledge organization skills to become “super systems engineers” who are able to quickly tap both needed domain knowledge and systems engineering tools and processes to rapidly and effectively architect, design, integrate, support, and manage complex systems of all types that involve humans, organizations, and technologies. The need to help individuals acquire these new information and knowledge organization abilities has become a new challenge for systems engineering education.

Professional organizations will face demands to conduct their events with both geographically and time-dispersed participants. As the trend toward globalization continues, interested stakeholders from many corners of the globe will want to participate without the many expenses of having to travel extensively, and thus telecommuting and networking are vital issues in professional development. Systems thinking and systems engineering will continue to improve, thereby widening the scope of the domains and areas to which they are applied, driving education to infuse systems thinking and systems engineering into many more academic disciplines, as well as in the development of transdisciplinary education in systems engineering (and systems management) itself.

There have been a number of studies of contemporary engineering education. In one noteworthy study of almost a decade ago, the changing environment for engineering and engineering education was noted and several important issues established[4]:

1) Availability of a many new engineered materials, and an associated much larger "design space" from which the engineer must choose.
2) Pervasive use of information technology in the products and processes of engineering.
3) Increasing number and complexity of constraints on acceptable engineering solutions. Where cost and functionality were once the dominant concerns, ecological and natural resource concerns, sustainability, safety, and reliability and maintainability are now also major concerns.
4) Globalization of industry and the associated shift from a nationally differentiated engineering enterprise to one that is far more global.
5) Major increases in the technical depth needed in manufacturing and service sectors, both in terms of absolute specific technical knowledge and the breadth of knowledge needed.
6) Expanded role of the engineer as part of integrated product and process teams, and the broad business knowledge required.
7) Increased pace of change in which there appears to be less time to assimilate and adapt.

Each of these, individually and particularly in combination, lead to many new challenges for engineering education, especially as they relate to the technical direction and knowledge brokerage needed to bring about trustworthy systems through systems engineering.

In another notable and particularly relevant work[5], relevant, attractive, and connected engineering education is outlined as education that results from engineering programs that undertake several important action items.

1) Establish Individual Missions for Engineering Colleges, such that an effective planning process that enacts a clear vision supportive of excellence drives each program.
2) Re-Examine Faculty Rewards, such as to identify incentives that assure commitment and which support the programmatic mission.
3) Reshape the Curriculum to enable relevance, attractiveness, and connectivity.
4) Ensure Lifelong Learning of all, supported in part by new and innovative technologies for education.
5) Broaden Educational Responsibility; such that engineering programs provide support for elementary and secondary education.
6) Accomplish Personnel Exchanges, such that faculty are able to obtain relevant experience in industry and government, and such that industry and government experience are able to contribute their talents to programs in engineering education.
7) Establish Across the Campus Outreach, such that high quality and relevant courses in engineering are made available throughout the university.
8) Encourage Research/Resource Sharing, Open Competition Based on Peer Review, and Enhanced Technology Transfer.

The attributes associated with reshaping the curriculum are of special importance in that these are directly focused on educating students for careers as professional engineers, for research, for planning and marketing, and for the many other functions performed by engineers. The major ingredients associated with reshaping the curriculum were suggested as:

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1) team skills, and collaborative, active learning;
2) communication skills;
3) a systems perspective;
4) an understanding and appreciation of diversity;
5) appreciation of different cultures and business practices, and understanding that engineering practice is now global;
6) integration of knowledge throughout the curriculum and development of multidisciplinary perspectives;
7) commitment to quality, timeliness, continuous improvement;
8) undergraduate research and engineering work experience;
9) understanding of social, economic, and environmental impact of engineering decisions; and
10) ethics.

Each of these is particularly important for engineering education, and especially for systems engineering education. This is especially so in light of the need for engineering to become more integrated with societal and humanistic concerns, such as to enable engineers to better cope with transdisciplinary issues and questions that effect technologies, humans, and organizations.

SE Education Vision

In the near term, information technology will potentially enable the delivery of just-in-time education on engineering, including systems engineering, subjects, so engineers in any discipline will be able to add relevant systems engineering information and knowledge when they need this. More undergraduate programs, both in engineering and in other fields, will include education in systems thinking and systems engineering. More graduate degree programs will also include systems thinking and systems engineering as a central component. There will continue to be a major need for postgraduate programs in systems engineering, often to complement the bachelor and master degree work in a classical disciplinary engineering specialization.

Initial experiences during the past ten years with academic programs for system engineering/product development have revealed a number of needs. Many of the advances in commercial systems engineering/product development practice have occurred in industry. Transfer of this operational knowledge and integration into academic programs has proven to be elusive. In the future we will see new arrangements to improve the integration of knowledge practices with knowledge principles.

Web-enabled information technologies used today to deliver courses leading to graduate degrees will continue to be used for that purpose with upgrades in technology as they are developed. Information chunking will become increasingly important in education and training. This will affect systems engineering education in two ways. First, systems engineering education itself will need to be “chunked” to enable just-in-time delivery to a wide variety of consumers. Second, information chunking where the same basic information can be used for a wide array of purposes will become a new required systems engineering skill.

Corporations and governments will provide more support for and cooperation in the development and delivery of systems engineering education. Systems Engineering certification will be increasingly used as a career path enhancer for some organizations.

SE Education Far-Term Vision

Engineering education is a professional activity and an intellectual activity. It is necessary that the faculty responsible for this educational delivery in engineering remain at the cutting edge of relevant technologies, including emerging technologies, as technology does change rapidly over time. Research and some exposure to hands on professional experience are, therefore, absolute essentials in engineering education. It is possible through relevant research, and associated knowledge principles, to develop new engineering knowledge principles and practices that are relevant to societal improvements that result from better use of information and technological innovations. Research is exceptionally important for engineering education, as it is strongly supportive of a primary educational objective of the university. It is vital to remain vigilant relative to the educational mission, and this requires that faculty remain at the cutting edge of technology in order that they are able to provide education, meaning teaching, at that forefront. It is because of the need to remain current in the classroom in order to deliver education for professional practice that the strong need and a mandate for faculty research in engineering necessarily emerges. This suggests that research activities in engineering education should generally be very student oriented. It suggests that students are an inseparable and integral part of faculty research. It suggests a major role for students in development and cooperative/internship ventures with industry and government. This creates the strong need for sponsored research and internships that assure the needed industry-government-university interactions. In addition to being intimately associated with the educational process, sponsored research also provides faculty with released time from exclusively teaching efforts for scholarly pursuits necessary to retain currency in the classroom.

Also needed are innovative efforts to transfer research in emerging technologies with potential marketplace success to a position where these results are useful in systems engineering. To bring this about satisfactorily requires much attention to risk management and the necessary determination of the many intersections where planning and marketing, RTD&E and system acquisition can each enjoy success. The knowledge and skills required in engineering, and in engineering education, come from all of the sciences, and from the world of professional practice. This suggests that faculty in a professional school of engineering need to keep abreast of progress in relevant sciences, both the natural sciences and the economic and social sciences, and the mathematical and engineering sciences. Taken together, these comprise knowledge principles. It suggests also that engineering educators must keep abreast of and contribute to industrial practices in relevant professional practice areas. It is for this reason that engineering schools are and must remain professional schools. This is also why close industry-university and government–university interactions, becomes a most desirable, and in fact essential, part of successful, high-quality engineering education programs.

Efforts in engineering must necessarily involve likely future technological developments as well, if the customers for systems engineering education are to be satisfied. Thus, we see the need for knowledge practices, knowledge principles, and knowledge perspectives in engineering education. These knowledge components, and the necessary learning to enable transition and natural evolution of one form of knowledge into the other, are very important for both technology transfer and for engineering education as they relate to engineering in general and systems engineering in particular.

One of the major new developments in engineering education was Engineering Criteria 2000[6], which is comprised of criteria intended to emphasize quality and preparation for professional practice. The criteria retain the traditional core of engineering, math, and science requirements. However, they also place importance on formal efforts that stress teamwork, communications, and collaboration as well as global, economic, social, and environmental awareness. They are based on the premises that:

- Technology has been a driver of many of the changes occurring in society over the last several years;
- It will take on an even larger role in the future; and
- The engineering education process must promote innovation and continuous improvement to enable institutions to prepare professional engineers for exciting future opportunities.

These criteria are focused on insuring competence, commitment, communications, collaboration, and the courage needed for individual responsibility. These, augmenting the usual listing of competence and assumption of individual responsibility as the two traditionally accepted key characteristics of a professional, might be accepted as the new augmented attributes of a mature professional. They should truly support the definition, development, and deployment of relevant, attractive and connected (quality) systems engineering education that will:

- include the necessary foundations for knowledge principles, practices, and perspectives;
- integrate these fundamentals well through meaningful design, problem solving, and decision-making efforts;
- be sufficiently practice oriented to prepare students for entry into professional practice;
- emphasize teamwork and communications, as well as individual efforts;
- incorporate social, cultural, ethical, and equity issues, and a sense of economic and organizational realities—and a sense of globalization of engineering efforts;
- instill an appreciation of the values of personal responsibility for individual and group stewardship of the natural, techno-economic, and cultural environment; and
- instill a knowledge of how to learn, and a desire to learn, and to adapt to changing societal needs over a successful professional career.

The unprecedented technological advances in the information technologies of computation, communication, and networking create numerous opportunities for enhancing: our life quality, the quality of such critical societal services such as health and education, and the productivity and effectiveness of organizations. We are witnesses to the emergence of new human activities that demand new processes and management strategies for engineering systems. The major need is for appropriate management of people, organizations, and technology as a social system.

Systems engineering is basically concerned with finding integrated solutions to issues that are complex and of large scale and scope. Educational programs in systems engineering need to be especially concerned with the emergence of systems engineers who can cope with these challenges. They need especially to be concerned with: the three levels of support for systems engineering efforts: methods, tools, technologies, and metrics; processes; and systems management. They need to be especially concerned with the evolution of technological innovations through life cycle processes that involve: research, development, test, and evaluation, planning and marketing; and systems acquisition, manufacturing, sustainment, reengineering, and retirement. They need to be concerned with efforts that are reactive to observed deficiencies, interactive to avoid errors to the extent possible; and proactive, such as to enable the determination of processes and systems

[6] Engineering Criteria 2000: Accreditation Board for Engineering and Technology, Jan. 1998.

management procedures based on realistic future perspectives. They must pay critical attention to integration at the level of product, processes, and systems management; and they must be aware of the need for knowledge integration itself. Also, there is much need to be concerned with the knowledge brokerage and technical directions necessary to insure success in the engineering of trustworthy and useful large-scale systems of humans, organizations, and technologies. These efforts will ensure the appropriate cost, schedule, and performance tradeoffs to ensure best solutions in the sense of achieving capability based performance.

In this section, we have seen that there are many "elements" that need to be architected, designed, and integrated to produce a desired system or system of systems. Today we are much concerned with "system families" that need to be integrated, and this has given rise to the notion of a “System of Systems,” and the means by which success in engineering these systems of systems can be ensured. This is a complex undertaking, and there are many evolutionary and adaptation concerns associated with this complexity. These pose many challenges for systems engineering principles and practices, and perspectives as well, and are also major challenges for systems engineering education which necessarily also must be evolutionary in nature.

There are additional challenges. Integrative knowledge, or transdisciplinarity, is much needed for resolution of many major contemporary issues in systems engineering. While one can cite many issues that seem to be based primarily in one of the established disciplines, any realistic examination of a particular issue soon takes us beyond the bounds of that specific discipline in which the issue was initially thought to be best placed. Systems engineering is an inherently transdisciplinary effort.

In order to accommodate the need for an ever-increasing depth of knowledge, there is generally a narrowing of the scope of knowledge possessed by any given individual. Thus, the oft-cited difficulty of ultimately learning absolutely all there is to know about nothing at all becomes increasingly close to a reality, as well as a near requirement for a doctoral degree in many of the highly-specialized areas in a modern university. This is a dilemma since a great many contemporary issues are associated with resolution efforts that are associated both with knowledge-depth and with knowledge-breadth. This is absolutely the case in systems engineering practice and needs to be a very important concern in systems engineering education as well.

There are potential approaches to overcoming the resulting disciplinary quagmire. One often cited approach to deal with this quandary is to use teams of knowledge workers to deal with contemporary issues. To accomplish this satisfactorily requires communications and coordination across team members, and the associated receptivity to the ideas and thoughts of others that allows for effective communications. One of the major roles of systems engineers is to act as intelligent brokers and communicators of the knowledge necessary to engineer a system from all relevant perspectives

There are many illustrations of how disciplinary fragmentation has generally resulted in individual bodies of knowledge that are, in and of themselves, unable to resolve a number of contemporary problems that are of large scale and large scope. As a result of this fragmentation, the “spheres” of knowledge of the typical disciplines show virtually no overlap. In some cases these difficulties are due to language differences across communities of knowledge workers, rather than fundamental lack of overlap of these spheres. A number of problem-solvers attempt to resolve these dilemmas. Generally, this is accomplished by looking for more fundamental contexts for research into, and associated practices for, problem-solving and systems engineering. Two potential approaches emerge. One is associated with knowledge integration such that the formerly separated disciplines are, to some extent at least, integrated. Thus, the spheres of knowledge then intersect. The extent to which the knowledge of the disciplines is integrated indicates the extent to which it can most readily be used for problem resolutions that require integrated knowledge.

Another approach is to attempt to develop an integrated knowledge process that can attempt to synthesize together relevant knowledge from different perspectives such that it can be brought to bear on problem solving and issue resolution. These two approaches are not mutually exclusive and combination of the two approaches is certainly appropriate and, in most cases, highly desirable. Systems engineering is concerned, of necessity, with each of these approaches and systems architecting in necessarily concerned with the multiple perspectives of the many stakeholders that have a “stake” in the system being engineered.

New institutional forms and frameworks may often be needed in order to bring about the transformation that will result in the needed transdisciplinarity. These frameworks will involve: humans, organizations, technologies, and environments in a way that leads to knowledge integration, knowledge process integration, or transdisciplinarity as is best appropriate in specific circumstances for resolution of contemporary issues of large scale and scope. One appropriate definition of transdisciplinarity is that it is the transformation, restructuring, and integration of knowledge from multiple perspectives such as to produce a new holistic perspective. The notion that the prefix “trans” in transdisciplinarity carries with it a process notion is an especially cogent one. This affects the various ingredients that, taken together, comprise transdisciplinary efforts: cooperation, appreciation, disaggregation or taking apart, aggregation or putting together, modification, and transformation. Ultimately, also, this will usually lead to the ability for successful knowledge generalization.

A major challenge for systems engineering team is that of the defining, developing, and deploying systems in terms of architectures. The resulting system may well be a physical product or service. It is generally rare that a completely new physical product is produced. Usually, there are a variety of legacy systems or legacy products and the “new” product must be capable of being integrated with these legacy systems. Also, products are generally used to support some organizational process and an important role in systems engineering is the engineering of appropriate processes to effectively accommodate humans, organizations, and technologies. Often, today, there is a major need for considering organizational networks and organizational scope issues in the engineering of large systems. Thus, we immediately see that all of the knowledge integration and management issues discussed here arise. Immediately, we see that systems engineering is an inherently transdisciplinary profession. This is clearly the case with respect to systems engineering education and also provides the intellectual basis for systems engineering.

The students learning systems engineering over the next two decades will be practicing their profession well into the 2040’s, 2050’s, and probably 2060’s. The increased pace of change cited by Wulf in 1997 continues to accelerate, as does the complexity of the systems or systems of systems that need to be perceptively engineered. This presents many serious but exciting challenges to systems engineering education, including:

- Keeping courses and courseware continually refreshed and up-to-date;

- Anticipating future trends (as in this Technical Vision) and preparing students to deal with them;
- Monitoring current principles and practices and separating timeless principles from out-of-date practices;
- Packaging smaller-scale educational experiences in ways that apply to large-scale projects;
- Participating in leading-edge systems engineering research and practice, and incorporating the results into the curriculum;
- Helping students learn how to learn, through state-of-the-art analyses, future-oriented educational games and exercises, and participation in research; and
- Offering lifelong learning opportunities as systems engineers continue to practice their profession.

All of these need to be implemented with concern for the fact that we are necessarily engineering complex systems families that will necessarily have evolutionary, emergent, and adaptive characteristics.

These issues are continually being addressed in the international engineering education community. Two recent reports[7, 8] describe the situation facing engineering and engineering education in the year 2020. The first of these studies suggests that the engineering profession should take the initiative in defining its future. However, to do this successfully, the report presents cogent arguments that the profession must

(1) Come to agreement a vision for its future;
(2) Transform engineering education to help achieve this vision;
(3) Establish a clear image of the resulting new roles for engineers, including becoming broad scope technology leaders and establishing this image in the perceptions of the public and prospective students;
(4) Accommodate innovative developments into engineering that arise initially in non-engineering areas; and
(5) Find approaches that will focus the energies of the different disciplines of engineering toward common agreed upon objectives that will ensure world sustainability and progress.

While the results of this study indicated that there is no consensus on strategies and tactics at this time, it was agreed that innovation is the key driver and that engineering is essential to enabling innovation. However, it was stressed that engineering will only be able to contribute to success if it is able to continue to adapt to emerging new trends and to educate the next generation of students by providing them with knowledge principles, practices and perspectives needed for the world as it will be tomorrow, and not as it is today.

In the second report, specifically on engineering education, a dedicated effort was made to answer the question, "What will or should engineering education be like today, or in the near future, to prepare the next generation of students for effective engagement in the engineering profession in 2020?" The report is very concerned with identifying approaches to enrich and broaden engineering

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[7] *The Engineer of 2020: Visions of Engineering in the New Century*, National Academy Press, Washington DC, 2004.

[8] *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, National Academy Press, Washington, DC, 2005.

education so that the products of the educational process will be better prepared to work in today's constantly changing economy. The report does discuss education after the baccalaureate degree; however, its major focus is on undergraduate education, and not graduate level education or academic research. There were fourteen major recommendations of this study relative to reengineering engineering education.

(1) The baccalaureate degree should be recognized as the "pre-engineering" degree or "bachelor of arts" in engineering degree.
(2) Engineering schools should create accredited "professional" masters degree programs intended to expand and improve the skills and enhance the ability of engineers to practice engineering. In support of this, the Accreditation Board for Engineering and Technology (ABET) should change their present policy and allow accreditation of engineering programs of the same name at both the baccalaureate and graduate levels in the same department.
(3) Engineering schools should exploit flexibilities inherent in the outcomes-based accreditation approach of ABET to experiment with novel models for engineering education. ABET should ensure that evaluators look for innovation and experimentation in curricula and not hold to a strict interpretation of the present guidelines as perceived by individual evaluators. In this way, each college and university is allowed and encouraged to develop their own plans and programs that best suit their stakeholders and then be evaluated on whether the plans are efficacious and whether the desired outcomes of this planning are achieved.
(4) The iterative process of designing, predicting performance, building and testing - should be taught from the earliest stages of the curriculum, including the first year. This supports the emergent, evolutionary, and adaptive nature of an engineering education system of systems, as noted earlier. It also encourages a broad interpretation of these iterative process activities to include early attention to associated educational benefits analysis and assessment.
(5) The engineering education establishment, potentially through the Engineering Deans Council, should endorse research in engineering education as a valued activity for engineering faculty.
(6) Colleges and universities should develop new faculty qualification standards such as, for example, to require experience as a practicing engineer. They should adapt their faculty development programs to support professional growth of engineering faculty.
(7) Engineering schools must teach engineering students how to learn, and work along with professional organizations in facilitating life long learning.
(8) Engineering schools should introduce interdisciplinary learning in undergraduate programs, rather than only having it as a possible feature of graduate programs.
(9) Engineering educators should explore the development and use of case studies of engineering successes and failures and should encourage appropriate use of case studies in undergraduate and graduate curricula. In this connection, we note current INCOSE efforts to develop systems engineering case studies.
(10) Four--year engineering schools should work with local community colleges to assure effective articulation, in as seamless as possible a manner, with 2-year community college programs.
(11) Graduate students from all over the world have flocked to the U.S. for years to take advantage of the excellent graduate education available. At the same time, they should not to neglect domestic students. Thus, U.S. engineering schools must develop programs to encourage/reward domestic engineering students to aspire to the MS and/or Ph.D. degree.
(12) Engineering schools should support national efforts at improving math, science and engineering education at the K-12 level,

(13) The engineering education profession should participate in coordinated national efforts to promote public understanding of engineering through public technology literacy.

(14) The National Science Foundation (NSF) should collect comprehensive data concerning engineering department/school program philosophy and student outcomes, such as student retention rates by gender and ethnicity, percent of entering freshman that graduate, time to degree, and information on jobs and admission to graduate school. The purpose of this would be to provide marketplace information, knowledge, and understanding across programs.

The INCOSE educational vision is generally in support of each of these efforts, and we are pleased, especially, to note activity (2) which also suggests that while accreditation of undergraduate programs in systems engineering should be strongly encouraged, graduate level accreditation should be an individual option for the concerned programs and universities at this time for those universities that have undergraduate systems engineering programs. We would also encourage that the question of graduate level accreditation for those universities that do not have undergraduate systems engineering programs be considered optional and at the discretion of the particular university and their special efforts in activities (3) and (4). While this particular report is devoted in large part to USA based engineering education, we believe that analogous statements can generally be made relative to international engineering education, including education in systems engineering.

Summary

In this section, we have presented a wide scope discussion of systems engineering education. We have discussed the emergence of concerns for large systems of humans, organizations, and technologies. We have discusses some of the principles of systems engineering that need necessarily be incorporated into relevant curricula. We have stressed systems engineering education as preparation for professional practice, and the need for faculty to have relevant contemporary hands on experience in systems engineering practice, as well as for the development of knowledge principles through research. We have focused on contemporary concerns relative to educational quality and responses to these, and educational needs and standards for the 21st Century to achieve this quality. A flow chart of interactions of systems engineering education would show a very large number of linkages across many related elements thereby indicating that engineering education itself is a system of systems of large scale and scope. Our discussion is necessarily wide scope in that systems engineering education itself is necessarily wide scope.

A systems engineer must surely understand the principles of the natural and mathematical sciences. They must have this understanding in order know how to use these to support the definition, development, and deployment of cost effective and trust-worthy systems and also to have the background necessary to retain intellectual currency throughout a lifetime of continued learning. The purpose behind engineering systems is the development of products, services, and processes that are successful in the marketplace through fulfillment of societal needs. Technological, organizational, and societal change are the order of the day, just as they have been throughout history. If these changes are to be truly effective and effective, over the long term especially, they must serve societal needs. This suggests that change needs necessarily to be guided by principles of social equity and justice, as well as by concerns for sustainable development and marketplace competition. There is strong evidence that this needed guidance does not always occur and that the hoped for productivity gains from technological advances may be elusive. This provides the mandate for a major component of the social and behavioral sciences, and the political and policy sciences, in systems engineering education and in engineering practice as necessary ingredients for success. It also provides a mandate for major integrative knowledge components in systems engineering education and for educational standards that reflect these needs, as recognized in the reengineering efforts for education and engineering education suggested by the sources cited here. These support the emergence of a multidimensional and transdisciplinary (including transinstitutional and transorganizational) framework for systems engineering and systems engineering education, some of the many components of which have been discussed here.

Systems Engineering Degree Programs in the United States

Wolter J. Fabrycky, Ph.D., P.E.
Academic Applications International, Inc.
Lawrence Professor Emeritus, Virginia Tech
Blacksburg, Virginia 24060 USA
Fab@vt.edu

Dr. Elizabeth A. McCrae
Academic Applications International, Inc.
Corporate Administrative Operations
Woodstock, Vermont 05059 USA
Info@a2i2.com

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Abstract. The authors have observed a widespread need for general information regarding the availability and characteristics of Systems Engineering (SE) academic degree programs. This paper provides a compilation of SE degree programs in the United States, giving insight regarding academic content, administrative structure, accreditation status, and establishes a benchmark for the continued advancement of these degree programs. Description and analysis is offered by the authors to set a baseline that may be utilized to assess the future of existing and developing degree programs. The model for description and analysis utilized in this paper will be extended to the international domain in the near future.

Introduction

Systems Engineering degree programs are probably the most tangible and visible connection between academic institutions and the private and public domains comprising industry and government. Programs of study leading to basic and advanced degrees provide opportunities for individuals to prepare themselves for professional practice. Programs of advanced study within academia are promulgated concurrently with creative scholarship and research projects, with the benefits awaiting recognition within industry and government. Further, at the doctoral level, degree programs and research prepare individuals for the professorial ranks.

This paper will subject Systems Engineering degree programs as a whole to a number of classifications to facilitate discussion of their similarities, differences, and characteristics. Over time, infusion of "systems thinking" into engineering curricula has been formalized in discrete courses, but Systems Engineering means different things to different people. This holds true for the meaning imparted to degree programs by academic administrators and faculty members. A degree program containing the SE designation at one institution may not be the same as a degree program with the same designation at another institution. Therefore, in considering the content of degree programs called Systems Engineering, one should go directly to the published curriculum and examine its course content.

It is encouraging to note that most schools and colleges of engineering are continually evolving their course offerings and degree requirements. Faculty members and administrators from these institutions meet periodically with corporate and governmental leaders to discover and consider changing needs. This same propensity compels most to seek formal peer approval in the form of programmatic accreditation through the Accreditation Board for Engineering and Technology (ABET). The Systems Engineering "voice" of government, industry, and even academia will grow increasingly stronger as the International Council on Systems Engineering (INCOSE) continues to emerge as the lead society for the SE body of systematic knowledge.

Categories of Systems Engineering Degree Programs

Seventy three (75) institutions in the United States offer 130 undergraduate and graduate degree programs in Systems Engineering (SE). To facilitate analysis, we partition these programs into two broad categories: *Systems Engineering Centric Programs* (see Appendix A) and *Domain Centric Systems Engineering Programs* (see Appendix B).

Systems Engineering Centric (SEC) Programs. Basic and advanced level programs leading to a bachelors or higher degree in Systems Engineering comprise a distinct category with a discipline-like focus. Included herein are only those degree programs where the concentration is designated as Systems Engineering; where SE is the intended major area of study.

There are currently 31 institutions offering 48 degree programs in the SE Centric category. The count by degree program level is given in Table 1:

Table 1. Systems Engineering Centric Programs (from Appendix A)

	BS		MS		PhD	
Program count	11	+	27	+	10	Total = 48

Domain Centric Systems Engineering (DCSE) Programs. Basic and advanced level programs leading to a bachelors or higher degrees with the major designated as X Systems Engineering, Systems and X Engineering, etc. Included in this distinct category are those degree programs naming Systems Engineering along with a parent engineering domain.

There are currently 48 institutions (4 of these duplicate institutions on the Appendix A list) offering 82 Domain Centric Systems Engineering degree programs across the array of domains summarized in Table 2.

Table 2. Domain Centric Systems Engineering Programs (from Appendix B)

	BS	MS	PhD	
SE with Biological Engineering	16	5	3	24
SE with Computer Engineering	1	4	2	7
SE with Electrical Engineering		1		1
SE with Industrial Engineering	14	15	7	36
SE with Management Engineering		3	1	4
SE with Manufacturing Engineering	1	8	1	10
Totals	32	36	14	= 82

Organization and Administration of SE Degree Programs

Not all degree programs listed in this paper are administered through the classical departmental structure of the host institution. Although most undergraduate programs are classically organized, the following variants will be found:

1. There are instances where an academic administrative unit will be the home for more than one degree program or major; e.g., Systems Engineering and Industrial Engineering. The department name may or may not subsume the names of all degree programs.
2. There are instances where the institution will offer both a SE Centric (SEC) and a Domain Centric SE (DCSE) program; e.g., Systems Engineering and Manufacturing Systems Engineering. The DCSE program may be administered in an interdepartmental mode, whereas the SEC program will usually be administered within a department.
3. In those instances where an institution offers a SEC program at the basic and advanced levels, all are usually administered within a department. This is also true for DCSE programs, except that the SE component may not exist at all degree levels.

The above variants are mentioned to emphasize that one must be aware of the administrative and organizational home for a degree program of interest. The focus in this paper is always on the degree program itself. In discussing the basic and advanced level programs in the SEC and DCSE categories, this program focus will be strengthened by recognizing that Systems Engineering is broad in nature. It cannot be viewed in the same context as the traditional engineering disciplines. This notwithstanding, many domains of engineering are seeking a better technological balance by adopting systems thinking. This is the primary reason for the rapid growth in the number of engineering domains adding a systems component to their programs

Undergraduate Programs in Systems Engineering

Forty three (43) of the 130 academic programs in Systems Engineering are at the undergraduate level (33% of the total). Eleven (11) out of the 48 (23% of the total) are SE Centric and 32 out of 82 (39% of the total) are Domain Centric SE. From this, one may infer that Systems Engineering is developing primarily at the graduate level, especially in the SE Centric category. Some cite this as evidence that SE study should requires a degree in an engineering domain as a prerequisite, with SE offered at the graduate level as a first professional degree.

With exceptions noted earlier, undergraduate degree programs in Systems Engineering are organized in departmental mode within a school or college of engineering, similar to any other academic program. The undergraduate approach to SE education is rarely interdepartmental in nature. Quite often these programs emphasize systems analysis in recognition of the demand on available time for other required courses. Synthesis and the systems engineering process is difficult to accommodate at the undergraduate level. They are normally reserved for an upper level capstone course, such as a senior design project, or for graduate study.

Programs of study at the undergraduate level are usually quite uniform for all registered engineering students. A standard curriculum is prescribed and published in the university catalog. Flexibility is usually limited by the number of electives allowed in the curriculum but, even then, the electives must be selected from approved lists. Development and modification of the curriculum is typically the responsibility of a departmental curriculum committee. University-wide curriculum review is normally used to review recommendations of the departmental committee against university curriculum policies. Outside review is popular at the undergraduate level, taking the form of oversight by the Engineering Accreditation Commission (EAC) of the Accreditation Board for Engineering and Technology (ABET).

The departmental faculty is usually a closely-knit working group who teach the program to students in residence. There are few instances of undergraduate programs being offered off-campus, although some undergraduate courses are offered by distance learning methods.

An example of an undergraduate program in Systems Engineering from the Systems Engineering Centric (SEC) category is exhibited in Table 3. This degree program is not orientated toward any specific engineering domain. The characteristics of note are: 1) a strong foundation in mathematics, probability, and statistics as appropriate for systems modeling and analysis, 2) an almost complete absence of courses in the engineering sciences, 3) a broad list of systems analysis and computer science courses, and 4) some coursework in system design, including a capstone design project. More detail regarding this sample degree program and the courses it contains may be found at http://www.seas.virginia.edu/degree.php#undergraduate

Table 3. A Curriculum Leading to an Undergraduate Degree in Systems Engineering

First Semester			*Second Semester*		
APMA 111	Single Variable Calculus	4	APMA 212	Multivariate Calculus	4
CHEM 151	Intro. Chem. for Engr.	3	PHYS 142E	General Physics I	3
CHEM 151L	Intro. Chemistry Lab	1	PHYS 142W	Physics Workshop	1
ENGR 162	Intro. to Engineering	4	CS 101	Intro. to Computer Science	3
STS 101	Language Communication			Science Elective I	3
	in a Technological Society	3		HSS Elective	3
		15			17
Third Semester			*Fourth Semester*		
APMA 213	Ordinary Differential Eq.	4	APMA 310	Probability	3
PHYS 241E	General Physics II	3	APMA 308	Linear Algebra	3
PHYS 241W	Physics Workshop	1	SYS 202	Data and Information Engineering	3
CS 201	Software Devel. Methods	3	STS XXX	STS 2xx/3xx Elective	3
SYS 201	Systems Engr. Concepts	3		Science Elective II	3
	HSS Elective	3			15
		17			
Fifth Semester			*Sixth Semester*		
APMA 312	Statistics	3	SYS 334	System Evaluation	3
SYS 321	Deterministic Decision Models	3	SYS 360	Stochastic Decision Models	3
SYS 323	Human Machine Interface	3	SYS 362	Discrete Event Simulation	4
SYS 355	SE Design Colloquium I	1		Application Elective	3
	Technical Elective	3		Unrestricted Elective	3
	HSS Elective	3			16
		16			
Seventh Semester			*Eighth Semester*	The Engineer, Ethics, and Society	3
STS 401	Western Technology Culture	3		Systems Design II	3
SYS 421	Linear Statistical Models	4		Technical Elective	3
SYS 453	Systems Design I	3		Application Elective	3
SYS 455	SE Design Colloquium II	1		Unrestricted Elective	3
	Application Elective[(4)]	3			15
	Unrestricted Elective	3		Total Credits	128

In contrast to the SE Centric program above is an example of an undergraduate program from the Domain Centric SE (DCSE) category as exhibited in Table 4. This degree program is centric to the domain of Industrial Engineering with a systems orientation. The characteristics of note are: 1) a concentration on mathematics and statistics appropriate for systems analysis and modeling, 2) some recognition of the engineering sciences, 3) an extensive list of required Industrial Engineering courses, and 4) some coursework in system design, including a capstone senior design project. More detail regarding this sample degree program and the courses it contains may be found at http://www.usc.edu/dept/ise/academics/undergraddesc.html

Table 4. A Curriculum Leading to an Undergraduate Degree in Industrial and Systems Engineering

COMPOSITION/WRITING REQUIREMENT: 7 WRIT 140 Writing and Critical Reasoning (4) WRIT 340 Advanced Writing (3) **GENERAL EDUCATION: 20** Category III is fulfilled by PHYS/CHEM requirement **PRE-MAJOR REQUIREMENTS: 32** Mathematics Requirement MATH 125 Calculus I (4) MATH 126 Calculus II (4) MATH 226 Calculus III (4) MATH 225 Linear Algebra & Differential Equations (4) Physics Requirements PHYS 151 Fundamentals of Physics I (4) PHYS 152 Fundamentals of Physics II (4) Chemistry Elective MASC 110L Materials Science, or CHEM 105aL General Chemistry, or CHEM 115aL Advanced General Chemistry (4) Economics Requirement ECON 203 Principles of Microeconomics (4) **MAJOR REQUIREMENTS: 59** Business Course ACCT 410x Accounting for Non-Business Majors (4)	**MAJOR REQUIREMENTS (CONTINUED):** Electrical Engineering Course EE 326L Essentials of Electrical Engineering (4) Computer Science Courses CSCI 101 Fundamentals of Computer Programming (3) ISE 382 Introduction to Computer Systems, or CSCI 485 File and Database Management (3) Industrial and Systems Engineering Courses ISE 105a Introduction to Industrial & Systems Engineering (2) ISE 105b Introduction to Industrial & Systems Engineering (1) ISE 220 Probability Concepts in Engineering (3) ISE 225 Engineering Statistics I (3) ISE 232 Manufacturing Processes (3) ISE 310L Production I: Facilities and Logistics (4) ISE 330 Introduction to OR: Deterministic Models (3) ISE 331 Introduction to OR: Stochastic Models (3) ISE 370L Human Factors in Work Design (4) ISE 410 Production II: Production, Scheduling and Control (3) ISE 426 Statistical Quality Control (3) ISE 435 Discrete Systems Simulation (3) ISE 440 Work, Technology, and Organization (3) ISE 460 Engineering Economy (3) ISE 495 Senior Design Project (Fa: 1; Sp: 3) **MAJOR ELECTIVES: 10** Departmentally approved technical electives (4) Free Electives (6) **Total units required for the program: 128**

Graduate Programs in Systems Engineering

Although conducted within a school or college of engineering, graduate programs normally come under the preview of the university acting through a Graduate School. The graduate school is an administrative unit under a Dean with operating policies for graduate study established by a Graduate Committee or Council. Students pursuing a graduate degree do not have a prescribed curriculum to follow as do undergraduates. They must develop a Plan of Study for approval by an advisory committee and the Graduate School.

The candidate's academic advisory committee for the Master's degree is normally composed of three individuals, with at least two being from the faculty (five individuals for the doctorate with at least three from the faculty). The non-faculty individuals may be selected from outside the University (industry, government agency, or equivalent). The Committee Chair must be a full-time member of the faculty, usually representing the engineering domain constituting the candidate's area of concentration.

The degree candidate is responsible for selecting his or her major professor (or Chairperson) and recommending the composition of an advisory committee to the Graduate School. Accordingly, he/she would approach a faculty member who conducts a class in the subject area and who expresses a willingness to serve as major professor. A subject concentration for course selection and the choice of the topic for research and thesis is then proposed for approval.

An example of a graduate program in Systems Engineering is exhibited in Table 5. This degree program is not orientated toward any specific engineering domain. It is an example from the Systems Engineering Centric (SEC) category. The characteristics of note are: 1) a strong orientation toward system architecture, system design, and evaluation, 2) concentration on engineering depth, 3) a strong list of systems analysis and computing courses, and 4) a group project or thesis requirement spanning one full year. More detail regarding this sample degree program may be found at http://www.cse.afit.edu/page.cfm?page=13&sub=54

Table 5. A Plan of Study leading to a Master of Science Degree in Systems Engineering

A sample education plan for an 18-month thesis student follows. The core courses and thesis credits are shown where they would typically appear in a plan of study. While only one engineering depth sequence is required for graduation, students normally take at least two engineering depth sequences (Tech Elective sequences A & B) as shown below. Total required quarter credits are 72.

Short Term Review
Calculus & Linear Algebra
Object Oriented Programming Design
Dynamics Review
Computers
Total - 4 Courses

1st Quarter–Fall
SENG 520 - Systems Engineering Design, 4
CSCE 593 - Introduction to SW Engineering, 4
XXXX xxx - Mathematics Course, 4
XXXX xxx - Tech Elective A I, 4 Eng. Depth
Total - 16

2nd Quarter–Winter
SENG 640 - Systems Architecture, 4
OPER 632 - Cost Analysis for System Design, 4
XXXX xxx - Tech Elective A II, 4 Eng. Depth
XXXX xxx - Elective, 4
Total - 16

3rd Quarter - Spring
SENG 610 - Systems Eng. Management, 4
XXX xxx - Tech Elective A III, 4 Eng. Depth
XXX xxx - Elective, 4
Total - 12

4th Quarter–Summer
SENG - 799 Thesis, 4
XXXX xxx - Tech Elective B I, 4 Eng. Depth
XXXX xxx - Elective, 4
Total - 12

5th Quarter–Fall
SENG - 799 Thesis, 4
XXXX - xxx Tech Elective B II, 4 Eng. Depth
Total - 8

6th Quarter–Winter
SENG - 799 Thesis, 4
XXXX - xxx Tech Elective B III, 4 Eng. Depth
Total - 8

The capstone of the SE program is the group design project. Typically, the students form a SE team and perform a group design study to be defended orally. However, in certain situations such as exists for part time students or single student classes, an individual thesis may be performed. The group project / thesis for the GSE program will be 12 credits of SENG 799, typically spread over three or more quarters. . In any case, the team or individual works on a major project of AF interest allowing the student to apply the systems approach to a real problem in a controlled environment.

In contrast to the SE Centric (SEC) graduate program above, is an example graduate program from the Domain Centric SE (DCSE) category, exhibited in Table 6. This degree program is directed toward the domain of Manufacturing Systems Engineering. The characteristics of note are: 1) an orientation toward competitive manufacturing to be developed through four core courses, 2) some orientation toward corporate strategy for manufacturing, including agile manufacturing systems, 3) little coursework in traditional manufacturing engineering science, 4) a strong list of required manufacturing systems engineering courses, and 5) a project or research thesis, with the project having an industrial problem focus. More detail regarding this sample degree program may be found at http://www.lehigh.edu/~inmse/gradprogram/curriculum.html

Table 6. A Plan of Study Leading to a Masters of Science Degree in Manufacturing Systems Engineering.

Four Core Courses are required of all candidates for the Master of Science in Manufacturing Systems Engineering degree. These are:

MSE 421 - Technology, Operations, and Competitive Strategy
MSE 362 - Logistics and Supply Chain Management
MSE 427 - Automation and Production Systems
MSE 438 - Agile Organizations and Manufacturing Systems

Elective Courses - In addition to the core courses, students must complete at least 4 - 5 graduate level elective courses to complete the minimum 30 credit hours towards their degree. For students pursuing the thesis option the minimum number of electives is four; for students undertaking a project, the minimum number of elective courses is five. It is a requirement that at least one elective is an MSE-numbered course.

Electives are chosen by each student, in consultation with an academic adviser. Electives should be chosen which meet an individual's technical and professional development needs. Electives may be selected from graduate course offerings in the Colleges of Engineering and Applied Science and Business and Economics to provide a balance of technical and business courses in each student's program.

MSE 423 - Product Design / Analysis
MSE 431 - Marketing and the Invention to Innovative Processes
MSE 433 - Technology and the Factory of the Future
MSE 446 - International Supply Chain Management
MSE 496 - Microelectronics Manufacturing Systems and Technologies
MSE 498 - Special Topics

Project / Thesis Option - MSE degree candidates must complete either an engineering project or a research thesis. Project SE - 451) - The three credit hour project focuses on the analysis and solution to an engineering problem. It can take the form of a simulation study, development of a software package, implementing a hardware system, analyzing and/or designing a manufacturing system or modification thereof. The results of project activity should afford benefit to a company.

Interdisciplinary Graduate Programs in Systems Engineering

When an academic institution augments its traditional discipline structure with interdisciplinary centers, clusters, institutes, and programs, Systems Engineering is often included in the planning. The body of knowledge in Systems Engineering principles is gaining recognition, causing a strong demand for the SE Centric approach to augment engineering domain manifestations of SE. Under these conditions, it is essential that a SE Program Advisory Committee (SEPAC) be organized at the school or college level to represent the participating departments.

It is evident that the normal or typical graduate school administrative structure described in the prior section can accommodate degree candidates who choose to stretch their experience in Systems Engineering by incorporating interdisciplinary elements. However, faculty members from the participating departments must assume the responsibility and authority to define, develop, implement, and achieve program objectives based on stakeholder needs and inputs. This includes the establishment of program requirements pertaining to academic content (i.e., admissions criteria, course selection, student plans of study, project/thesis guidelines, final examinations/defenses, and exit criteria). This SEPAC should meet at least once each semester and be responsible not only to ensure that all academic requirements are met, but to provide ongoing review and evaluation of program output and effectiveness relative to resources allocated to the interdepartmental effort.

The SE Program Advisory Committee should consist of three to five members of the engineering faculty, one from each of the participating engineering disciplines. The faculty selected for these positions should be appointed and supported by the appropriate academic Department Head. The responsible Chairperson should be a SEPAC member with the academic rank of Associate Professor (or higher) with tenure. The Program Chairperson will work closely with the SE PAC relative to matters of an academic and programmatic nature, and with the Dean or Associate Dean of Engineering on matters of an administrative and fiscal nature.

Degree candidates enrolled in an interdisciplinary graduate program will be registered in one of the participating departments. His/her personal advisory committee should be formed under a major professor in one department. The candidate will also identify and request two other qualified individuals to serve on the advisory committee. At least one of these individuals must be a full-time member of the faculty. One other can be a professional from industry, a government agency, or equivalent, as long as there is no conflict of interest relative to inhibiting the candidate from pursuing the desired project or area of research. The committee composition should be interdisciplinary, to align with the plan of study and project topic.

There have been a number of interdisciplinary or interdepartmental degree programs established in schools and colleges of engineering as early as the 1960's. Even smaller colleges will likely find members of its faculty with the maturity and interest to collaborate in the offering of graduate study in Systems Engineering. The motivation for doing so, particularly at the Masters level, often comes from practicing engineers in the area, with encouragement from their companies and governmental agencies. With the advent of INCOSE in the 1990's, a number of academically inclined members have worked diligently to establish SE degree programs within their local institutions worldwide.

An example set of guidelines for an interdisciplinary graduate program in Systems Engineering is exhibited in Table 7. This interdepartmental initiative was established in 1968 and the first M.S. degree was awarded in 1972. Through 1995-96, more than 350 practicing engineers received their Masters degree under this interdisciplinary mode. The total to date exceeds 500. More information regarding this program is available at http://www.ise.vt.edu

Table 7. Example Interdepartmental (Interdisciplinary) Guidelines for the Masters Degree in SE

Three required courses: ENGR 5004 - The SE Process, ENGR 5105 – Applied SE, and ENGR 5904 – Project and Report or ENGR 5994 – Research and Thesis.
Four engineering domain courses: At least 12 credits from the SE oriented courses in an engineering department (i.e., AOE, CE, IE, etc.).
Other engineering domain courses: At least 6 credits from the SE oriented courses in another engineering departments.
Non-engineering courses: At least 3 credits outside of engineering.
Final oral examination: A defense of the report or thesis before an interdisciplinary committee of three with general questioning.

During 1995-96, the decision was made to shift the Systems Engineering graduate program administratively and fiscally from the Office of the Dean of Engineering to the Department of Industrial and Systems Engineering (ISE). The intent was for Systems Engineering to continue as an interdisciplinary program within the College of Engineering, with each participating department playing its former role. But, the natural dominance of the disciplines over the interdisciplinary can be problematic. Vigilance is required to maintain interdepartmental cooperation when the program focus ceases to be at the college level.

Details regarding the sample program in Table 7 (program organization, administration, academic structure and related matters) are available in the *Program Description and Charter for the Interdisciplinary Graduate Program in Systems Engineering*, July1996. It may be obtained from www.a2i2.com

Accreditation of Systems Engineering Programs

Currently there is no professional society (and no specific criteria) for accrediting academic degree programs in Systems Engineering. At present, Systems engineering programs are accredited by ABET upon request under a special or "Other" category. The SE programs now accredited in this manner are found at www.abet.org and exhibited in Table 8.

Table 8. Systems Engineering Programs Accredited Under the ABET 'Other' Category

Institution	Degree Program	Classification
Air Force Institute of Technology	M.S. in Systems Engineering	SEC
Case Western Reserve University	B.S. in Systems and Control Engineering	SEC
George Mason University	B.S. in Systems Engineering	SEC
Oakland University	B.S. in Systems Engineering	SEC
Ohio State University	B.S. in Industrial and Systems Engineering	DCSE
Rensselaer Polytechnic Institute	B.S. in Computer and Systems Engineering	DCSE
San Jose State University	B.S. in Industrial and Systems Engineering	DCSE
State University of NY at Binghamton	B.S. in Systems and Industrial Engineering	DCSE
United States Military Academy	B.S. in Systems Engineering	SEC
United States Naval Academy	B.S. in Systems Engineering	SEC
University of Arizona	B.S. in Systems Engineering	SEC
University of Arkansas at Little Rock	B.S. in Systems Engineering	SEC
University of Florida	B.S. in Industrial and Systems Engineering	SEC
University of Pennsylvania	B.S. in Systems Science and Engineering	SEC
University of Virginia	B.S. in Systems Engineering	SEC
Virginia Tech	B.S, in Industrial and Systems Engineering	DCSE
Washington University	B.S. in Systems Science and Engineering	SEC
Wright State University	B.S. in Industrial and Systems Engineering	DCSE
Youngstown State University	B.S. in Industrial and Systems Engineering	DCSE

The Accreditation Board for Engineering and Technology. The Accreditation Board for Engineering and Technology (ABET) is the professional body that accredits academic programs in engineering and engineering technology. This is accomplished through the Engineering Accreditation Commission (EAC) of ABET. Unlike bodies that accredit the entire academic institution, ABET focuses on the characteristics of programs and the products of these programs for the purpose of advancing the quality thereof. The mission of ABET is accomplished through the professional engineering societies serving as participating bodies. The International Council on Systems Engineering hopes to become a participating body very soon.

Anticipated INCOSE Role Within ABET. INCOSE aspires to become the lead professional society for accrediting Systems Engineering programs through ABET. Program criteria, now being established at the basic and advanced levels for these programs, will emphasize the process and means embraced by the INCOSE definition of Systems Engineering, as well as the need for systems thinking within the profession of engineering. INCOSE has a unique dual role to fulfill within ABET. Systems Engineering Centric (SEC) programs provide one academic population and Domain Centric SE Programs (DCSE) provide another. The latter must be pursued in cooperation with the participating bodies representing the domains of engineering.

The International Council on Systems Engineering (INCOSE) is the leading professional society with an inherent capability and keen desire to determine and implement appropriate criteria for Systems Engineering accreditation. INCOSE was founded in 1990 and is now solidly established and rapidly expanding domestically and internationally. Its activities are focused to develop, nurture, and enhance the interdisciplinary approach in the realization of successful systems via its strong and enduring ties with industry, academia, and government. In this symbiotic relationship, INCOSE will continue to:

1. Provide a focal point for dissemination of Systems Engineering knowledge.
2. Promote collaboration in Systems Engineering education and research.
3. Assure the establishment of professional standards for integrity in the practice of Systems Engineering.
4. Improve the professional status of persons engaged in the practice of Systems Engineering.
5. Encourage governmental and industrial support for research and educational programs that will improve the Systems Engineering process and its practice.

INCOSE has an opportunity and obligation to advance its interest in the quality of Systems Engineering education by offering to support the mission of ABET. The ABET opportunity is viewed by INCOSE to be critical to the advancement of SE in its own right as well as essential to the infusion of SE thinking within the domain manifestations of engineering. INCOSE desires to lead in the category of SE Centric programs and collaborate with the professional bodies now participating in ABET for Domain Centric SE programs.

Tentative Program Criteria. Criteria for the accreditation of Systems Engineering programs at the basic level are based upon the published General ABET Criteria for those institutions offering the program at the basic level. Institutions seeking accreditation for the first professional degree in Systems Engineering at the advanced level must meet the published General ABET Criteria for advanced level programs. This is in addition to the basic level criteria. INCOSE fully supports the General ABET Criteria as it applies to basic level and to advanced level accreditation, recognizing that the decision to apply for accreditation review at the basic or the advanced level is to be made by the institution. Perticipating bodies provide the criteria and institutions choose the accreditation level to be sought.

Program criteria unique to Systems Engineering emphasizes certain characteristics that must be present in the curriculum. Additionally, the program faculty must be able to impart an understanding of systems thinking by virtue of their academic preparation and professional experience. Specific criteria applicable to curriculum and to faculty currently under discussion and development and are:

1. Curriculum **-** The program must demonstrate that graduates have the ability to participate in the design and integration of effective, life-cycle balanced systems by addressing the form, fit, and function of both the product and the development process. An emphasis on system design for successful life-cycle outcomes must be present, with evidence that the curriculum provides preparation for engineering practice as part of a development team.

2. Faculty **-** Evidence must be provided to show that most of the program faculty have a personal knowledge of professional practice in Systems Engineering and analysis, including an understanding of at least one version of the systems engineering process. Faculty must have the responsibility and authority to define, develop, implement, and achieve program objectives based on stakeholder needs.

Application of Program Criteria. ABET leaves it to the institution to choose the level at which it will seek program accreditation; that is, to declare whether the first 'professional' degree for entry into the profession is to be at the undergraduate (basic) or the advanced level. Of course, opportunity for choice exists only in those program areas for which criteria have been established at both levels. The current mandate is for INCOSE to develop and implement criteria for both basic and advanced level accreditation.

INCOSE is well prepared to support ABET in the accreditation process with the appropriate resources and dedicated individuals. Many INCOSE members hold advanced degrees and all are practicing engineering professionals. All are vitally interested and committed to the quality and vision of Systems Engineering education and research.

Summary and Conclusions

Several classifications of Systems Engineering degree programs were adopted in this paper; SE Centric, Domain Centric SE, Undergraduate SEC and DCSE, Graduate SEC and DCSE at both the Masters and Doctoral levels, and finally, Interdisciplinary Graduate SE. Although elaborate, complete insight into the complexity of Systems Engineering academic degree programs would not be possible without this taxonomy. The taxonomy was then populated by a compilation of 130 degree programs offered by 75 independent institutions in the United States. The results were presented in two Appendix Tables (A and B).

It is evident that Systems Engineering education in the United States is itself a system and can be argued to bear out two qualities inherent in the systems concept; the first, a locus for innovation, malleability, and variety; the second, contemporaneous usefulness and a semblance of permanence when any particular point of perfection has been achieved. Accordingly, the authors invite consideration of other models of description and analysis that could provide classification insight beyond that offered herein.

Since cross-currents of study and professional advancement run life-long and cross all geographic and national boundaries, and the workplace is anywhere on the globe, engineers need more and more to speak each others' language. Schools and colleges of engineering in the United States are the loci for the study reported in this paper. But the effort applied must not stop there. Accordingly, the authors affirm that the rationale of this paper is solely theirs and invite educators, professional engineering societies, and individuals in industry and government to invest their best thought into the unfolding issues worldwide.

Systems Engineering has experienced rapid growth in the commercial and governmental sectors. The need for talent in SE has increased beyond the available supply, and forward-looking corporations and governmental agencies are increasingly interested in helping to alleviate the problem. We hope that the findings in this paper will contribute appropriate insight.

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APPENDICES

APPENDIX A - Systems Engineering Centric (SEC) Programs

Institution	Degree Programs
Air Force Institute of Technology	M.S. in Systems Engineering
Arlington State University	M.S. in Systems Engineering
Boston University	Ph.D. in Systems Engineering
Case Western Reserve University	B.S., M.S., Ph.D. in Systems and Control Engineering
Colorado School of Mines	M.E., M.S., Ph.D. in Engineering Systems
Cornell University	M.S. in Engineering / Systems Engineering Option
George Mason University	B.S., M.S. in Systems Engineering
George Washington University	B.S., M.S., Ph.D. in Systems Analysis and Engineering
Iowa State University	M.S. in Systems Engineering
Johns Hopkins University	M.S. in Systems Engineering
Naval Postgraduate School	M.S. in Systems Engineering
Oakland University	B.S., M.S., Ph.D. in Systems Engineering
Polytechnic University at Farmingdale	M.S. in Systems Engineering
Portland State University	M.E. in Engineering / Systems Engineering Option
Rochester Institute of Technology	M.E. in Systems Engineering
Southern Methodist University	M.S. in Systems Engineering
Southern Polytechnic State University	M.S. in Systems Engineering
Stevens Institute of Technology	M.E. in Systems Engineering
United States Military Academy	B.S. in Systems Engineering
United States Naval Academy	B.S. in Systems Engineering
University of Alabama at Huntsville	M.S.E., Ph.D. in Systems Engineering
University of Arizona	B.S., M.S., Ph.D. in Systems Engineering
University of Arkansas at Little Rock	B.S. in Systems Engineering
University of Idaho	M.E. in Systems Engineering
University of Maryland	M.S. in Systems Engineering
University of Missouri at Rolla	M.S. in Systems Engineering
University of Pennsylvania	B.S., M.S.E., Ph.D. in Systems Science and Engineering
University of Southern California	M.S. in Systems Architecture and Engineering
University of Virginia	B.S., M.S., Ph.D. in Systems Engineering
Virginia Tech	M.S., M.E. in Systems Engineering
Washington University	B.S., M.S., Ph.D. in Systems Science and Engineering

Data in these tables was obtained from *Peterson's Guide to Graduate Programs in Engineering and Applied Sciences*, Thompson Learning, 2004 and other sources. More detail is available from the authors or from http://www.a2.2.com

APPENDIX B - Domain Centric Systems Engineering (DCSE) Programs

Institution	Degree Programs
Auburn University	B.S. in Biosystems Engineering B.S., M.S. in Manufacturing Systems Engineering M.E.,M.S., Ph.D. in Industrial and Systems Engineering
Boston University	M.S. in Computer Systems Engineering
California State University at Fullerton	M.S. in Electrical Engineering / Systems Engineering Option
Clemson University	B.S. in Systems Bioengineering
Florida A and M University	B.S. in Biological and Agricultural Systems Engineering
Lehigh University	M.S. in Manufacturing Systems Engineering
Massachusetts Institute of Technology	Ph.D. in Engineering Systems
Michigan State University	B.S. in Biosystems Engineering
New Jersey Institute of Technology	M.S. in Manufacturing Systems Engineering
North Carolina A and T University	B.S. in Agricultural and Biosystems Engineering
North Dakota State University	B.S. in Agricultural and Biosystems Engineering
Northeastern University	M.S., Ph.D. in Computer Systems Engineering
Ohio State University	B.S., M.S., Ph.D. in Industrial and Systems Engineering
Oklahoma State University	B.S., M.S. in Industrial and Manufacturing Systems Engineering
	B.S., M.S., Ph.D. in Biosystems Engineering
Polytechnic University	M.S. in Information Systems Engineering and Systems Integration
Purdue University	Ph.D. in Manufacturing and Production Systems Engineering
Rensselear Polytechnic Institute	M.S. in Manufacturing Systems Engineering B.S., M.S., Ph.D. in Computer and Systems Engineering
Rutgers, The State University	B.S., M.S., Ph.D. in Industrial and Systems Engineering
San Jose State University	B.S., M.S. in Industrial and Systems Engineering
South Dakota State University	B.S. in Agricultural and Biosystems Engineering
Stanford University	M.S. in Manufacturing Systems Engineering
State University of NY at Binghamton	B.S., M.S., Ph.D. in Systems and Industrial Engineering
Tennessee Tech University	B.S. in Industrial and Systems Engineering
Texas Tech University	M.S. in Manufacturing Systems and Engineering
University of Arizona	B.S. in Agricultural and Biosystems Engineering
University of California, Davis	B.S. in Biological Systems Engineering
University of Central Florida	M.S. in Systems Engineering and Management
University of Florida	B.S., M.S., Ph.D. in Industrial and Systems Engineering
University of Hawaii at Manoa	B.S. in Biosystems Engineering
University of Houston	M.S. in Computer and Systems Engineering
University of Idaho	M.S. in Biological Systems Engineering
University of Memphis	B.S., M.S. in Industrial and Systems Engineering
University of Michigan	M.S. in Industrial Engineering with concentration in Systems
University of Michigan at Dearborn	M.S. in Industrial and Systems Engineering M.S.E. in Industrial and Manufacturing Systems Engineering
University of Minnesota	B.S. in Biosystems and Agricultural Engineering M.S. in Infrastructure Systems Engineering

University of Nebraska at Lincoln	M.S. in Biological Systems Engineering
University of Pittsburgh	M.S. in Manufacturing Systems Engineering
University of South Florida	B.S., M.S.E. in Industrial and Management Systems Engineering
University of Southern California	B.S., M.S., Ph.D. in Industrial and Systems Engineering
University of Southern Colorado	B.S., M.E. in Industrial and Systems Engineering
University of St. Thomas	M.S. in Manufacturing Systems Engineering
University of Tennessee	B.S. in Biosystems Engineering
University of Wisconsin	B.S. in Biological Systems Engineering
Virginia Tech	B.S., M.S., Ph.D. in Biological Systems Engineering B.S., M.S., Ph.D. in Industrial and Systems Engineering
Washington State University	B.S., M.S., Ph.D. in Biological Systems Engineering
Wright State University	B.S., M.S. in Industrial and Systems Engineering
Youngstown State University	B.E., M.S. in Industrial and Systems Engineering

Data in these tables was obtained from *Peterson's Guide to Graduate Programs in Engineering and Applied Sciences*, Thompson Learning, 2004 and other sources. More detail is available from the authors or from http://www.a2.2.com

Biographical Sketches

Wolter J. Fabrycky is chairman of Academic Applications International, Inc. He is also the Lawrence Professor Emeritus of Industrial and Systems Engineering at Virginia Tech and a Registered Professional Engineer in both Arkansas and Virginia. Dr. Fabrycky joined Virginia Tech in 1965 where he served as Founding Chairman of Systems Engineering, Associate Dean of Engineering, and then as Dean of Research for the University. He was named an INCOSE Fellow in 1998 and received INCOSE's Pioneer Award in 2000. Fabrycky is co-author of six Prentice Hall engineering textbooks and co-edits the Prentice-Hall International series in Industrial and Systems Engineering.

Elizabeth A. McCrae directs the Corporate Administrative Operations for Academic Applications International, Inc. She received her doctorate from Boston University in 1974, and subsequently served on the administrative staff of the Boston University School for the Arts from 1978 through 1983. In the arts arena, Dr. McCrae has been the executive administrator for Alea III, the Founding Director for Summerstrings, and served as President of the Chromatic Club of Boston. Dr. McCrae has recently taken on the challenge of collecting, organizing, updating, and communicating the national and international information database pertaining to Systems Engineering and its engineering domain manifestations.