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DEPARTMENTAL STATEMENT ON SYSTEMS ENGINEERING SCHOLARSHIP

Systems Engineering Department, Naval Postgraduate School

August 2004

This document elaborates the principles and standards of scholarship that have been adopted by the faculty of the Department of Systems Engineering at the Naval Postgraduate School. They are applicable to both students and faculty in Systems Engineering. These principles and standards are intended to:

- guide the selection and execution of research projects
- establish a basis for determining the quality of systems engineering research
- provide an objective basis for promotion and tenure decisions

Systems engineering is a relatively new discipline that is poorly understood by much of the academic community. Even the name is not universally recognized. Both “systems engineering” and “system engineering” are in widespread use. NPS has opted for the use of the term “systems engineering” as opposed to “system engineering”. An elementary definition of systems engineering has been used for years by the Total Ship Systems Engineering program and was agreed to by consensus of the 1997 Ad Hoc Committee on Systems Engineering at NPS. It can be stated as:

Systems Engineering is an integrated approach to the synthesis of entire systems, (and the processes to produce them), designed to perform tasks in what is expected to be most efficient possible manner, with each component of the system designed to function as part of a single entity.”

This definition encompasses the key elements of almost every other definition that has been presented. Alternative definitions emphasize specific aspects of the “integrated approach” or specific characteristics of the “system”, but do not alter the basic definition.

Systems engineering resides within the Graduate School of Engineering and Applied Sciences (GSEAS). The other entities within GSEAS can be described as being devoted to education in and advancement of pure sciences, applied sciences, or engineering disciplines. The pure sciences deal with the discovery and interpretation of the fundamental principles & processes that govern the behavior of the physical world. The applied sciences deal with characterization of those fundamental principles & processes and the application of those principles & processes to solve technical problems. The traditional engineering disciplines deal with the application of the fundamental principles & processes to the design, implementation, and characterization of devices to perform specific functions.

Systems engineering is distinguished from pure and applied scientific disciplines in that it does not deal with fundamental scientific principles & processes except as constraints on the possible solution space. Systems engineering is distinguished from other engineering disciplines by dealing with entities (systems) that are composed of objects that are the products of multiple engineering disciplines. Because systems engineering is fundamentally different from other scientific and engineering disciplines, it is to be expected that systems engineering scholarship is fundamentally different from the scholarship associated with the traditional disciplines.

Most organizations accept that there are at least four kinds of scholarship: scholarship of discovery, scholarship of application, scholarship of integration, and scholarship of pedagogy.

Scholarship of discovery involves investigation of fundamental principles & processes and characterization of devices and applications. Successful practice of scholarship of discovery is usually measured by publications in peer-reviewed, prestigious, scholarly journals. The more prestigious the journal, the more significant the publication is assumed to be. The scholarship of discovery is emphasized by most GSEAS departments.

Scholarship of application involves the application of engineering, scientific, and other principles and knowledge to the solution of significant problems. Successful practice of scholarship of application is usually measured in terms of customer satisfaction, if the scholarship was performed for a customer. An alternative measure of success, if permitted, is the publication of formal technical reports, monographs, or books. Scholarship of application is a significant aspect of scholarship in most GSEAS departments. However, in the traditional disciplines there is a tendency to emphasize the scholarship of discovery aspects (that often occur as a natural adjunct to scholarship of application) over the scholarship of application itself.

Scholarship of integration involves the synthesis of new concepts by the bringing together of seemingly disparate elements or the identification of previously-unrecognized relationships between concepts. Successful practice of the scholarship of integration may be measured by publication of articles in professional or trade journals or the publication of book and monographs. Scholarship of integration is definitionally multi-disciplinary. Thus, it is not a major component of the scholarship of most GSEAS department.

Scholarship of pedagogy involves investigation of methods of teaching. This may involve development of teaching materials, laboratory demonstrations, courses, curricula, degree programs, or new teaching media (e.g., asynchronous courses). It may also involve experimentation with course content or comparison of effectiveness of different teaching methods. Successful practice of the scholarship of pedagogy may be measured in several fashions. One is the permanent adoption of new courses within a curriculum or the adoption of a new curriculum or specialty track within a department. Another is the publication of articles in peer-reviewed journals devoted to technical education. Scholarship of pedagogy is a minor component of scholarship in departments with established disciplines, courses, curricula, degree programs, and teaching media. For example, there are only two thin journals (*American Journal of Physics* and *The Physics Teacher*) devoted to the scholarship of physics pedagogy, while there are hundreds of thick journals devoted to the scholarship of discovery in physics. Most GSEAS departments perform some scholarship of pedagogy, but it is not a major emphasis in any of the traditional departments.

Because the nature of systems engineering differs significantly from the traditional scientific and engineering disciplines, the nature of scholarship within the systems engineering department should be expected to differ significantly from that in other GSEAS department. SE department members should not and will not be judged by the same metrics used to judge quality of scholarship in other departments.

Systems engineering scholarship should concern systems engineering. However, this will be broadly defined. The following topics are considered by the systems engineering community to be appropriate topics of scholarship:

- Systems Engineering Process
- Systems Design
- Systems Analysis
- Systems Engineering in the Acquisition Process
- Requirements Engineering
- Complexity and Chaos in Systems Engineering
- Operations Analysis (relating to systems analysis)
- Systems Simulation and Modeling
- Reliability, Maintainability, Availability, Logistics, Supportability, etc.
- Survivability
- Human Factors
- System Safety
- System Software Engineering
- System Integration
- System Producibility
- System Quality Assurance
- Test and Evaluation
- System Cost Estimation
- Risk Assessment and Management
- Technology Assessment
- Systems Project Leadership
- Systems Engineering Pedagogy
- Control Systems
- Systems Engineering of:
 - Ship Systems
 - Combat Systems
 - Unmanned Vehicle Systems
 - Aircraft Systems
 - Land Systems
 - Space Systems
 - Networked Systems
 - Distributed Systems
 - Enterprise Systems
 - C4ISR Systems
 - Training Systems
 - Critical Infrastructure Systems
 - Military Systems
 - Societal and Governmental Systems

This list is not meant to be exhaustive. New topics can be added by majority consent of the SE department faculty.

Systems engineering is primarily an application and integration discipline. *Scholarship of discovery* should **not** be the primary emphasis of systems engineering scholarship. The

department should and will emphasize *scholarship of application* and *scholarship of integration*. This does not mean that scholarship of discovery will be ignored (all scholarship provides the opportunity for discovery), but it will not be given priority and extra significance relative to other modes of scholarship.

Because systems engineering is integrative and multidisciplinary, collaboration with other departments and disciplines is encouraged. **Scholarship in any form on any topic in which an SE department member is a co-author and that satisfies the quality of scholarship requirements relevant to the department of primary authorship will be treated as though it were a work of systems engineering.** However, systems engineering scholarship should bear some strong relationship to systems engineering. Individual scholarship on topics not recognized as relevant to systems engineering (see above) will not be counted as systems engineering scholarship simply because the scholar is a systems engineer. **Individual non-systems engineering scholarship will be weighted less heavily than systems engineering scholarship in deliberations about promotion and tenure.**

As the Department of Systems Engineering is a new department and systems engineering is a new discipline at NPS, **it is expected that there will be considerable opportunities and need for *scholarship of pedagogy* during at least the next 5 to 10 years.**

Because the scholarship emphasis of the Systems Engineering department is significantly different from that of other GSEAS (and NPS) departments, and because the Systems Engineering department intends to base promotion and tenure decisions on its own models of acceptable scholarship, it is essential that mechanisms be in place to ensure the highest quality in all work used to make such decisions. Such quality assurance is essential if the traditional disciplines are to acknowledge the Systems Engineering department's authority to set its own standards of excellence.

The following standards will apply to all forms of scholarship within the Department of Systems Engineering. **All scholarship must be documented in a formal and archival fashion.** Articles in print journals (refereed or not), articles in regular NPS publications, articles in published conference proceedings, formal NPS technical reports, chapters in books or encyclopedias, and books or monographs published by outside publishers will be considered acceptable forms of documentation. The department will establish an NPS technical report series to facilitate documentation of all scholarship. Exhibits submitted to the NPS Academic Council relevant to approval of new courses, curricula, or degree programs will be considered acceptable documentation for the scholarship of pedagogy. Viewgraph collections, e-mails, memoranda, or lecture notes will not be considered as acceptable documentation, unless advance preparation has been made to guarantee formal retention by the Department.

It is expected that a significant portion of the scholarship performed in the Systems Engineering department will be classified. **To the maximum extent possible, classified scholarship will be published in classified NPS technical reports.** If publication in any form is prohibited by the sponsor, then the sponsor must be willing to supply some evidence of the quantity and quality of the work performed, or the research cannot and will not be considered for purposes of promotion and tenure.

Quality of scholarship will be emphasized over quantity. A single large monograph that defines in detail a complete and extensive body of work or that outlines a whole new field of exploration, will be considered no less significant than a large number of small publications on the same topic. The publication-multiplying practices of submitting the same material in slightly different form to several different journals, of breaking one long article into several smaller articles, and of publishing entirely in the form of a series of short “letters”, are recognized as gamesmanship and will not be rewarded. Nor will this gamesmanship be punished. It is the author’s prerogative to publish his work as he sees fit.

Quality of scholarship will be verified. Articles published in refereed journals or books published by commercial or society presses will be assumed to be of acceptable quality. Those deemed of especial significance will be subjected to external quality checks. All significant technical reports and other forms of documentation will be subject to similar external quality checks. In the case of reports documenting reimbursable research, quality may be assumed if the sponsor extends funding beyond the initial period of performance. Written testimonials should be obtained wherever possible, but some sponsors may prefer not to make such endorsements.

The following discussion addresses the relationship of each type of scholarship to systems engineering as it is understood by those in the systems engineering department.

Scholarship of Discovery. Although scholarship of discovery will not be emphasized to the detriment of other forms of scholarship, there will be many opportunities for discovery related to systems engineering. Systems engineering is process oriented. Good systems engineering is represented by an intelligent way of approaching and solving problems, not simply by a body of knowledge. No process, no matter how thoroughly refined, can ever be perfect. There are opportunities to investigate the systems engineering process and make improvements. Investigation of modifications to the process, quantification of previously qualitative factors, development of new models, examining improved optimization strategies, and elaboration of new tools are aspects of the scholarship of discovery relevant to the systems engineering process.

For example, requirements allocation can be tied more closely to the status and rates of improvement of component technologies. This may lead to improved optimization strategies. The relationships of complexity theory, chaos theory, and catastrophe theory to systems engineering have not been adequately investigated. Are there limits to the ability to engineer complex systems that are similar to the provability limits that mathematicians have discovered in analysis? Can systems be so complex they can never be engineered to perform in predictable fashions? Systems engineering is data intensive. Computer-aided systems engineering tools can facilitate the acquisition, storage, and manipulation of systems engineering data. Existing tools need to be evaluated and new tools need to be developed.

Each of the disciplines related to systems engineering (listed above) is fertile ground for scholarship of discovery. For example, improved models for predicting reliability can be developed. New control system concepts can be invented. New insights into risk perception can be acquired. Models and tools for improving cost estimates can be developed. Better

approaches to technology assessment and prediction can be established. The short monograph on Technology Assessment for Strategic Planning and Innovation is representative of the scholarship of discovery in a systems engineering related discipline.

Scholarship of Application. In large measure, systems engineering is application. It is expected that the scholarship of application of the systems engineering process to real problems will be significant in academic systems engineering. This is represented in the decision to require completion of a design project and a project report, in lieu of a thesis in the various systems engineering degree programs. It is expected and is acceptable that some faculty will opt to conduct individual design studies or participate on Government design teams as part of their reimbursable research activities. Scholarship of application is expected to include application of any disciplines determined to be an integral part of systems engineering. It is also expected to include application of systems engineering principles and processes to any of the major systems categories listed under “Systems Engineering of:” in the list of topics above.

A thorough, detailed design of a solution to a realistic problem is an acceptable systems engineering scholarly activity. A systematic analysis of a multidisciplinary problem is also an acceptable systems engineering scholarly activity. Application of systems engineering processes to investigating or modeling a complex multidisciplinary problem is an acceptable systems engineering scholarly activity. An example of such scholarship of application is the Unconventional Weapons of Mass Destruction project that NPS has conducted for almost a decade. This project stretches across at least six major disciplines (physics, chemistry, biology, psychology, economics, and national security) and has since spun off several separate research activities. The original publication that started the funded programs, Unconventional Weapons of Mass Destruction and Terrorism, analyzed and cataloged a wide variety of previously neglected threats and provides a basis for intelligently assessing responses to deal with them.

Faculty leadership of design projects (whether by individual students, student teams, or teams of student teams – as in the Meyer Institute’s integrated project) is expected on a regular basis and should replace the traditional requirements for thesis supervision imposed by other NPS departments. Since it is planned that few systems engineering students (except those at the doctoral level) will do traditional theses, this is not only acceptable but also necessary. Failure to participate in design projects should be a negative factor in promotion and tenure considerations. However, leadership of student design projects is not a substitute for faculty research. The NPS publications that result from student design projects are significant but they will be assumed to be primarily the product of the students. Faculty co-authorship will provide evidence of project leadership, but will not be counted as primary research publications.

This does not mean that student projects cannot lead to significant faculty scholarship of application. A faculty member may perform analyses based on student inputs that extend beyond the results briefed in the students’ project reports. For example, the predecessor to the SEA program performed student projects related to access denial. Six different student teams developed notional adversary force structures aimed at denying the U. S. the ability to project power into the adversary’s region of interest. A subsequent and separate faculty research project analyzed the results of the student teams and found a consistent set of themes that any adversary might exploit. The faculty study was documented as a separate NPS report called The Enemy’s

Access Denial System. This report qualifies as an excellent example of scholarship of application that can result from student projects and was well received at the highest levels of the Department of Defense.

Scholarship of Integration. Systems engineering is recognizable by the necessity to integrate disparate concepts and/or technical disciplines into a unified and functional whole. The scholarship of integration is expected to make a contribution to overall scholarly activity in systems engineering that ranks just behind the scholarship of application (to projects). The search for and recognition of relationships between concepts or technologies previously thought unrelated is an acceptable form of scholarship in systems engineering. Similarly, solving problems or identifying the true nature of problems by bringing together pieces from multiple disciplines is equally acceptable.

One current activity in the Department of Systems Engineering involves analysis of the topics normally contained in a Combat Systems Curriculum. In practice, Combat Systems is a collection of disciplines that interact poorly with each other. They are “stovepiped”. Ideas go in the bottom of one stovepipe and come out the top, but they never cross from one stovepipe to another. This is not only unnecessary, it is counter-productive. Systems Engineering seeks to transcend the stovepipes and promote mutual interaction. The stovepipes have made it difficult to educate systems engineers that are well-versed in all aspects of Combat Systems Engineering. The NPS project is using the teaching of a time-limited sequence of combat systems courses to find and capitalize on the commonalities between stovepiped elements to provide a more comprehensive combat systems education without increasing the numbers of courses or contact hours required. The generation of the multi-volume series of textbooks on Combat Systems is one example of the kind of product that might result from scholarship of integration in Systems Engineering.

Scholarship of Pedagogy. Since the Department of Systems Engineering is endeavoring to teach systems engineering principles to its students, there is always a need for scholarship of pedagogy. Many of the current systems engineering programs are themselves experiments in teaching. Examples include the substitution of a project report for the thesis, the two-quarter intensive teaching mode of the SEA curriculum, and the Meyer Institute integrated project. All of these activities deserve closer examination to determine if the activities are successful or unsuccessful and why or why not are they successful or unsuccessful. Such study is important for the futures, as other programs are considering these activities as models for their own execution. The success or failure of the novel approach being used in the Combat Systems course sequence also deserves further investigation.

Another aspect of scholarship of pedagogy that is relevant to the Department of Systems Engineering is the development of new courses, new specialization tracks, new curricula, and even new degree programs. Such entities can be created and developed in a rather casual or haphazard fashion OR they can be developed with full considerations of requirements, functionality, and optimal performance (just like any other “system” is properly developed). Leadership and success in obtaining full approval and implementation of any of these academic entities should be considered acceptable examples of the scholarship of pedagogy and treated appropriately in promotion and tenure decisions.

Faculty investigation and experimentation in novel ways of teaching is encouraged. For example, most of the curricula could make better use of computer modeling and computer-aided engineering tools and hands-on labs could facilitate understanding many of the combat systems principles covered in the combat systems sequences. Activities associated with the incorporation of those tools and development/integration of those labs are acceptable forms of scholarship of teaching. The idea of an extended seminar to make classwork more relevant and to broaden the horizons of the students should be investigated.

Finally, let us briefly consider scholarship with respect to a future doctoral program. After consideration of shorter periods of performance and lesser quantity of output during a nominal 3-year doctoral program vice a 6-year, the scholarship standards expected of doctoral dissertation work should not vary significantly from the acceptable standards imposed for promotion and tenure of faculty. It is expected that original contributions to the scholarship of discovery, the scholarship of application, the scholarship of integration, or the scholarship of teaching would be acceptable. Most of the specific examples of scholarship related above should be deemed adequate, had they been performed by a doctoral student instead of a member of the faculty. Indeed, some of the projects described above encompass far more effort and far more product than is typically found in many doctoral dissertations.