

Global Workforce Development Projects in Software Engineering

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Two projects now underway have the potential to significantly improve the worldwide software engineering workforce. The Integrated Software and Systems Engineering Curriculum Project (ISSEC) recently published *Graduate Software Engineering 2009 (GSWE2009): Curriculum Guidelines for Graduate Degree Programs in Software Engineering*. Initially sponsored by DoD with over 40 authors, the IEEE Computer Society and the Association for Computing Machinery now maintain and evolve GSWE2009 with support from the International Council on Systems Engineering (INCOSE). The second project, Body of Knowledge and Curriculum to Advance Systems Engineering (BKCASE), is creating two products: a body of knowledge for systems engineering and guidelines for a professional master's degree in systems engineering. Both the body of knowledge and the reference curriculum will incorporate software engineering as appropriate, to reflect the critical importance that software plays in modern systems. DoD, INCOSE, IEEE Systems Council, and IEEE Computer Society Educational Activities Board support and participate in BKCASE. Together, the products of ISSEC and BKCASE should accelerate the collaboration and potential integration of the systems and software engineering workforces.

Improvements in the software engineering workforce that support the DoD and its contractor community depend, in part, on the strength of community agreements on how to educate, guide, inform, evaluate, and certify the workforce. Two projects with broad community involvement are providing some of those agreements:

- 1) ISSEC
- 2) BKCASE

ISSEC Summary

ISSEC was launched by Art Pyster at the Stevens Institute of Technology (Stevens) in 2007 with DoD sponsorship and a coalition from academia, industry, government and professional societies providing authors. In September 2009, its more than 40 authors published version 1.0 of a reference curriculum that reflects current development practices and the greater role of software in today's systems. The report, titled *Graduate Software Engineering 2009 (GSWE2009): Curriculum Guidelines for Graduate Degree Programs in Software Engineering* [1], is available at <http://www.gswe2009.org>. Two companion documents followed in November 2009, Comparisons of GSWE2009 to Current Master's Programs in Software Engineering and Frequently Asked Questions on Implementing GSWE2009. Both are also available on the GSWE2009 website.

ISSEC continues today, focused on aiding dissemination and adoption of GSWE2009.

The IEEE Computer Society and the Association for Computing Machinery (ACM) have recently signed a copyright transfer agreement with Stevens to become the owners and primary sponsors of GSWE2009. The two professional societies now assume responsibility for evolving and maintaining the guidelines to the same level that they manage curriculum guidelines in other disciplines. INCOSE is playing a supporting role in the evolution of GSWE2009. Stevens and a number of the original author team members maintain purview over the two companion documents.

BKCASE Summary

BKCASE began in September 2009 under the joint leadership of Art Pyster from Stevens and Dave Olwell from the Naval Postgraduate School. As did ISSEC earlier, BKCASE has enjoyed strong support from both DoD and INCOSE since the project began. The IEEE Systems Council and the IEEE Computer Society Educational Activities Board offered their support for BKCASE in November 2009. As of the writing of this paper, BKCASE has 45 authors from 10 countries, and is supported by over a hundred reviewers.

BKCASE will produce two primary products:

- 1) **Systems Engineering Body of Knowledge (SEBoK— pronounced "sea" "Bach")**
- 2) **Graduate Reference Curriculum for Systems Engineering (GRCSE— pronounced "Gracie")**

In the second half of 2010, BKCASE will publish version 0.25 of both the SEBoK and GRCSE. Version 1.0 will follow sometime in 2012. BKCASE will, quite naturally, turn to SEBoK for the material that should be included in GRCSE. Both products will incorporate substantial aspects of software engineering, which will help bridge the historical gap between professional software and systems engineers.

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The ISSEC Project

In 1989 the SEI of Carnegie Mellon University published a landmark report on graduate education in software engineering [2]. Several universities used the recommendations in that report to establish their software-engineering degree programs. Since then, the way software is developed has changed dramatically, yet little effort has been made to foster further implementation and update the Software Engineering Institute's (SEI) original recommendations for graduate education in software engineering [2].

In 2007, Kristen Baldwin, then Deputy Director for Software Engineering and System Assurance of the Office of the Under Secretary of Defense Acquisition, Technology and Logistics, approached Art Pyster of Stevens Institute regarding the findings of a software industrial base study that had been conducted at the request of the Office of the Secretary of Defense. The study reflected that software drives the performance of almost all major military systems today and the development phase of any major system typically involves substantial amounts of software development. The study found a critical shortage of trained senior-level software talent required by the complex, software-intensive systems developed and forecasted by the Department of Defense.

Baldwin and Pyster concluded that a critical long-term strategy for the DoD was to ensure a strong and relevant foundation for training and education of senior software talent through establishment of a reference curriculum that would represent the fundamentals of software engineering as well as address the current challenges of scale, complexity, and criticality. Based on these conclusions, ISSEC began.

ISSEC built GSwE2009 on the SEI curriculum plus those of other initiatives, such as the Guide to the Software Engineering Body of Knowledge (SWEBOK) [3] and Software Engineering 2004: Curriculum Guidelines for Undergraduate Degree Programs in Software Engineering [4]. ISSEC followed an iterative, evolutionary approach in creating the guidelines, beginning with the formation of a Curriculum Author Team (CAT). First established in July 2007, the CAT is a collection of invited experts from industry, government, academia, and professional associations. CAT membership grew as GSwE2009 matured. In addition to representatives from the ACM, IEEE Computer Society, and INCOSE, ISSEC had the benefit of authors from the Brazilian Computer Society and the U.S. National Defense Industrial Association Systems Engineering Division.

Originally, GSwE2009 was known as GSwERC, which stands for Graduate Software Engineering Reference Curriculum. The CAT released GSwERC 0.25 in February 2008, GSwERC 0.5 in October 2008, and GSwE2009 1.0 in September 2009. The software engineering community was invited to review versions 0.25 and 0.5 to provide the necessary feedback to develop version 1.0. The review of version 0.5 generated more than 800 individual review comments, which were adjudicated for use in creating version 1.0. The

detailed comments and their adjudication can be found on the GSwE2009 website.

GSwE2009 Content

GSwE2009 includes the following elements:

- >> **A set of outcomes to be fulfilled by a student who successfully completes a graduate program based on the curriculum**
- >> **A set of student skills, knowledge, and experience assumed by the curriculum, not intended as entrance requirements for a specific program, but as the starting point for the curriculum's outcomes**
- >> **An architectural framework to support implementation of the curriculum**
- >> **A description of the fundamental or core skills, knowledge, and practice to be taught in the curriculum to achieve the outcomes. This is termed a Core Body of Knowledge (CBOK) and includes topic areas and the depth of understanding a student should achieve**

A university considering the creation or modification of a graduate software engineering program should be able to use the CBOK and the architectural framework to design appropriate courses and degree requirements. The outcomes and entrance assumptions should help in determining the expected market and value of the program to potential students and their employers.

In addition, GSwE2009 includes the following:

- >> **The fundamental philosophy for GSwE2009 development as described in a set of guiding principles**
- >> **A discussion of how GSwE2009 will evolve to remain effective**
- >> **A mapping of expected outcomes to the CBOK and to the total GSwE2009 program recommendations**
- >> **A description of Knowledge Areas discussed in GSwE2009 that are not yet fully integrated into the current version of the SWEBOK**
- >> **Glossary, references, and other supporting material**

Expected Student Outcomes

Graduates of a master's program that satisfies GSwE2009 will do the following:

- >> **Master the CBOK**
- >> **Master software engineering in at least one application domain, such as finance, medical, transportation, or telecommunications; and one application type, such as real-time, embedded, safety-critical, or highly distributed systems. That mastery includes understanding how differences in domain and type manifest themselves in both the software and the engineering of the software, and includes understanding how to learn a new application domain or type**

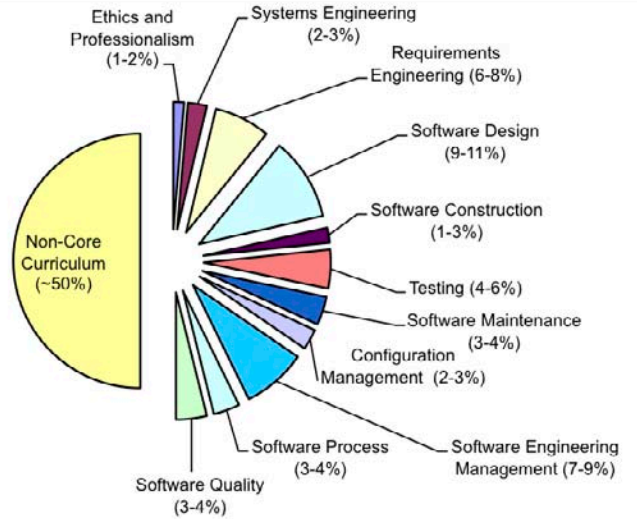
- >> Master at least one Knowledge Area or sub-area from the CBOK to at least the Bloom Synthesis level [5]
- >> Be able to make ethical professional decisions and practice ethical professional behavior
- >> Understand the relationship between software engineering and systems engineering and be able to apply systems engineering principles and practices in the engineering of software
- >> Be an effective member of a team, including teams that are international and geographically distributed; effectively communicate both orally and in writing; and lead in one area of project development, such as project management, requirements analysis, architecture, construction, or quality assurance
- >> Be able to reconcile conflicting project objectives, finding acceptable compromises within limitations of cost, time, knowledge, existing systems, and organizations
- >>> Understand and appreciate feasibility analysis, negotiation, and good communications with stakeholders in a typical software development environment, and be able to perform those tasks well; have effective work habits; and be a leader
- >> Be able to learn new models, techniques, and technologies as they emerge, and appreciate the necessity of such continuing professional development
- >> Be able to analyze a current significant software technology, articulate its strengths and weaknesses, compare it to alternative technologies, and specify and promote improvements or extensions to that technology

Core Body of Knowledge

The CBOK includes all of the fundamental or core skills, knowledge, and experience to be taught in the curriculum to achieve the expected student outcomes. The primary source for developing the CBOK was the SWEBOK. Knowledge elements were also derived from the Software Engineering 2004 curriculum guidelines [4], the INCOSE Guide to Systems Engineering Body of Knowledge [6] and especially the INCOSE Systems Engineering Handbook [7].

Figure 1 shows the knowledge elements of CBOK and their expected relative proportions of the GSwE2009 curriculum. Although specific systems engineering knowledge elements only represent 2–3% of the CBOK, they are considered a cross-cutting concern that arises in many other areas. For example, systems engineering material would also be covered under requirements engineering, testing, configuration management and project management.

Figure 1. CBOK knowledge elements as percentages of GSwE2009 curriculum

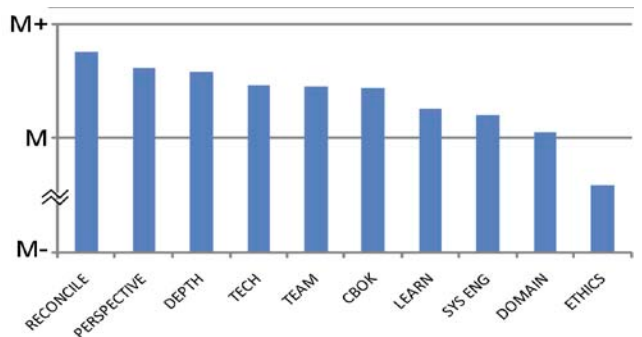


Companion Reports

In addition to GSwE2009, ISSEC has published two companion reports on its website: Comparisons of GSwE2009 to Current Master’s Programs in Software Engineering and Frequently Asked Questions on Implementing GSwE2009. The latter report is intended to help schools establish or modify a graduate software engineering program to align with the new curriculum recommendations.

The comparison report provides information on about a dozen current programs. Since most programs have alternative tracks, two or three hypothetical students from each of these schools are described. Using the courses in their individual programs, an assessment is made of each student’s ability to achieve the new recommended outcomes. While all programs compare fairly well, all had areas where they could improve. For example, most programs do not cover ethics or systems engineering topics as thoroughly as recommended by GSwE2009.

Figure 2. Average Outcome Fulfillment



Comparison of GSwE2009 Guidance and Actual Programs

GSwE2009 comparisons were performed in collaboration with representatives of 12 currently offered software engineering programs, nine from North America. The focus was on comparison of the 10 GSwE2009 outcomes with the expected outcomes currently attained by up to three diverse, hypothetical, but typical, students from each program. Many interesting facts were learned about the differences among current software engineering programs, but space does not permit further elaboration here.

By the GSwE2009 guidelines, the programs examined clearly do a reasonable job of satisfying the outcomes to a “medium” level, at least for the “typical” students described. As shown in Figure 2, each program had some room for improvement to fully meet all GSwE2009 outcomes for most students. The outcomes least likely to be attained at a higher level are ethics (few programs offer much coverage of this), systems engineering (many programs cover this topic only lightly) and application domain depth (some of the programs do not afford their students an opportunity to attain such depth).

Similar entrance requirements (required degrees, levels of experience, etc.) do not always correspond to similar levels of outcome attainment, even when the students appear to have similar backgrounds. Individual programs vary greatly from one another in the overall outcome attainment levels of their students, but most programs do make a difference—that is, outcome attainment upon graduation is typically much higher than upon entry. Industry experience typically results in higher outcome attainment. Hypothetical students within most of the programs vary in their levels of outcome attainment, suggesting that their choices of electives and tracks make a significant difference.

The most commonly required courses are software project management, software architecture and design, software requirements, and testing or verification and validation. By contrast, relatively few programs require courses in construction, metrics, ethics, or systems engineering.

Data from three non-U.S. programs suggest that there are significant differences of perspective, and that the GSwE2009 model is more U.S.-centric than originally intended.

The BKCASE Project

BKCASE, which began in September 2009, will generate two related products by 2012—SEBoK and GRCSE. BKCASE is organized along similar lines to ISSEC. A diverse author team, currently composed of 45 people from 10 countries, meets face to face every three months and works in smaller groups via collaboration technology between workshops. The first author workshop was held at the Naval Postgraduate School in December 2009, refining and ratifying the project charter, project scope, and resulting in the formation of early teams to begin writing the SEBoK. Teams began working on GRCSE at the second workshop, held at the end of March 2010 at Embry-Riddle Aeronautical University.

As with ISSEC, BKCASE products will initially be owned and managed by the author team and copyrighted by Stevens. Ultimately, SEBoK and GRCSE will have the greatest impact if major professional societies become their “stewards,” responsible for their evolution and maintenance. INCOSE and the IEEE Systems Council or Computer Society are the most natural stewards. These societies have several authors participating in BKCASE. See <<http://www.bkcase.org>> for more complete and current information.

Systems Engineering Body of Knowledge

Readers will benefit from a body of knowledge in systems engineering as described in the value proposition for SEBoK:

- >> **There is no authoritative source that defines and organizes the knowledge of the systems engineering (SE) discipline, including its methods, processes, practices, and tools. The resulting knowledge gap creates unnecessary inconsistency and confusion in understanding the role of SE in projects and programs; and in defining SE products and processes. SEBoK will fill that gap, becoming the “go to” SE reference.**
- >> **The process of creating the SEBoK will help to build community consensus on the boundaries and context of SE thinking. It will also help the community understand and improve the ability of management, science and engineering disciplines to work together.**
- >> **Having a common way to refer to SE knowledge will facilitate communication among systems engineers and provide a baseline for competency models, certification programs, educational programs, and other workforce development initiatives around the world. Having common ways to identify metadata about SE knowledge will facilitate search and other automated actions on SE knowledge.**

At the first author workshop, the authors confirmed this value proposition and that there are two disciplines related to SE that require special attention in the SEBoK—software engineering and project management. Software engineering was singled out because the functionality and character of virtually every interesting system these days relies on software. Software drives much of the architecture, security, safety, scalability, interface, and countless other characteristics of modern systems. Much, if not the majority of the risk and cost of systems development rests with the software elements. Given the enormous impact of software on systems, the SEBoK will contain, in integral fashion, software engineering knowledge. At the first workshop, however, no decisions were made on how to accomplish the integration of software engineering knowledge or project management into the SEBoK.

For Version 0.25, the SEBoK will be domain independent. There will be no effort to define knowledge areas in terms or methods that are specific to a particular domain such as finance, medical devices or defense systems. Domain-specific knowledge will be discussed in companion case studies,

AWARD WINNERS



DoD Systems Engineering Top 5 Program Awards

Sponsored by Department of Defense Systems Engineering Directorate and National Defense Industrial Association Systems Engineering Division

The awards, presented to both government and industry, recognize significant systems engineering achievement by teams of industry and government personnel.

Winners:

- Army: Advanced Field Artillery Tactical Data System (AFATDS)
- USAF: Battlefield Airborne Communications Node (BACN) JUON
- Army: Base Expeditionary Target & Surveillance Systems-Combined (BETSS-C)
- Army: Defense Readiness Reporting System-Army (DRRS-A)
- USAF: C-17 Globemaster III Modernization

Awards presented at the annual NDIA Systems Engineering Conference
San Diego, CA, October 25–28, 2010

<http://www.acq.osd.mil/se/apr/top5awards.html>

which will address a few domains and walk through how their methods, processes, and terminology align with SEBoK. This decision will be revisited after the release and review of Version 0.25.

Graduate Reference Curriculum for Systems Engineering

Readers will benefit from a graduate reference curriculum in systems engineering as described in the value proposition for GRCSE:

- >> **There is no authoritative source to guide universities in establishing the outcomes graduating students should achieve with a master's degree in SE, nor a guidance source on reasonable entrance expectations, curriculum architecture, or curriculum content**
- >> **This gap in guidance creates unnecessary inconsistency in student proficiency at graduation; makes it harder for students to select where to attend; and makes it harder for employers to evaluate prospective new graduates**
- >> **GRCSE will fill that gap, becoming the "go to" reference to develop, modify, and evaluate graduate programs in SE.**

GRCSE will be based on the SEBoK and will be analogous to GSWE2009 in form. It will define the entrance expectations, curriculum architecture, curriculum content, and expected student outcomes for graduate programs in SE. GRCSE will recommend that students know or learn about

the application of SE in an application domain or business segment. The use of GRCSE for guidance will enable consistency in student proficiency at graduation, making it easier for students to select where to attend and for employers to evaluate prospective new graduates. Naturally, based on the earlier comments about the ties between software and systems engineering, GRCSE will weave education on software engineering into its recommendations for graduate students studying systems engineering.

Summary

The development of a high-performance systems and software engineering workforce in a world of increasing complexity requires a foundation of authoritative knowledge and guidance in systems and software. Nowhere is this more vital than with the U.S. military, which develops many of the largest and most complex systems in the world. Two projects, the ISSEC and the BKCASE have stepped up to the challenge of building this foundation. ISSEC published GSWE2009: Curriculum Guidelines for Graduate Degree Programs in Software Engineering to provide authoritative guidelines—based on the current and impacting the future revision of the software engineering body of knowledge—on the development of graduate software engineering curriculum. BKCASE will produce both a SEBoK and a GRCSE by 2012. Together, these projects and products support the development of a strong global software engineering workforce and a systems engineering workforce with the necessary software engineering skills to solve tomorrow's global systems problems.

In addition, readers are encouraged to consider some of the following ways to use the guidelines produced by these projects:

- >> **To use as a reference for locating technical information about systems engineering**
- >> **To inform their workforce of development efforts**
- >> **To assess the educational background of their technical staff**
- >> **To develop continuing education curricula or courses for their technical staff**
- >> **To advise local universities or training vendors regarding the kinds of courses and/or educational programs needed by their technical staff and future hires, and to use as a framework for selecting educational programs for employees**
- >> **To define qualifications for contracted workforce**

Any reader who is interested in contributing to either project or adopting any of the resulting products should send an e-mail with background information and areas of interest to bkcase@stevens.edu. ♦

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David H. Olwell is Professor of Systems Engineering at the Naval Postgraduate School, where he recently completed a five-year term as department chair. His research interests are reliability engineering and statistical quality control. He previously was on the faculty of the United States Military Academy.



Art Pyster is a Distinguished Research Professor at Stevens Institute of Technology and Deputy Executive Director of the Systems Engineering Research Center. Previously he served in a number of senior technical and executive roles including Deputy Chief Information Officer for the U.S. Federal Aviation Administration and Senior Vice President and Director of Systems Engineering and Integration at SAIC.



Alice Squires is a PhD candidate and faculty member in Systems Engineering at Stevens Institute of Technology. She has over 28 years of experience and has served as a technical lead for IBM, a Senior Systems Engineering manager for both Lockheed Martin and General Dynamics, and a Senior Systems Engineer consultant to Lockheed Martin, IBM, and EDO Ceramics.

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