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Graduate Curricula in Software Engineering and Software Assurance: Need and Recommendations

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Introduction

In discussions about the development and use of computer systems and software products, the term "professional software engineer" is used repeatedly. In the last two decades there has been significant effort devoted to enhancing and advancing the state of professional software engineering (SwE) – new software engineering processes, methods, tools, and practices; creation of a software engineering body of knowledge [1]; development of a code of ethics and professional conduct [2], and software certification and licensing programs [3] . In 1989 the Software Engineering Institute (SEI) of Carnegie Mellon University published a landmark report on graduate education in software engineering [4]. The guidelines in that report were used by several universities in establishing graduate software engineering degree programs that helped address the problem of improving professional software engineering. Since then, software's scale, complexity, and criticality have accelerated; yet, until recently, no significant effort has been made to revisit and update the original SEI guidelines. This paper discusses two related efforts to provide guidance about improving professional software engineering through graduate education: a project which produced the *Graduate Software Engineering 2009 (GSwE2009): Curriculum Guidelines for Graduate Degree Programs in Software Engineering* [5] and a current SEI project which is developing a *Master of Software Assurance Reference Curriculum (MSwA2010.*

GSwE2009 Features

GSwE2009 was developed as part of the Integrated Software & Systems Engineering (ISSEC) Curriculum Project, at Stevens Institute of Technology. An underlying focus of GSwE2009 is how to advance the state of software engineering practice and to support a better understanding and agreement about the nature of "professional software engineers". The key features of GSwE2009 include:

- A set of guiding principles for GSwE2009 development .
- A baseline of student skills, knowledge, and experience assumed by the core curriculum.
- A set of student outcomes to guide the development of a curriculum.
- A description of the fundamental skills, knowledge, and experience to be taught in the curriculum to achieve the outcomes, identified as the GSwE2009 Core Body of Knowledge (CBOK).
- An architectural framework that supports flexible curriculum implementation by allowing each university to fashion a program guided by its own specialties and the demographics of its student body.

MSwA2010Feature

Due to the increasing role of software in the nation's industrial infrastructure, there is a growing need to address software's impact on systems safety. Examples of industrial control systems requiring particular attention are the power grid, nuclear power stations, water and food plants, chemical factories, oil refineries, railway, and air traffic. To increase assurance of such systems, specifically in the view of growing Internet connectivity impact, security concerns have to be taken into account, These concerns were considered by the National Cyber Security Division of the Department of Homeland Security which recently sponsored an SEI program to initiate work on creation of a graduate curricula guidance (MSwA2010) focusing specifically on software assurance. The objective of the program has been to address software assurance targeted specifically to the security and correct functioning of software systems. For the purpose of this reference curriculum, the following definition of software assurance was used: "*Software assurance (SwA)* is the level of confidence that software is free from vulnerabilities, either intentionally designed into the software or accidentally inserted at any time during its life cycle, and that the software functions in the intended manner."

The GSwE2009 structure and content provided a foundation document for the MSwA2010 work, providing the general software engineering capability need by software assurance professionals. Features similar to those in the GSwE2009 *Guidelines* were included in the MSwA2010 *Reference Curriculum*:

- A set of guidelines that embodied goals, constraints and ideas.
- The background expected of students entering a software assurance graduate program.
- A set of student outcomes describing the knowledge, skills, and capabilities that a graduate would posses upon completion the MSwA program.
- A description of the MSwA2010 BoK, the core body of knowledge for an MSwA degree.
- An architectural framework that focuses on software assurance issues, but has sufficient flexibility to be incorporated into an GSwE2009 curriculum.

Expected Background

For students to be successful in any program they must possess not only appropriate capability but also adequate prerequisite knowledge. This background is dependent on the expected program outcome and the content of the curriculum. Table 1 provides a summary of the expected background for GSwE2009 and MSwA2010. In addition the GSwE2009 advocates two years of industrial software development experience as part of an entering student's background.

Table 1. Curriculum Background Expectations

GSwE2009 Expectations	MSwA2010 Expectations
Mathematics (discrete structures, propositional and predicate logic, probability and statistics)	Discrete Mathematics
	Programming Development Fundamentals (programming languages, OO programming, data structures and algorithms, including elements such as pointers, threads, and memory allocation)
Computing Fundamentals (programming fundamentals, data structures and algorithms, module design and construction , operating systems, computer architecture, networks and communication,)	Computer Fundamentals (computer organization; assembly and microcode organization; memory organization and access; communication interfaces; multiprocessing)
	Networks and Communications
Software Engineering Fundamentals (requirements, design, construction, testing, maintenance, management, process, quality)	Programming Environments (operating systems, real-time and embedded systems, performance analysis)
	Software Engineering Fundamentals
	Security Engineering Fundamentals

Student Outcomes

The outcomes described in this section specify the knowledge, skills, and capabilities that graduates of GSwE2009 and MSwA2010 programs should possess on completion of their program. The outcomes represent the minimum capabilities that should be expected of a professional when they complete a master's degree program. Table 2 lists the student outcomes for GSwE2009 and Table 3 for MSwA2010. For both projects, the student outcomes provide the focus for the degree and highlight the essential principles, concepts and practices that must be part of the curriculum. As such, they act as the high-level requirements for a program and guide the development of appropriate knowledge core and curriculum architecture.

Table 2. GSwE2009 Student Outcomes

CBOK	Master the Core Body of Knowledge
DOMAIN	Master software engineering in one application domain, such as finance, medical, transportation, or telecommunications, and in one application type, such as real-time, embedded, safety-critical, or highly distributed systems.
DEPTH	Master at least one KA or sub-area from the CBOK to the Bloom Synthesis level [6].
ETHICS	Make ethical professional decisions and practice ethical professional behavior.
SYS ENG	Understand the relationship between software engineering and systems engineering and be able to apply systems engineering principles and practices in the engineering of software.
TEAM	Be an effective member of a team, including teams that are multinational 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.
RECONCILE	Reconcile conflicting project objectives, finding acceptable compromises within limitations of cost, time, knowledge, risk, existing systems, and organizations.
PERSPECTIVE	Understand and appreciate feasibility analysis, negotiation, and good communications with stakeholders in a typical software development environment, and perform those tasks well; have effective work habits and be a leader.
LEARN	Learn new models, techniques, and technologies as they emerge, and appreciate the necessity of such continuing professional development.
TECH	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.

Table 3. MSwA2010 Student Outcomes

1. Assurance Across Life Cycles	Incorporate assurance technologies and methods into life-cycle processes and development models for new or evolutionary system development, and for system or service acquisition.
2. Risk Management	Perform risk analysis, trade-off assessment, and prioritization of security measures.
3. Assurance Assessment	Analyze and validate the effectiveness of assurance operations and create auditable evidence of security measures
4. Assurance Management	Make a business case for software assurance, lead assurance efforts, understand standards, comply with regulations, plan for business continuity, and keep current in security technologies.
5. System Security Assurance	Incorporate effective security technologies and methods into new and existing systems.
6. System Functionality Assurance	Verify new and existing system functionality for conformance to requirements and absence of malicious content.
7. System Operational Assurance	Monitor and assess system operational security and respond to new threats.

Core Body of Knowledge

The primary sources for developing the GSwE2009 Core Body of Knowledge (CBOK) was the SWEBOK [1], SE2004 [7]. Some changes in areas and topics were needed to support the GSwE2009 expected student outcomes and to accommodate the needs and views of academia, industry, and the computing professional societies. For example, two knowledge areas, not absent in the SWEBOK, were added: Systems Engineering Fundamentals, and Ethics and Professional Conduct. Fig. 1depict

the knowledge areas in the CBOK and the recommended minimum percentage of the total curriculum.

Since there is no single recognized source for software assurance knowledge, a significant part of the MSwA2010 effort was devoted to research and analysis of software assurance sources and theMSwA2010 *Reference Curriculum* contains a comprehensive description of these sources. The analysis of the sources greatly influenced the development of the student outcomes. As a result, the MSwA2010 CBoK was organized around the outcomes and divided into the seven areas listed in the left hand column of Table 3: Assurance Across Life Cycles, Risk Management, Assurance Assessment, Assurance Management, System Security Assurance, System Functionality Assurance, and System Operational Assurance. Each of these areas has been broken down to identify specific subareas and detailed topics.

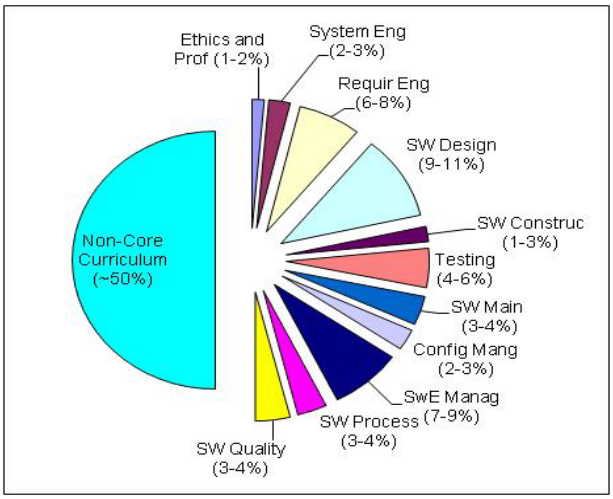

Fig. 1. CBOK Organization

Curriculum Architecture

The outcomes guided and controlled the development of both the structure and content of the curriculum models. The structure of the GSwE2009 curriculum is represented in the architectural model depicted in Fig. 1. The GSwE2009 curriculum architecture includes preparatory material, core materials, university-specific materials, elective materials, and a capstone experience. The heavy black line in Fig. 1 represents the baseline preparatory knowledge for students in a GSwE2009 master's program. GSwE2009 strongly recommends that students demonstrate their accumulated skills and knowledge in a capstone experience, which might be a project, a practicum, or a thesis.

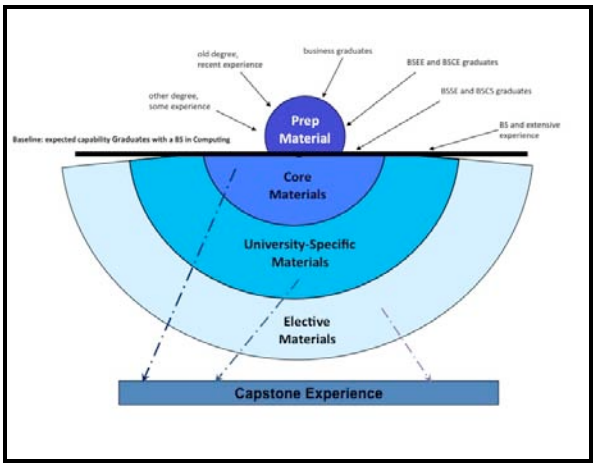

Fig. 2. GSwE2009 Curriculum Architecture

The MSwA2010 curriculum architecture includes preparatory, core, and elective materials, and a capstone experience. Fig. 3 provides an overview of the curriculum architecture. The Preparatory Materials represent the baseline expectations described in Table 1 for students entering the program. The MSwA Core material and everything below it is mastered after program entry. The MSwA2010 project recommends that students demonstrate their accumulated skills and knowledge in a capstone experience, which engages the student in a realistic team project emphasizing software assurance concepts and practices.

Preparatory Materials	Computing Foundations Software Engineering Security Engineering
MSwA Core	Assurance Across Life Cycles Risk Management Assurance Assessment Assurance Management System Security Assurance Assured Software Analytics System Operational Assurance
Electives	Courses Related to Assurance in Selected Domains
Capstone Experience	Project

Fig. 3. MSwA2010 Architecture

Next Steps

The GSwE2009 document is just the initial step in the set of activities needed to advance professional software engineering through the enhancement of graduate software engineering education programs. In order for GSwE2009 to be considered a successful product, the model must be available, understood by the targeted academic and industrial communities, viewed as a key reference for software engineering curriculum development, and actually used in the development and modification of software assurance focused curricula. The recent agreement by the ACM and the IEEE Computer Society to sponsor GSwE2009 will advance the acceptance of its recommendations by both the academic and professional community.

The MSwA2010 Reference curriculum will be completed in summer 2010 and is expected to be published as a SEI Technical Report and posted on the SEI website. The encouragement and support of this project by the Department of Homeland Security will provide a foundation for acceptance by the software security community. Other dissemination activities are being considered, including the delivery of special workshops devoted to helping faculty introduce MSwA2010 concepts.

We encourage those who are stakeholders in professional software engineering and software assurance education (managers, practitioners, educators) to become involved in these efforts: download the full documents; read and study them; share your views of them with your colleagues; promote or lead an effort to create a new program or enhance an existing program using either the GSWE2009 or MSwA2010 guidance, or both.

Acknowledgments

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The paper describes the results of two graduate curriculum projects: GSwE2009, which developed Graduate Software Engineering 2009: Curriculum Guidelines for Graduate Degree Programs in Software Engineering and MSwA2010, a current project, which is developing a Master of Software Assurance Reference Curriculum. The authors, who actively participated in the development of the recommendations, discuss the background, identification of the programs objectives and outcomes, relation to the respective Bodies of Knowledge, the audience and the required preparation, proposed curricula architecture, and the implementation comments. Ill. 3, bibl. 7, tabl. 3 (in English;

Т. Б. Хильбург, А. Ю. Корнецки. Исследования потребности и рекомендации программ в учебном процессе магистров // Электроника и электротехника. – Каунас: Технология, 2010. – № 6(102). – С. 67–70.

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Pateikti dviejų magistro studijų programų projektų tyrimo rezultatai: GSwE2009, kuriuo remiantis sukurta studijų programa „Programų inžinerijos magistras 2009: programų inžinerijos magistranto mokymo programų gairės“ ir MSwA2010 – dabartinis projektas, kurį vykdant kuriami studijų programos „Programų patikrinimas“ nurodymai. Aprašomas projekto planas, programos tikslai ir pageidaujamas rezultatų indentifikavimas, sąsajos su atitinkamomis mokslo institucijomis, tikslinė grupė ir reikalingas pasirengimas. Siūloma mokymo plano architektūra. Il. 3, bibl. 7, lent. 3 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).