An overview of GRCSE: Graduate Reference Curriculum for Systems Engineering

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ABSTRACT
With the ever increasing complexity of engineered systems, there is a need for educating and training additional systems engineers to meet future demand. Over the last three years, educators and professional systems engineers from around the world have been working on the development of a Graduate Reference Curriculum for Systems Engineering (GRCSE™), which is scheduled to be released by December 2012. This work has been supported by the US Department of Defense and many international organizations such as the IEEE Computer Society, IEEE Systems Council, INCOSE, and ACM.
1. INTRODUCTION

With the ever increasing complexity of engineered systems, there is a need for educating and training additional systems engineers to meet future demand. Over the last three years, educators and professional systems engineers from around the world have been working on the development of a Graduate Reference Curriculum for Systems Engineering (GRCSE), which is scheduled to be released by December 2012. This work has been supported by the Department of Defense and many international organizations such as the IEEE Computer Society, IEEE Systems Council, INCOSE, and ACM.

GRCSE provides a reference curriculum for system engineering graduate training and education, and uses the Systems Engineering Body of Knowledge (SEBoK) as its foundation. The main objective of the GRCSE authors was to define system engineering curriculum guidelines that satisfy the following conditions:

- The curriculum shall satisfy international post secondary education systems requirements.
- The curriculum shall allow the universities to customize their degree based on their stakeholders needs.
- The curriculum shall be based on standards that best represent the state of the systems engineering.
- The graduates of the universities which follow the guideline for the reference curriculum shall be ready to contribute to the companies in need of systems engineering workforce.

The following actions have been taken by the GRCSE team, in order to satisfy the above conditions:

(a) An international author team assembled from across the world, representing two major (American and European) educational systems.
(b) The author team has representatives from the North America, South America, Australia, Europe, and Asia.
(c) The author team has representatives from academia, government, and industry.
(d) The curriculum technical content shall follow the Systems Engineering Body of Knowledge (SEBoK), which is the representation of the current state of the systems engineering, and it is expected to be updated annually.
(e) GRCSE will define only 50% of the curriculum content based on the SEBoK, this will allow the universities to use the remaining 50% to create a curriculum that meets their stakeholder needs.

The remainder of this paper provides an overview of the GRCSE document.

2. GRCSE ORGANIZATION

GRCSE is organized into nine chapters and seven appendices; the following presents a brief description of each chapter.

2.1. Chapter one

This chapter provides an overview of the GRCSE document, followed by the discussion of the rationale behind the GRCSE. Finally, a discussion of how one would pursue a graduate degree is presented. Typically there are two paths to graduate degree, either entering the graduate degree immediately after the bachelor degree, or after gaining number of years of industry experience. Given the complexity of systems, we believe students who pursue their graduate degree after some industry experience will be better prepared to appreciate these complexities and as a result, they would be better prepared for their graduate work.

2.2. Chapter two

This chapter describes the educational objectives, and how one would establish such objectives. Program educational objectives are defined with the consultation of program stakeholders. Objectives represent what the graduates of the program will be able to accomplish, within three
to five years of their graduation. This chapter also presents three different sets of program objectives, two representing existing programs, and one representing a generic set of objectives a program may have.

2.3. Chapter three
This chapter describes a common set of program outcomes, which is the representation of what graduates of the program should be able to accomplish at the time of graduation. The primary factors impacting the achievement of outcomes are the content and manner of teaching of the program, the broader institutional context in which students study, and the abilities that students have at the time that they enter the program. There are thirteen GRCSE outcomes that have been divided into four major categories.

- The Systems Engineering Concepts outcomes concentrate on the necessary depth and breadth of fundamental systems engineering knowledge that students should attain upon the graduation.
- Systems engineers are typically required to work on multi disciplinary projects, where they need to either need to interact with technical people from other disciplines and/or perform some minor tasks that are typically conducted by people from other discipline. The Systems Engineering Role outcomes concentrate on the knowledge and skills that the students should attain in order to be an effective member of the multi-disciplinary teams.
- Systems engineers are required to perform wide range of tasks throughout the development life-cycle, which starts with the customer needs assessment through system disposal. The Systems Engineering Practice outcomes concentrate on the knowledge and skills that students should attain in order to be an effective systems engineer throughout the systems life-cycle.
- Finally, systems engineer should perform their tasks in a professional and ethical manner as a member of a society and project team. The Software Engineering Professionalism outcomes concentrate on the set of characteristics that students should display upon graduation.

2.4. Chapter four
This chapter details the background students are expected to possess before entering a master’s program. As one of the first steps in the development of the GRCSE, the author team conducted a survey of the existing systems engineering graduate degrees. One of the questions in this survey dealt with the entrance requirements for students pursuing the systems engineering graduate degree, and the rationale for such requirements. As a result of the analysis of this survey and the nature of GRCSE, the following entrance requirements where recommended in order to accomplish GRCSE outcomes:

- The equivalent of an undergraduate degree in engineering, the natural sciences, mathematics, or computer science. More specifically, students should have the necessary fundamental knowledge in mathematics (probability and statistics, and calculus), natural science, engineering, and computing. In addition, it is expected that entering students are familiar with issues related to ethical and professional conduct.
- At least two years of practical experience in some aspect of SE. This experience should include participation in teams and involvement in the life cycle of a system, subsystem, or system component.
- Demonstrated ability to effectively communicate technical information, both orally and in writing, in a program’s language of instruction.

2.5. Chapter five
This chapter presents a curriculum architecture for structuring a SE graduate degree. The GRCSE curriculum architecture is organized into six different components: preparatory knowledge, foundation knowledge, concentration knowledge, domain knowledge, program specific knowledge, and a mandatory capstone project. The foundation and the concentration knowledge are focused on SEBoK content, which is referred to as the Core Body of Knowledge (CorBoK), and is discussed in chapter 6. Figure 1 represents the architectural structure of the GRCSE curriculum.
The following briefly describes the six components of the GRCSE curriculum:

- **Preparatory knowledge** – Students who do not meet the entrance requirement discussed in chapter 4, are expected to learn this knowledge/experience in order to satisfy the entrance requirements.
- **Foundation knowledge** – This is the set of common knowledge, skills and abilities (KSA) that every systems engineer should possess, regardless of educational institution, location, or the student’s anticipated future role.
- **Concentration knowledge** – It is expected that each systems engineering student choose a SE related concentration area. The concentration area specifies additional topics that should be mastered by the student at a specified Bloom’s level, or foundational knowledge topics that should be mastered by the student to a higher specified Bloom’s level. The concentration areas are dependent on the intended future role of the SE graduate, and support a flexible curriculum, while also meeting the needs of a comprehensive program. Concentration areas addressed in this version of GRCSE are Systems Engineering Management (SEM) and Systems Design and Development (SDD).
- **Domain knowledge** – A system is typically built for one or more domains. For example, an air traffic management system is related to the aviation domain, or an investment profile management system is related to the financial domain. It is expected that each systems engineering student, based on their personal interest and/or the nature of their university, will choose one or more specific domains to study.
- **Program specific knowledge** – It is expected that each program selects one or more topics of special interest to include as part of their curriculum. These topics are based on program particular interest, faculty expertise, and/or institutional focus. For example, a program with number of faculty with expertise in real-time systems may choose to include some topics in the area of real-time systems.
- **Capstone experience** – Each program expects students to demonstrate their accumulated KSAs in a mandatory capstone experience. The capstone can be implemented through a variety of methods, including individual or team capstone projects or a practicum. The technical work for a project may be distributed through multiple courses, such as by performing system architecture and design at increasing levels of detail. A master’s thesis, which meets the expectations for the capstone experience is also a possible implementation.

![GRCSE curriculum architecture](image)

*Figure 1. GRCSE curriculum architecture.*
2.6. Chapter six
This chapter describes the CorBoK, which includes both the foundation (topics which should be learned by all students) and the concentrations (topics which should be covered by students focusing on a specific SE role). The CorBoK is intended to cover no more than 50% of the total knowledge conveyed in a graduate program. Making the core knowledge 50% of the program instills critical commonality among programs. Employers will have more information regarding what students graduating with a master’s program have learned and are capable of doing. Restricting the CorBoK to no more than 50% encourages significant variation among programs while simultaneously building on the common foundation. This ensures an opportunity for the student to develop a deeper knowledge in topics of particular interest, such as requirements elicitation and analysis, or system architecture. As previously mentioned, the content of the CorBoK is driven by the content of the SEBoK, therefore as it is expected, the components identified in the CorBoK are the same knowledge areas as is defined in SEBoK. About 60% of the CorBoK is the content related to part 3 of SEBoK, which includes topics related to life cycle models, concept definitions, systems definition, system realization, system deployment and use, systems engineering management, product and service life management, and systems engineering standards. The remaining 40% of the CorBoK is associated with the part 2 (system fundamentals, system science, system thinking, system representation with models, and system approach applied to engineering), part 4 (product/service/enterprise system engineering, and systems of systems), part 5 (enabling business and enterprise, teams, and individuals), and part 6 (software engineering, project management, industrial engineering, procurement and acquisition, and specialty engineering as it relates to systems engineering). In addition to defining the knowledge areas in the CorBoK, the author team also identified the goal level of attainment, based on the Bloom taxonomy, for each knowledge area.

2.7. Chapter seven
This chapter includes guidance on implementation, focusing on using GRCSE as a tool for curriculum development and revision. It includes considerations for tailoring GRCSE recommendations to fit a program’s specific needs in terms of stakeholder requirements and environmental constraints. Some examples of these program customizations include:

- Modification to the program entrance criteria.
- Modification/addition to the GRCSE’s thirteen outcomes listed in Chapter 3, in order to meet the program’s clientele, faculty interests, and other relevant factors.
- Customization of the program curriculum above and beyond the CorBoK in order to prepare graduates of the program more attractive to the employers.
- Etc.

2.8. Chapter eight
This chapter provides guidance for developing assessment rubrics to ensure that graduate programs achieve their intended objectives and outcomes. In addition, some guidelines associated with the student performance assessment, and course outcome assessment is provided in this chapter. Finally, there is a discussion of how the assessment data can be used as part of program and process improvement. It is important to point out that the author team has no intention of using the GRCSE as part of the accreditation criteria; however, the program may use these guidelines, in combination with other tools, in order to prepare for accreditation.

2.9. Chapter nine
This chapter explains the intended evolution and long-term support of GRCSE. As discussed, there is a strong coupling between the GRCSE and SEBoK documents. Currently, there is a plan to publish two updates to the SEBoK document annually, where the first updates typically deal with minor modifications and the second update expected to be more substantive updates. In another word, SEBoK will have a major updates annually. Of course, since the changes to the curriculum are typically a long and tedious process, the GRCSE team decided to publish updates to the guidelines once every three years.

As previously mentioned, GRCSE includes nine chapters also includes seven appendices. However, the discussion of these appendices is beyond the scope of this paper.
3. SUMMARY
A graduate reference curriculum establishes a baseline for educators in order to design and implement a graduate program that meets a set of requirements common throughout educational systems. It is expected, that the graduates of the programs who have followed the reference curriculum, would meet a minimum set of knowledge, skills and abilities that are defined by the reference curriculum. Therefore, employers of these graduates have a sense of assurance as to the quality of their employees, and the level of competency that they should expect from these employees on their first day at work. The GRCSE provides such a reference curriculum for the systems engineering graduate. This paper provided an overview of the GRCSE.

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REFERENCES