To Be Presented at the Summer Computer Simulation Conference (SCSC), San Jose, CA, July 2004, Education Track.

Graduate Education in Modeling & Simulation: Rationale and Organization of an Online Masters Program

Hessam S. Sarjoughian[1]
Arizona Center for Integrative Modeling & Simulation
Dept. of Computer Science & Engineering
Arizona State University, Tempe, AZ, 85281-8809

Jeffery K. Cochran
Arizona Center for Integrative Modeling & Simulation
Dept. of Industrial Engineering
Arizona State University, Tempe, AZ, 85287-5906

James S. Collofello
Arizona Center for Integrative Modeling & Simulation
Dept. of Computer Science & Engineering
Arizona State University, Tempe, AZ, 85281-8809

Jeffrey S. Goss
Center for Professional Development
Fulton School of Engineering
Arizona State University, Tempe, AZ, 85287-4411

Bernard P. Zeigler
Arizona Center for Integrative Modeling & Simulation
Dept. of Electrical & Computer Engineering
University of Arizona, Tucson, AZ 85721-0104

Keywords: Graduate Program, Masters Degree, Online Education, Modeling & Simulation.

Abstract

The lack of education in modeling and simulation is acknowledged by corporations, government, and academia alike. In order to respond to increasing demand for simulation-based system development, we have established an online Modeling & Simulation Master of Engineering Program where a mixture of foundational modeling and simulation courses are enriched with state-of-the-art advances in computer science and industrial engineering. This program offers online delivery to serve traditional students as well as professionals in industry, government, and universities. This paper describes the program and its uniqueness with emphasis on the foundational and applied aspects of modeling and simulation.

Introduction

The role and impact of modeling and simulation (M&S) is evident in the development of virtually any complex, large-scale system. Numerous branches of sciences, engineering, and the arts are experiencing unprecedented advances through the use of simulation modeling concepts, methods, tools, and practices. However, while experts in industry, government, and academia increasingly recognize modeling and simulation in its own right, pedagogy in modeling and simulation remains challenging. In fact, it can be argued that without proper education in the fundamentals and applied aspects of modeling and simulation, progress in its use and advances in its theories, methodologies, applications, practices, and tools will be difficult to achieve.

Therefore, to meet the existing and on-the-horizon needs of the scientific and engineering workforce, a handful of universities have embarked on offering graduate degrees in modeling and simulation [1]. A number of universities and their affiliated centers have

[1] For correspondence contact the author at sarjoughian@asu.edu.

been actively seeking "academic recognition" for modeling and simulation [2-5]. These programs consider modeling & simulation (M&S) to be distinct from other disciplines such as computer science, industrial engineering, and mathematics. The need for educating M&S professionals is well recognized, and educators have debated whether it is appropriate for M&S to be considered disciplinary or multidisciplinary [2]. Related issues and concerns were considered in workshops held in 1997 and 1998 [6, 7] where attendees from industry, government, and academia examined alternative views on how best to educate M&S graduates who will eventually become professionals. More recently M&S communities have been attempting to reach a consensus on the foundations to teach and consequently the knowledge to require from simulation professionals. While an overall consensus was impractical to reach, key objectives including education, were recognized. Indeed, in the last several years education and annual educational and training tracks have been held in conferences such as the Summer Computer Simulation Conference and Winter Simulation Conference [8, 9]. In these tracks a variety of topics (e.g., course offerings and textbooks) and panels (e.g., undergraduate and graduate programs) continue to further define and coordinate educational activities (see for example [5, 10].

Based on the ubiquity of modeling and simulation, it is important to move away from *ad hoc* education and training to programs where the principles and practices of simulation modeling are delivered according to academic standards and practices. Some of the key benefits of having a rigorous framework for M&S education are quality assessment of courses and degree programs which result in graduates who are well prepared to practice and advance M&S frontiers. This will ultimately produce M&S professionalism in the service of the society.

In the remainder of this paper, we will describe our rationale and approach toward the development of the Arizona State University's Modeling & Simulation Master of Engineering Program. We will also discuss the program's online delivery and offer some thoughts on the role this program may play in the future of modeling and simulation.

Approach

Given the depth and breadth of modeling theories and simulation technologies, and their practical applications, it is not surprising that the graduate programs offered at institutions such as ASU, CSU-Chico, Old Dominion University, Naval Post Graduate School, and University of Central Florida each have unique elements that combine particular strengths of the institution and faculty[1]. For instance, ASU's program combines computer science and industrial engineering, arming students with a strong basis in foundations of theories of modeling, simulation techniques with applications to defense systems, supply chain networks, software design, and intelligent systems.

Successful completion of projects across an array of domains such as aerospace, transportation, manufacturing, and healthcare relies heavily on best suitable modeling and simulation practices and technologies. We can view the stakeholders of M&S to be the industry, government, and academia. Each of these stakeholders generally plays dual roles of consumer and producer. The stakeholders share the common objective of succeeding in their respective activities to achieve their individual and collective short- and long-term goals in disciplined settings.

In describing the role of each stakeholder, it is important to note that M&S education and training require a synergistic worldview among academia, government, and industry. We can view academia, government, and industry as *producers* of the educational resources (i.e., curricula, body of knowledge, licensing, standardization, and accreditation, and ethics [2]). Academia continues to act as the primary producer by continually educating and training students with general and specialized knowledge in modeling and simulation. Industry and government also play the *producer* role, to a lesser extent, by serving the needs for licensing and standardization, and offering specialized courses on industry practices and tools. Industry and government, however, primarily play the *consumer* role. The separation of producer and consumer is important to support building M&S into a discipline instead of a multifaceted practice that discourages and potentially prohibits a disciplinary emergence.

Every university has a mandate to educate the public at large. At the same time, a graduate program must be congruent with the university's scholarly mission and its vision for sustaining and indeed advancing its role in building the future workforce. A well educated modeling and simulation workforce, therefore, will be able to employ the underpinnings of the simulation modeling science, engineering, and their resulting innovations and technologies to develop solutions.

To support academia's encompassing role, establishing a new degree program such as the *Master of Engineering* in *Modeling & Simulation* (M&S MEng) [11] requires placing it within existing graduate programs as well as determining how it may be impacted by (or influence) undergraduate programs. For a new university program to be successful, it is crucial for it to provide value to its clients within the confines of the university's goals. Creating a new graduate program also involves making key choices – i.e., academic unit, concentration areas,

faculty, syllabus, and delivery mode – that best suit the needs and objectives of the program.

Given the interplay among academia, government, and industry, each of the existing academic programs has its own unique features such as focus on research, attracting targeted student population(s), and mechanisms to address satisfying the needs of industry and government. For example, the research focus of the program described here is on advancing modeling and simulation theory and methodologies infused with best practices on integrated education and industry practices. Our approach offers students integrated research experience along with traditional course work and leads them on a pathway toward becoming M&S professionals. Various options are available to the students to gain research experience with the program faculty. For example, research experience is available with the faculty members of the Arizona Center for Integrative Modeling and Simulation (ACIMS [12]). Alternatively, professionals may choose to collaborate with the M&S MEng program faculty to extend and focus their ongoing research and development activities.

M&S MEng Program

Based on ASU and ACIMS faculty strengths and research interests as well as the short- and long-term strategies of administrators, the MEng in Modeling & Simulation was established within the Fulton School of Engineering. In order to reach large dispersed populations of traditional students and professionals, the program was designed from the outset to be offered online.

Within the Fulton School of Engineering, the program was conceived to include the Computer Science & Engineering (CSE) and Industrial Engineering (IE) departments. This two-pronged program allows offering courses founded on (i) the fundamentals and principles of simulation modeling and engineering design, (ii) software engineering, and (iii) application areas where state-of-the-art M&S advances are key. This strategic decision aims our efforts at defense applications, large-scale computer and supply chain networks, software factory, and intelligent systems. The expected outcome is for the graduates of the program is to be 1) knowledgeable in M&S concepts, principles ,and tools and 2) to be able to *engineer* novel M&S-based solutions for multifaceted problems facing government (e.g., the Departments of Defense and Homeland Security), industries, private and non-profit agencies, and research labs in academia or elsewhere.

Another aim of the program is to prepare students to contribute to the development of the field, as promoted by M&S organizations such as DMSO (Defense Modeling and Simulation Organization [13]), M&SPCC (M&S Professional Certification Commission [14]), SCS (Society for Modeling and Simulation International [8]), and SISO (Simulation Interoperability Standards Organization [15]). These organizations collectively lay out the future directions, emerging technologies, and practices in the field.

Description

Graduate academic programs offered in science and engineering disciplines are generally devised in such a way to require mastery in the program's core while allowing a student and faculty advisor to 'customize' the student's course work and research emphasis. For example, the Master of Engineering (M.E.) Program, offered by the ASU Fulton School of Engineering, requires 24 units of course work and 6 hours of thesis. Within this framework, each department has flexibility to design its own curricula. For example, in the Computer Science and Engineering department, a student is required to take 3 courses, one from each of the *Foundations*, *Systems*, and *Application* core areas, with the rest of courses taken from within the CSE or other engineering departments.

The Modeling & Simulation Master of Engineering Program curriculum, like the M.E. Program [16], is devised to consist of *core* and *area* courses. However, it differs from the general M.E. programs in that the choices for core and area courses are focused on modeling and simulation underpinned with software engineering and information and enterprise engineering offered by Computer Science and Engineering and Industrial Engineering departments.

Each student must complete a total of 30 credit hours offered by the Computer Science and Engineering (CSE) and Industrial Engineering (IE) departments at Arizona State University. Some of the courses listed in Tables 1 and 2 are also offered in the department of Electrical and Computer Engineering at the University of Arizona.

Tables 1 and 2 list five *Core* and eleven *Area* courses as well as one *Applied Project* course. The Core courses are required and the Area and Applied Project courses are selected based on students' interests. Some students may choose to concentrate on modeling methods, simulation techniques, and software engineering of modeling and simulation environments. Others may focus on domain applications such as large-scale computer networks, supply-chain enterprise, and system of systems. Yet, others may decide to focus on the intersection of fundamentals, application domains, and initiatives such as SBA (Simulation-Based Acquisition), SMART (Simulation and Modeling for Acquisition, Requirements, and Training), and SCOR (Supply Chain Operations Reference-model).

Table 1: Core Courses

▪ Modeling and Simulation Theory and Application
▪ Simulating Stochastic Systems
▪ Design of Engineering Experiments
▪ Software Analysis and Design
▪ Software Project, Process, and Quality Management

Table 2: Area Courses

▪ System Simulation
▪ Simulation in Manufacturing
▪ Supply Chain Modeling and Analysis
▪ Parallel and Distributed Simulation
▪ Scheduling and Network Analysis Models
▪ Factory Physics
▪ Applied Stochastic Operations Research Models
▪ Software Requirements and Specification
▪ Software Verification, Validation, and Testing
▪ Hardware Description Languages
▪ Synthesis with Hardware Design Language
▪ Applied Project

Each student selects a faculty member advisor from either CSE or IE and with the advisor's approval either *(i)* completes only course work and passes an oral examination or *(ii)* defends a practice-oriented project. In both cases, the student together with the advisor will select a three-member committee which will approve a successful completion of the student's practice-oriented project or oral examination. The committee is composed of the advisor with the two remaining members being either faculty or one faculty and one practicing professional. The faculties are from the M&S MEng program. Additional information on the Program Study is available at the CPD website [17].

Admission

The program is designed to attract students with strong demonstrated academic records or professional skills in science and engineering. The minimum requirement is holding a Bachelor of Science or engineering (preferably in computer science and engineering or industrial engineering). To attract high-quality students from non-traditional backgrounds (e.g., environmental sciences), individuals who have taken courses equivalent to those required qualify for admission. Admission to the M&S MEng program is congruent with other master's programs at ASU, requiring a minimum grade point average of 3.25 and proficiency in the English language (more detail is available in [18]).

Benefits

An important objective of this program is to enable graduates of the program to tackle key technical barriers faced by industry, government, and, more generally, engineers and scientists engaged in research and development. The graduates of the program are expected to engineer solutions for increasingly complex decision-making systems. To achieve this objective, students are expected to gain experience in cutting-edge research, education, and professionalism, which will equip them with the necessary skills and tools to embark on highly competitive and rewarding careers in modeling and simulation.

Students will be able to learn proven and new theories, approaches, and tools to analysis, design, and development of solutions. Through research, graduate students in modeling and simulation will gain in-depth technical knowledge to develop large, complex systems using integrative simulation-based design and development methodologies and techniques. Furthermore, class projects and research internships allow students to interact with M&S professionals and develop new solutions outside of traditional views.

Online Program Delivery

The importance of online course and program delivery especially for professionals who do not have the luxury of attending traditional classrooms is well known. In 2001, the Fulton School of Engineering invested in a state-of-the-art online infrastructure and created the Center Professional Development (CPD) [17]. CPD offers technical capabilities and management resources to provide near seamless in-class learning and teaching experiences. The CPD's infrastructure provides multiple ways to access and use course materials in addition to traditional online posting. Students can interact seamlessly with the course materials – e.g., students can not only customize capabilities of the Blackboard to match their needs, but also can experience in-class use of simulation and software tools. The CPD staff will support the students with admission, registration, and monitoring of their progress toward completion of their degrees. The staff with expertise in online education delivery will offer students professional service to have in-class experience through online media.

Future and Outlook

The proposed approach relies on a collective vision, coordination, and commitments among academia, industry, and government toward achieving disciplined modeling and simulation with key benefits to researchers, practitioners, and ultimately the consumers. ASU's Modeling & Simulation MEng program is expected to contribute toward the establishment of the body of knowledge, creation of undergraduate/graduate curricula and programs, development of standardizations, and professional certification of simulation professionals. In addition, the graduate program is expected to synergize with a proposed M&S undergraduate program at the *ASU East campus. The combination of graduate and undergraduate courses* will further the realization of modeling and simulation as a discipline.

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