A PROPOSED MODEL FOR AN UNDERGRADUATE ENGINEERING PROGRAM IN MODELING AND SIMULATION

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ABSTRACT

This paper examines the needs, opportunities, requirements, and competing approaches to developing an undergraduate engineering program in modeling and simulation. The paper is the result of a synergistic partnership between Arizona State University, East Campus (ASU East), where a new undergraduate engineering program is under consideration and the Society for Modeling and Simulation International (SCS) that is committed to providing leadership in the formulation, assessment, and accreditation of undergraduate and graduate programs in modeling and simulation

1. BACKGROUND

Over the past several years there has been a continuing discussion pertaining to the development of Modeling and Simulation (M&S) degree programs. The motivation for the discussion comes from the maturation of M&S as a discipline, a continuing increase in the development of simulation applications and research, and a growing demand for simulationists. In an attempt to "spark debate on the modeling and simulation profession," Rogers [1997] presented a panel consensus view of the elements of an ideal simulationist that included suggested attributes, skills, and knowledge. Fujimoto [2000] later suggested a set of guiding principles as a framework for establishing a consensus relating to "standards for curricula development in the M&S field." Others have contributed to the discussion by elucidating the challenges and issues of creating M&S degree programs [Szczerbicka et. al, 2000; Nance, 2000; and Nance and Balci, 2001], and by proposing a strategic approach for establishing an undergraduate M&S degree program [Sarjoughian and Zeigler, 2000]. Sarjoughian and Zeigler [2000] have concluded that there is a need for an accredited undergraduate M&S degree housed in engineering. In this paper we discuss: current M&S degree programs; the need for an M&S degree program; M&S program design issues; the "general" engineering M&S opportunity, key elements of an M&S program, and the challenges of M&S implementation in "general" engineering.

1.1 M&S Programs Today

Table 1 lists eight current M&S degree programs and some of the degree program characteristics. Six of the identified programs are masters level programs while two programs are offered at the bachelors level. The two bachelor level programs are not accredited. The University of Pennsylvania offers a Bachelor of Science in engineering degree as an interdisciplinary major focusing on entertainment. There are a number of other programs not listed that offer simulation concentrations within a degree. There are no accredited simulation programs, as accreditation criteria do not exist. Despite a lack of accreditation criteria, there are examinations for professional simulation certification [M&SPCC 2003].

2. THE NEED FOR AN M&S PROGRAM TODAY

The need for an undergraduate M&S program today is compelling and motivated by three key factors. First, given that technology is galloping at an incredible rate, the inherent interdisciplinary nature of M&S fosters a much-needed cross-disciplinary thinking in M&S engineers.

Second, the absence of professionals trained in M&S is keenly felt in the U.S. Military that is committed to network-centric warfare under the new Future Combat System program; by the financial services industry that is dependent on the computing and networking infrastructure; by the Homeland Defense department that must develop and test unprecedented architectures to defeat attacks by intelligent and dedicated terrorists; and in the industry in general that is increasingly becoming dependent on complex networked systems. Third, M&S' incredible promise to open new technological frontiers in simulation-based drug design and testing, examining the life cycle of a viral or bacterial epidemic through simulation, or understanding the construction and organization of the biological brain (humans, dolphins, squid, etc) is far from being tapped.

Table 1. Modeling and Simulation Degree Programs

Institution / Degree	Program Characteristics
University of Baltimore BTPS: Bachelor of Technical or Professional Studies in Simulation and Digital Entertainment.	For people who want to work in games, simulations, and interactive software.
University of Pennsylvania BS in Engineering Digital Media Design, Interdisciplinary Major	Technological underpinnings of web animation, game design, special effects, and visual communication.
University of Central Florida M.S. Degree in Modeling and Simulation, Interdisciplinary Program	Seven focus areas: Quantitative Aspects of Simulation Simulation Infrastructure Simulation Management Computer Visualization in M&S Simulation Modeling and Analysis Interactive Sim/Intelligent Systems Human Systems in M&S
California State University, Chico MS Degree in Interdisciplinary Studies	Three focus Areas Simulation in computer science, Simulation in applied mathematics, and Simulation in mechanical engineering
Old Dominion University Masters of Engineering or Masters of Science in Modeling and Simulation, PhD with a concentration in simulation	Concentrations: Simulation Based Instruction Analysis and Decision Making Human/Computer Interaction Simulation Development Distributed Simulation Systems
University of Alabama at Huntsville Masters of Engineering in Simulation	Program Information not available
RMIT University, Melbourne (Australia) Masters of Engineering in Simulation Technology	Option to get a certificate or move up to a diploma Certificate to Diploma Areas: Simulation Systems Simulation and Modeling Games Design
Naval Postgraduate School Master of Science in Modeling, Virtual Environments and Simulation	Called the MOVES Curriculum Two year, eight quarter program Two Tracks: Visual Simulation Human-Computer Interaction

3. M&S DESIGN ISSUES

Several issues have been identified in developing an M&S degree program. They include the degree level of the program, the type of program certification, the housing of the program, and the content and structure of the program.

3.1 An M&S Engineering Bachelorette Degree

Sarjoughian and Zeigler [2000] argue that the ideal career development path for professional practice should begin with the Bachelorette degree as preparation for professional practice (see also Gibbs [1996]) and that an M&S program should be accredited. Accreditation is often viewed as a vehicle for ensuring program regulation, consistency, content, and continuous improvement. Several researchers have concluded that a curriculum background in either science or engineering is essential for simulation education [Rogers, 1997; Nance, 2000; Szczerbicka, 2000] and Sarjoughian and Zeigler [2000] argue that the appropriate discipline is engineering due to the widespread use of simulation in engineering. Certainly arguments can be made against these conclusions. In this paper we assume these conclusions to be correct and examine the possibility of an accredited Bachelorette degree in engineering. Where the program would be housed, the program structure, and the program content are discussed in the next sections.

3.2 Housing an Undergraduate M&S Program

An important design consideration for an M&S program is where the program will be housed in engineering. Nance and Balci [2001] identify the following alternatives: a. House M&S in an existing department, b. Create a new Department, c. Make M&S an interdisciplinary program, or d. Create a Multi-University Program. Creating an M&S program within an accredited traditional disciplined engineering undergraduate program (e.g. Electrical or Mechanical Engineering) would be challenging since accreditation requirements typically leave very few technical electives to the student. It might be possible to embed the simulation curriculum into the specific discipline content, which would require significant structural overhaul and the development of new curriculum. A new program could be created within an existing department, but a clear path to accreditation would likely be required for institutional approval. Identifying to best engineering department would also be difficult since M&S is inherently interdisciplinary.

The creation of a new department of engineering simulation would require institutional support and for public universities, state government approval. The lack of accreditation criteria for an M&S program and the lack of precedent would pose a challenge to most institutions and legislatures. Three programs shown in Table 1 have created M&S masters programs as interdisciplinary programs between departments. At the undergraduate level interdisciplinary programs have a more difficult challenge with accreditation, as faculty and resources have an ambiguous relationship to the interdisciplinary program. The development of a multi-university program would chart new territory in the accreditation process. Thus there are significant challenges to all of the options when considering traditional engineering programs, particularly due to accreditation.

3.3 The M&S Bachelorette Degree Content

The knowledge base in the area of simulation has been continuously growing for decades. Nance and Balci [2001] have identified 13 distinct types of simulation. Any detailed coverage of all of these areas would be prohibitive at the Bachelorette level, and probably also at the master's level. Rogers [1997] examines the characteristics of an ideal simulationist from a panel perspective and Nance [2000] examines panel views from the mid 1970's of simulation education attitudes, skills, and knowledge; and compares them with Rogers work to identify persistent simulation education needs. Szczerbicka et al. [2000] examine concepts of curriculum for simulation education and present an infrastructure for the establishment of an M&S discipline. The infrastructure provides conceptual linkages between accreditation and the body of simulation knowledge, which includes curriculum, licensing, a code of ethics, and standardization. A simulation core and simulation specialization is recommended. Fujimoto [2000] suggests seven guiding principles for M&S programs. These are:

1. A solid grounding in fundamentals is essential.
2. Basic knowledge and skills in computing fundamentals are important.
3. Tight coupling with application domains must be maintained.
4. Exposure of students to a broad range of core M&S topics is essential.
5. Fluency in multiple modeling paradigms is a key to intellectual development.
6. Students should understand the full M&S life cycle.
7. Effective communication skills are a prerequisite for success.

These studies provide: a good comprehensive list of the attitudes, knowledge, and skills; a conceptual infrastructure for the development of an M&S degree program; and guiding principles for M&S degree program development. However, the elements are not delineated for a particular degree program.

Professional certification and undergraduate engineering education are closely related. Much of the undergraduate engineering core is consistent with the professional engineering fundamentals examination. Thus, another possible point of guidance for establishing specific content is the professional simulation certification examinations offered by The Modeling and Simulation Professional Certification Commission [M&SPCC 2003].

4. THE "GENERAL" ENGINEERING M&S OPPORTUNITY

The term "general" engineering refers to engineering programs that are accredited under the general accreditation criteria. Traditional discipline specific engineering programs are accredited under the general accreditation criteria and under discipline specific engineering criteria.

There are 33 programs accredited and under the ABET general engineering criteria. Most of these programs do not use the title "general". There are also several others that are seeking accreditation, but must wait until they have graduates to schedule a site visit. Several non-discipline specific programs are accredited as engineering science programs or engineering physics programs. The engineering sciences model is a legacy model developed out of the need to in the 1950's to make engineering fundable by NSF as a science. These programs are in a state of rapid decline, while the general engineering programs are on the rise [Newberry and Farison, 2003].

The ABET "general" criteria for engineering permits many educational model variations. Historically, many schools adopt a general engineering model as a transition model to discipline specific programs. These programs tend to have a fixed curriculum that offers discipline specific concentrations similar to traditional disciplines (e.g. Geneva). Some general engineering programs have been developed to provide greater flexibility for students. The more extreme flexible models permit student to design some of their own program (e.g. Purdue or Olin College). A semi-flexible model offers choice through the choice of a minor or a secondary concentration (e.g. Illinois and Idaho State).

Some offer flexibility by offering a greater number of elective hours (e.g. Baylor and Michigan Tech). An alternative general engineering model provides students with greater engineering breadth, characterized by a fixed curriculum, a larger engineering core, and fewer electives (e.g. Harvey Mudd). The flexibility provided under the ABET general accreditation criteria would allow for many variations of an M&S undergraduate program and reduce many of the difficulties previously noted. General engineering programs do not need to satisfy specific discipline requirements leaving more opportunity for simulation content. Next we present a summary of the ABET general engineering criteria.

4.1 The ABET "General" Engineering Criteria

An examination of the ABET general engineering accreditation criteria is not only useful for investigating how an M&S program could be accommodated, but also as a base model for the development of M&S accreditation criteria.

ABET evaluates all engineering programs in seven areas. Traditional disciplined engineering programs are also evaluated by additional specific criteria. The seven areas of evaluation (the general criteria) include:

1. Students: Addresses how students are monitored, evaluated, and advised. It also addresses policies for transferring courses and course evaluation.
2. Program Educational Objectives: Addresses program published objectives, the periodic evaluation of objectives, and how the curriculum meets the objectives.
3. Program Outcomes and Assessment: All engineering programs must demonstrate that their graduates have:
   (a) An ability to apply knowledge of mathematics, science, and engineering
   (b) An ability to design and conduct experiments, as well as to analyze and interpret data
   (c) An ability to design a system, component, or process to meet desired needs
   (d) An ability to function on multi-disciplinary teams
   (e) An ability to identify, formulate, and solve engineering problems
   (f) An understanding of professional and ethical responsibility
   (g) An ability to communicate effectively
   (h) The broad education necessary to understand the impact of engineering solutions in a global and societal context
   (i) A recognition of the need for, and an ability to engage in life-long learning
   (j) A knowledge of contemporary issues
   (k) An ability to use the techniques,
4. Professional Component: All graduates must have one year of mathematics and science, and one and a half year of engineering science and design.
5. Faculty: Addresses the sufficiency of faculty numbers, capability, and qualifications.
6. Facilities: Addresses sufficiency of classrooms, laboratories, and tools.
7. Institution: Addresses institutional support, financial resources, and leadership.

It is important to note that the content requirements of a general engineering program are not specific. The additional criterion for traditional disciplined engineering program specifies more specific content, but not in detail. An example of the eighth criteria for a traditional disciplined engineering program (mechanical engineering) follows.

"The program must demonstrate that graduates have: knowledge of chemistry and calculus-based physics with depth in at least one; the ability to apply advanced mathematics through multivariate calculus and differential equations; familiarity with statistics and linear algebra; the ability to work professionally in both thermal and mechanical systems areas including the design and realization of such systems (ABET 2003)" Next we examine simulation as a concentration in an accredited Bachelorette degree program in general engineering.

4.2 M&S Within a General Engineering Program

There are many advantages of building an M&S program within a general engineering program. Simulation content could represent more than 30% of the engineering program on top of the general criteria. As an example, Arizona Sate University requires 128 semester hours for an engineering degree (32 hours per year). Between 40-50 semester hours are typically devoted to discipline specific criteria, which could be simulation. About half of the 40-50 semester hours would need to be classified as engineering science or engineering design, which means that this simulation content would need to be embedded in engineering applications. One early opportunity for embedding simulation in engineering is within physics courses, which is part of criteria four (one year of mathematics and science). Physics engines for simulation could be introduced and used as a vehicle for studying the subject.

By coupling M&S within general engineering many of the attributes of the ideal simulationist addressed by Rogers [1997] would be achieved through the general engineering criteria. General engineering programs also have the flexibility to determine content. This flexibility facilitates multidisciplinary degrees where students have concentrations in both simulation and a more traditional engineering area. A general engineering could be used as an evolutionary model geared toward making an accredited specialization in M&S. A roadmap to accreditation is presented in the next section.

5. A ROADMAP FOR AN ACCREDITED UNDERGRADUATE M&S DEGREE IN GENERAL ENGINERING

M&S accreditation should be developed over time, as the M&S accreditation body and the M&S program need time to evolve while developing and refining criteria. Likewise, new curriculum needs to be developed that embeds simulation into engineering. The possible roadmap for evolving M&S into an accredited engineering degree follows.

1. Create a simulation concentration within a general engineering program coupled with other multidisciplinary concentrations. The concentration would not need to cover all of the attitudes, knowledge, and skills identified in the previously identified studies. The content could grow over time within the concentration or a second concentration. Each concentration should be developed cooperatively with the program and a simulation accreditation body.
2. Create content certification in specific areas. As concentration are developed and offered, the simulation

accreditation body should provide certification of the area. This would be advantageous to students seeking to practice professionally, faculty seeking to develop curricula and seeking institutional support, and industry seeking to employ competent students. Some of the content areas could be closely tied to the professional exams. As an example, a certification could be created for a "general" simulationist. This certification would specify the basic knowledge, skills, and attitudes required such as modeling, analysis, languages, architectures, standards, and validation. Multiple levels could then be certified such as "advanced" and "expert". Alternatively, there could be a certification in particular content areas.

3. Allow programs to propose the concentration content areas and request certification of content or levels. Each engineering program will have unique characteristics and serve a particular region, thus there should be some flexibility in the in program structure and content. This is consistent with ABET accreditation of discipline specific programs. In the example of engineering discipline specific criteria, the content areas were general and not detailed. Each program should choose how to achieve and demonstrate the criteria.
4. Develop specific evaluation criteria modeled after the ABET criteria. As the content and curriculum matures the simulation accreditation body should develop simulation engineering discipline specific accreditation criteria and procedures for evaluation.
5. Evaluate and accredit a simulation-engineering program. The simulation accreditation body would by this point have experience in content certification and criteria and procedures for evaluation. An option at this point would be to work with ABET to move the accredited simulation engineering program to a disciplined engineering degree status accredited through ABET. Alternatively, the new degree program would have accreditation from both ABET and the governing simulation body.

6. KEY ELEMENTS OF THE M&S PROGRAM: THE SCS PERSPECTIVE

The necessary elements in an M&S program are organized into a three-level tiered structure, shown in Figure 2 below. The innermost core will constitute the first part of the program, spreading over 1-2 years, and is intended to impart expertise in modeling real-world and abstract processes. The inner core represents the intermediate stage, spanning a year, where students are exposed to the fundamental principles of simulation. The final phase offers students to specialize in any of the areas of their choice and will include a major project that must include design, implementation, and testing, and demonstrate the student's mastery, depth-wise and breadth-wise in modeling and simulation.

The innermost core will provide the principles of modeling, especially logical behavior, causality, and timing; the medium through which executable models may be expressed, namely general-purpose and special-purpose programming languages; and the fundamental knowledge pieces from physics, mathematics, chemistry, biology, medicine, law, social behavior, business, and finance. The intent is for the knowledge pieces to assume the form of highly condensed rules, laws, core principles, and insights, and to provide students a unique ability to move freely across different disciplines as they progress in their careers. The inner core will include the topics of centralized and synchronous simulation, discrete event specification systems (DEVS), generalized DEVS (GDEVS), asynchronous distributed simulation, and stochastic variables. In their final year, M&S students may specialize in a number of areas including digital systems design, fault simulation and testing of VLSI, video game design, simulation of activities in outer space, automobile design and testing, net-centric warfare in the military, accelerated drug testing in the medical and pharmaceutical industry, harbor management and security, intelligent transportation, financial services systems, and others. The list of specialization areas will inevitably grow with time. SCS will develop the content of Figure 2 in a comprehensive manner to serve both as a guide and an accreditation standard. The specification would include in detail the skills and competencies expected of the M&S students and provide a description the pedagogical material, possibly in the form of a set of courses with their contents, laboratory exercises, and list of books wherever possible.

To provide greater depth at the graduate level, SCS is presently considering ideas related to graduate education in M&S. Under consideration is a certificate program that will consist of a set of four graduate courses in M&S as well as a full M.S. program in M&S. To ensure high quality, SCS will also take into consideration the idea of a comprehensive examination, developed and administered by SCS throughout the world, as the culmination of the graduate program.

7. CHALLENGES IN IMPLEMENTING THE PROPOSED MODEL

There are several broad challenges to implementing the proposed M&S model. First, new curriculum would need to be developed that embeds simulation into engineering science and design. However, the general engineering model would require less curricular embedding and development than a traditional disciplined engineering program. Second, content certification criteria recognized by industry needs to be developed. While the professional exams offer some content certification, these should be expanded. Third, the development of accreditation procedures and criteria will require significant commitment from a simulation accreditation body.

There are also several institutional challenges for the implementation. Building a new program will require an investment of resources including recruiting simulation faculty building new curriculum. Another challenge is to attract students to the new program. These challenges should be moderated through the proposed evolutionary implementation

8. CONCLUSIONS

The primary intent of this paper is to stimulate a vigorous discussion in the general engineering community and the modeling and simulation community on the need to design new M&S programs at the undergraduate and graduate levels to address a void in today's industry and to encourage new opportunities for the future.

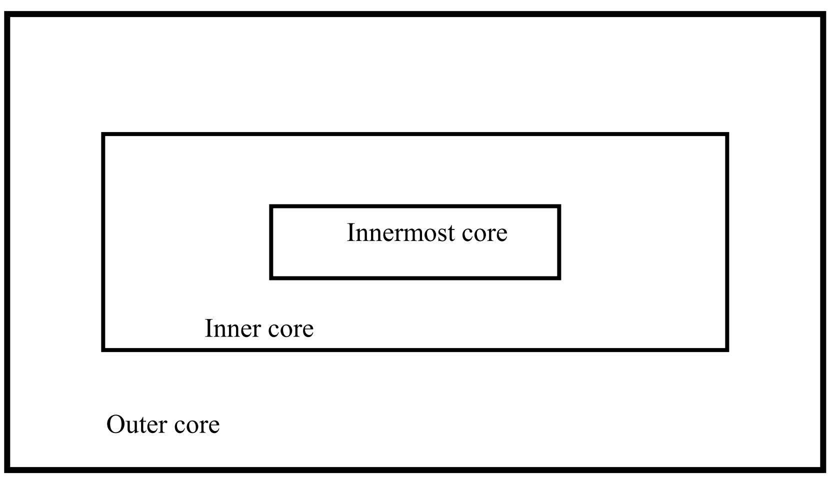

Figure 2

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Biography

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Sumit Ghosh earned his B.Tech degree from the Indian Institute of Technology in Kanpur, India,and his M.S. and Ph.D. degrees from Stanford University, California. He has worked at Silvar-Lisco, Fairchild Advanced Research and Development, Schlumberger Palo Alto Research Center, Bell Labs Research, Brown University, and Arizona State University prior to his current position. He has written five reference books -- Hardware Description Languages: Concepts and Principles (IEEE Press, September 1999), Modeling and Asynchronous Distributed Simulation: Analyzing Complex Systems (IEEE Press, June 2000, with Dr. Tony Lee), Intelligent Transportation Systems: New Principles and Architectures (CRC Press, January 2000, with Dr. Tony Lee, First Reprint June 2002), Principles of Secure Network Systems Design (Springer-Verlag, April 2002), and Algorithm Design for Networked Information Technology Systems: Principles and Applications, (Springer-Verlag, November 2003). He has also written 95 transactions/journal papers, 97 refereed conference papers, 4 book chapters, and 1 edited book. His research interests include networking, network security, hardware design languages, asynchronous distributed algorithms, modeling and simulation, intelligent transportation systems, synthetic creativity, engineering design, reconfigurable computer architecture, adapting biological processes into engineering, Ph.D. education, and a new program in networked computational systems engineering. Visit http://attila.stevens-tech.edu/~sghosh2 for more details