Simulation in Undergraduate Education Initiative in Electrical Engineering

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ABSTRACT
As demand for computational modeling and simulation (M&S) engineers continues to increase, much attention has been focused recently on what constitutes proper educational preparation for a career in this area. This paper presents an integrative concept for a modeling and simulation study program in electrical engineering at the undergraduate level used in developing a program for a cadre of students in the field of M&S at the Department of Electrical Engineering in the College of Engineering at the University of Nebraska-Lincoln (UNL). This integrative program is part of a course, curriculum, and laboratory improvement project called Undergraduate STEM Education Initiative in Creative Educational Innovations for Electrical Engineering Students (USE-ICE).

1. Introduction
In today’s complex and competitive world of technological innovation, determining the accuracy, financial viability, and utility of new discoveries depends increasingly on computational modeling and simulation (M&S). As an inexpensive, safe method for designing for unavailable physical circumstances, M&S is used to provide detail for design issues by verifying and validating the models of the design and analyzing the results obtained from the model — critical research elements needed in industry and government. Recognizing the importance of M&S, the 2006 NSF Blue Ribbon Panel [1] reported that continued advancement in the M&S field is critical for resolving a multitude of scientific and technological problems facing the United States. In addition, the White House American Competitive Initiative [2] report identified M&S as a key enabling technology of the 21st century. With pressure to cut costs while increasing technological development, researchers will necessarily turn to M&S in order to increase the development and understanding of the systems and their interactions. Hence, the demand for M&S engineers will continue to increase in order to address the above questions. In order to prepare electrical engineering graduates for a career in M&S, much attention has been focused recently on what constitutes a proper M&S educational program. This is the motivation for the educators to focus on developing a model curriculum for a B.S and/or M.S. degree in modeling and simulation to assist engineering schools in planning new programs in this field.

The task of defining a curriculum for a Masters degree in computational modeling and simulation is difficult, partly because M&S is not normally seen as a discipline in its own right at most universities. The area is usually regarded as a fragmented subject with components in a range of disciplines including, but not limited to, electrical and mechanical engineering, computer science and computer engineering, mathematics, the sciences and so forth. Furthermore, the range of applications of M&S is so wide that almost any university department could offer an M&S course applied to its particular discipline. This results in M&S course offerings which might be included in an M&S degree program being scattered throughout the university with no central responsibility for it as a discipline.

One way of addressing this lack of focus is to identify the skills that the graduates of an M&S program in electrical engineering should possess upon graduation. The educational issues regarding this degree and its educational component can be answered by a criteria and qualifications list that conforms with ABET requirements for academic education [3] as well as surveying relevant industries.

Developing the program will begin with identification of job skills. Then, educational standards and criteria for their evaluation by a responsible body will be developed. This will include defining various elements of the program in terms of the resources needed, the course components, and the
methodology used to identify the components and offer the program. This process is represented by the process workflow as shown in Fig. 1.

Fig. 1: Job criteria identification and review process workflow

As illustrated in Fig. 1, when criteria for qualifications, responsibilities, and educational components are developed, it is easy to map them into a curriculum and determine the resources needed. The curriculum will be based on a number of credit hours (courses) that will include fundamentals covering methodology, tools, and techniques and advanced topics covering focus area issues and advanced math. In addition, some elective courses at the upper level are needed to expand students’ knowledge base. There will be no restrictions as to department or discipline for these elective courses as long as they conform to the student’s academic goals and receive faculty committee approval. This emanates from a general agreement on leveraging the use of M&S in the learning and teaching process. M&S education also requires research through the construction of models, simulating the scenarios, and piloting realistic schemes.

2. Facing the ABET Requirements

Taking into account ABET Criterion No. 3 for Engineering Programs [3] and program outcomes and their assessment, engineering programs must demonstrate that graduates have M&S-specific knowledge and that they are able to:

1. Apply mathematics, science, engineering, and computing principles.
2. Design and conduct experiments, and analyze and interpret the data.
3. Create a system, component, or process model that will meet the need within realistic constraints, such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
4. Work with and/or lead multidisciplinary teams.
5. Identify, formulate, and solve engineering problems by selecting and applying appropriate M&S techniques.
6. Understand professional and ethical responsibilities.
7. Listen and communicate effectively.
8. Understand the impact of M&S-based engineering solutions in a global, economical, environmental, and societal context.
9. Recognize the need to engage in life-long learning.
10. Apply the techniques, skills, and modern engineering and M&S tools necessary for an M&S based engineering practice.
11. Consider the entire system in project solutions.
12. Acquire knowledge of contemporary issues such as:
   - Awareness of the contemporary tools and techniques in M&S throughout a system life cycle.
   - Awareness of the issues of architecture, scale, complexity, and utility in the design and maintenance of models and their simulations.
13. Exert the effort necessary for the job success.

It is important that the program provides engineers with the ability to consider the entire nature of a system in project designs and/or solutions rather than individual aspects of it, which is the traditional practice in development areas. As a result, electrical engineers are required to have the skill to work with designs that have a high degree of complexity and solutions that require the use of the advanced techniques that M&S can offer. UNL, Department of Electrical Engineering, programs that are ABET accredited will ensure that the new M&S program includes the criteria mentioned above as a measure for the professionalism of its graduates and that the graduates meet and surpass the ABET criteria.

The development of this work follows the work published at the SIE ABET Information Site of the University of Arizona [4]. Due to the general needs of electrical engineering, the UNL EE Department will focus on these primary requirements according to the educational goals described in the university catalogue. The program requirements were mapped into two goals to meet the criteria, which can be supported by metrics for measurement of the educational outcomes.

Goal No. 1

UNL EE students should have the ability to create a system, a component, or a process model, taking into account the entire nature of the system, the component, or the process model in project designs and/or solutions in order to meet the needs within realistic constraints, such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability. Such
a qualification requires using the techniques of mathematics, physics, electrical and computer engineering, sciences, and computer simulation.

As a result of this educational goal, the UNL graduates should have the ability to:
- Read, identify, and interpret electrical engineering problems.
- Understand the entire nature of a system, component, or process model created and their required criteria in electrical engineering.
- Implement all of the steps in creating the design process in electrical engineering.
- Formally document the entire design process in electrical engineering.
- Identify possible conflicting criteria from a variety of stakeholders and determining acceptable solutions.
- Identify critical electrical engineering problems that must be included in the system, component, or process models.
- Identify the appropriate M&S tool(s) needed for finding an adequate solution for the electrical engineering problem.
- Implement the identified M&S tool(s) needed to find an adequate solution for the electrical engineering problem.
- Interpret the results of the dynamic behavior of the electrical engineering problems through modeling and simulation.
- Perform a sensitivity analysis and interpret the results with regard to adaptability of the system, component, or process parameters.
- Perform a parameter estimation to achieve an optimal solution of the system, component, or process to be created and interpret the results.
- Understand the impact of the system, component, process model design solution on society and the environment.

The program outcomes and assessment can be demonstrated by:
- Scores on final exams in courses that contain significant design content and significant M&S experiences in electrical engineering.
- Scores on prerequisite design content and M&S assignments in advanced courses.
- Student self-assessment of abilities.
- Case studies that make use of the whole design process in electrical engineering.
- Case studies that make use of M&S techniques and solution interpretation.
- Project reports from the capstone design experience.
- Reports from undergraduate research experiences that contain the whole design process.
- Reports from design experience of the projects that include considerable amount of M&S.
- Successfully completing the capstone design project.

**Goal No. 2**

UNL EE students should have the ability to be contributing members of multidisciplinary teams and be able to lead projects, infuse the knowledge of contemporary issues into solutions, and exert the effort necessary for the success of the job.

As a result of this educational goal UNL graduates should have the ability to:
- Bring in valuable technical expertise that can be used by the multidisciplinary team.
- Bring in excellent communication skills.
- Bring in a valuable knowledge to successfully complete the task under implementation.
- Take different roles within the team structure as necessary.
- Appreciate the strengths and benefits of having diverse team members.
- Place knowledge of contemporary issues into solutions.
- Exert the effort necessary for job success.

The program outcomes and assessment can be demonstrated by:
- Successfully completing the multidisciplinary team constraints projects.
- Successfully infusing knowledge of contemporary issues into the solutions.
- Successfully completing the capstone multidisciplinary design project.
- Successfully finding optimal solution in design of multidisciplinary projects.
- Successfully completing the UNL technical writing course.
- Successfully using professional communication tools.
- Completing a student self-assessment of abilities in teamwork and communication.

**3. Perspectives on M&S Education in Electrical Engineering**

Computational modeling and simulation is an iterative process, consisting of model building and computer-assisted simulation by which the model structure and/or its parameters may be changed in an attempt to match the system, component, or process model created with the actual system. In effect, the derived model has served its purpose when an optimal match (solution) is obtained between the simulation results and the data obtained from the developed system, component, or process model under test.

In general the model building process entails the use of various types of information sources. In doing so one has to bear in mind:
- the goals and purposes of modeling, determining boundaries, components of relevance, and the level of detail,
- a priori knowledge of the system, component, or process being modeled,
• experimental data consisting of measurements on the system, component, or process inputs and outputs
• estimations of nonmeasurable data as well as state space variables of the system, component, or process model created.

With respect to the spectrum of available models and variety of levels of conceptual and mathematical representation, it is evident that the developed model depends on the goals and purposes for which the model was built, the extent of the a priori knowledge that was available, data gathered through experimentation and measurements or estimation on the system, component, or process model that was created. However, from a general point of view, two major facts are important when modeling systems, components, or processes:
• A model always is a simplification of reality but should never be so simple that it provides answers that are false.
• A model has to be simple to allow easy handling and working with it.

Moreover, there are two important constraints when modeling. They are compromise between model goodness, which means exactness of the results obtained from the model, and expenditure, which means the cost of developing the model, its implementation on the computer, and its simulation, as shown in Figure 2.

Fig. 2: Dependence of the modeling expenditure (costs) vs. the degree of accuracy (model quality)

From Figure 2 one can conclude that there is no reason to develop expensive models in electrical engineering, because the increment of goodness is less than the increase in cost. But a model not only describes the relationships between the system, component, or process inputs and outputs, it also gives detailed insight into the system, component, or process structure and into some system, component, or process internal relationships and, therefore, allows prediction of the system, component, or process behavior.

As a case study, let’s assume that a process controller needs to be designed for a wastewater treatment plant. This process [5] can be described by a set of process-dependent signals obtained from the sensors embedded in the plant. The process control can be shown in a block-oriented graphical programming environment with built-in measurements and analysis functions shown in Figure 3. The controller is embedded in the process computer, which is based on the PC 104+ standard. Furthermore, the process control with its event-driven task handling includes a database for data handling and a co-writer for process documentation.

The controller in Figure 3 is part of an overall wastewater treatment plant process control represented in block oriented graphical programming environment with built-in measurements and analysis functions. These functions allow rapid design and prototyping using control design techniques for constructing plant models in state-space form or transfer function form. Pole-zero-gain and analyzing system performance with pole-zero maps, step response graphs, and Bode plots may also be used. Through modeling and simulation, the model wastewater treatment plant can be combined with the model developed of the controller to investigate and optimize the overall wastewater treatment plant system. The simulation can be used to define the open- and closed-loop characteristics of the system under the test.

The above block-oriented graphical programming environment is based on the signal pathway concept that allows inserting blocks and/or elements, connecting blocks and/or elements, etc., via chains which communicate in real time with the adjacent blocks/elements and/or process control components, as shown in Figure 4.

The idea of this graphical programming environment concept is similar to the commercially available National Instruments LabVIEW that is used to create a fully functional measurement
application with analysis and a custom user interface using a variety of PCI- and USB-based data acquisition hardware [6]. A LabVIEW block that is used to generate a waveform containing a sawtooth wave is shown in Figure 5.

The waveform is represented by a sequence y, and the analysis function element that generates a pattern according to the equation:

\[ y[i] = \text{amp} \times \text{sawtooth}(\text{phase}[i]), \quad \text{for } i = 0,1,2,\ldots, n-1, \]

4. Basic M&S Curriculum Structure

As a result of the previous explanations, the general framework for the M&S study program in electrical engineering at the undergraduate level can be specified. In selecting the topics to be covered, different areas were selected to address the wide range of application domains in electrical engineering. From a more general perspective, the M&S study program requires a minimum of 12 semester units, which is equivalent to 4 courses of M&S fundamentals including methodology, tools and techniques, a seminar of at least 3 units on a M&S topic in EE and a project of at least 3 units on an electrical engineering topic related to M&S. From a general perspective, the following M&S study area subjects (SAS) are offered for an M&S study program in EE:

1. SAS-1: Fundamentals of computational modeling and simulation of continuous time systems and discrete time systems

2. SAS-2: Fundamentals of tools and techniques for computational modeling and simulation of continuous time systems and discrete time systems

3. SAS-3: Seminar on electrical engineering applications related to computational modeling and simulation

4. SAS-4: Electrical engineering project related to computational modeling and simulation

5. SAS-5: Electrical engineering MS thesis related to computational modeling and simulation

Each study area subject (SAS) is divided into a number of subareas (SA). Each subarea can be regarded as a module, which is the basis of a course, a number of modules end up in a whole single course, or even more than one course. The study area subject material for SAS-1 to SAS-4 is planned to be available as F2F (face to face) as well as BL (blended learning) education modules/packages, which can be downloaded from the web.

But whatever is the basis for an M&S study program in electrical engineering, it can only be helped by the availability of a set of generally agreed upon guidelines on the structure and composition of the degree (see Section 2 about ABET criteria). Hence, it is important that the guidelines be flexible, avoiding a “one size fits all” approach [7], as it was achieved in the CSE guidelines by specifying course content in the form of subareas (SA) rather than complete courses. This modularized form allows different subareas to be mixed and matched to produce individual courses that best fit the needs and resources of a particular M&S study program in electrical engineering. As long as the mix of modules provides for all of the study area subjects that are required and adequately provides for those that are optional, the M&S study program in electrical engineering conforms to the guidelines (see Section 2 on ABET criteria).

Students entering the program are assumed to have an adequate background (prerequisites) in basic topics in mathematics, science, computer science, and their primary EE BS discipline.

The authors make no claim that these study area subject definitions are complete. They are merely offered as a point for discussion and elaboration. The UNL EE Department would welcome all comments – positive and negative – including suggestions for alternate ways of arriving at a set of guidelines that are sufficiently prescriptive to provide positive guidance to program developers and sufficiently flexible to avoid undue restrictions on the development of innovative programs in an area that has so many facets and multidisciplinary aspects.
Quality Assurance
The mission of university education is to contribute to society through the pursuit of education, learning, and research at the highest international levels of excellence [8]. In order to ensure that the quality of learning and teaching activities excellencies maintained, the M&S study program in electrical engineering needs to embed a quality assurance procedure which allows examination and reflection and enhances teaching activities. Hence, quality assurance process has to review the teaching, learning, and assessment activities, including curriculum content and design, at appropriate regular intervals. Normally this would be at least annually, as part of a review of the quality statement or in response to reports of examiners or responses to student questionnaires, the student feedback on teaching and courses, which is considered essential for good practice. For this reason, criteria have to be established to enable the M&S study program in EE to assess its program and courses offered. This is based on the two goals and learning outcomes and how they relate to the course delivery and assessment. The learning outcomes focus, from a general point of view, on knowledge and skills and have been reflected in relation to the ABET requirements in chapter 2 and its accompanying measures, the two goals, with their respective professional alignment. Henceforth the quality assurance criteria are given in relation to the ABET requirements.

5. Conclusion
The first version of a model curriculum for an under-graduate degree in M&S in electrical engineering is proposed. We hope that this can be used as a basis for wide-ranging discussions that will lead to a published version sponsored by interested professional bodies, such as ACM, SCS; SIM SUMMIT, and IEEE-CS.

6. References
[3] Criteria for accrediting engineering programs - Effective for evaluations during the 2008-2009 accreditation cycle; incorporates all changes approved by the ABET Board of Directors as of November 3, 2007. Published by Engineering Accreditation Commission ABET, Inc.

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