AN ACCREDITED ENGINEERING CURRICULUM FOR MODELING AND SIMULATION

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ABSTRACT

The Accreditation Board for Engineering and Technology (ABET) is an internationally known organization for recognizing engineering programs that work towards student attainment in learning outcomes that conform to engineering disciplines and have a process for measuring attainment and continuous improvement. There are eight general criteria to be satisfied that include student outcomes, educational objectives, curriculum, facilities and faculty. Additionally, there may be program-specific requirements depending on the particular discipline. The modeling and simulation (M&S) engineering (M&SE) program at Old Dominion University satisfies the program criteria for general engineering in the ABET Engineering Accreditation Commission and declares detailed discipline-specific student outcomes to ensure unambiguous definition of a pioneering program in order to set a standard that can be utilized as a template for future up-and-coming M&SE programs. This paper presents the curriculum and program-specific outcomes that have been incorporated into our continuous improvement process for student attainment of our M&S engineering program outcomes.

Keywords: modeling and simulation, simulation education, engineering accreditation, student outcomes

1. INTRODUCTION

Modeling and Simulation (M&S) is now emerging as a recognized discipline much like the emergence of computer science in the early 1960s with one of the first departments at the University of North Carolina at Chapel Hill founded by Dr. Frederick P. Brooks Jr. Similarly, it would take decades before the emergence of Computer Engineering. Now-a-days, Computer Science and Computer Engineering departments are ubiquitous around the world. We believe M&S is on the same path and, therefore, have started the Department of Modeling, Simulation and Visualization Engineering (MSVE) in 2010 to administer the B.S. degree in M&S Engineering (M&SE). This effort was built upon a successful 12 year interdisciplinary program at the graduate (M.S. and Ph.D.) levels.

2. HOW DO WE DEFINE M&S

M&S is a discipline focused on advancing and using the theories and practices of selecting appropriate modeling techniques, creating associated models, executing models dynamically over time, utilizing visualizations for V&V, and evaluating a range of possible solutions through analytical techniques. Then, applying this knowledge in many domains.

The first step is in creating a model of an existing or perceived system utilizing the appropriate model for the system of interest. Just this step alone can depend upon several theoretical approaches and depends heavily on the objectives of the model but in the end the model will be an abstract representation of the target system. The next step is then simulating the system using the developed model. Computer simulation is an applied methodology in which the behavior of complex systems is described using a model (mathematical or symbolic and often stochastic) and executed on a digital computer. Components of the model are updated in an appropriate manner (in serial, parallel or distributively) and with regards to time and causality. Visualization goes hand-in-hand with simulation and so we would want to visualize the simulation/model to promote understanding and verification & validation (V&V). Scientific visualization of data, model performance and results allows verification and face validation of the model. Finally, possibly the most important step is statistical validation and analysis of the solution space generated by the simulation to be able to choose the best solution and take the best decision. Since simulation allows easy changes to input considerations which results in differing solutions, one must know how to compare solutions and determine which decision is best.

We believe this broad approach to engineering instills the methods and tools supportive of innovation and stresses problem-solving skills applicable to all engineering and science disciplines. After all, engineering is about problem-solving and M&S engineering is about finding and understanding a range of solutions to provide the best solution over a possibly unforeseen range of options.

3. M&SE CURRICULUM

The M&SE Program at ODU has a curriculum that provides students with strong coverage of the basic sciences, mathematics, and general education as identified in ABET EAC curriculum criteria requirements. Additionally, the curriculum prepares students for professional careers and further study in the M&SE discipline with a core set of engineering topics courses that focus on the development of a variety of models and simulations in software and with the utilization of simulation tools. The curriculum also culminates in a major design experience based on knowledge and skills acquired in the different levels of the curriculum. In the Appendix Tables A-1 and A-2 we show the full curriculum. Below we describe only the M&SE core courses [odu.edu/msve].

MSIM 201. Introduction to Modeling and Simulation Engineering.

This is the first course for Modeling and Simulation Engineering (M&SE) students. M&SE discipline is surveyed at an overview level of detail. Topics include basic definitions, M&S paradigms and methodologies, applications, design processes, and human factors. Information literacy and research methods are addressed. Papers and oral presentations are required and allow the student to investigate different aspects of the discipline. The course provides a general conceptual framework for further M&SE studies.

MSIM 205. Discrete Event Simulation.

An introduction to the fundamentals of modeling and simulating discrete-state, event-driven systems. Topics include basic simulation concepts and terms, queuing theory models for discrete event systems, structure of discrete event simulations, problem formulation and specification, input data representation, output data analysis, verification and validation, and the design of simulation experiments.

MSIM 281. Discrete Event Simulation Laboratory.

A laboratory course designed to provide a hands-on introduction to the development and application of discrete event simulation. Topics include an introduction to one or more discrete event simulation tools, common modeling constructs, data gathering and input data modeling, design of simulation experiments, output data analysis, and verification and validation. The design and implementation of a series of increasingly complex simulations of various discrete event systems are conducted.

MSIM 320. Continuous Simulation.

An introduction to the fundamentals of modeling and simulating continuous-state, time-driven systems. Topics include differential equation representation of systems, formulation of state variable equations, numerical integration, and techniques for numerical solution of differential equations including the Taylor algorithm and the methods of Runge-Kutta. Application domains considered include physical and biological systems.

MSIM 331. Simulation Software Design.

Introduction to data structures, algorithms, programming methodologies, and software architectures in support of computer simulation. Topics include lists, queues, sets, trees, searching, sorting, reusable code, and order of complexity. Simulation structures developed include event lists, time management, and queuing models. Software models are implemented and tested.

MSIM 382. Continuous Simulation Laboratory.

A laboratory course designed to provide a hands-on introduction to the development and application of continuous simulation. Topics include an introduction to one or more continuous simulation tools, modeling of various physics-based systems, and numerical solution of differential equations. The design and implementation of a series of increasingly complex simulations of various continuous sytems are conducted. Written communication skills are stressed; weekly writing assignments are required.

MSIM 383. Simulation Software Design Laboratory.

A laboratory course designed to provide a hands-on introduction to the development of simulation software. Topics include data structures, algorithms, and simulation executives. The students will conclude with the development of a basic simulation executive capable of managing discrete event simulations. Written communication skills are stressed; writing is required for each laboratory assignment.

MSIM 410/510. Model Engineering.

The goal of this course is to develop understanding of the various modeling paradigms appropriate for capturing system behavior and conducting digital computer simulation of many types of systems. The techniques and concepts discussed typically include UML, concept graphs, Bayesian nets, Markov models, Petri nets, system dynamics, Bond graphs, etc. Students will report on a particular technique and team to implement a chosen system model.

MSIM 441/541. Computer Graphics and Visualization.

The course provides a practical treatment of computer graphics and visualization with emphasis on modeling and simulation applications. It covers computer graphics fundamentals, visualization principles, and software architecture for visualization in modeling and simulation.

MSIM 451/551. Analysis for Modeling and Simulation.

An introduction to analysis techniques appropriate to the conduct of modeling and simulation studies. Topics include input modeling, random number generation, output analysis, variance reduction techniques, and experimental design. In addition, techniques for verification & validation are introduced. Course concepts are applied to real systems and data.

MSIM 487W. Capstone Design I.

Part one of the senior capstone design experience for modeling and simulation engineering majors. Lectures focus on providing professional orientation and exploration of the M&S design process. Written communication, oral communication and information literary skills are stressed. Individual and group design projects focus on the conduct of a complete M&S project. Industry-sponsored projects are an option. Individual and team reports and oral presentations are required.

MSIM 488. Capstone Design II.

Part two of the senior capstone design experience for modeling and simulation engineering majors. Lectures focus on providing professional orientation and exploration of the M&S design process. Written communication, oral communication and information literacy skills are stressed. Individual and group design projects focus on the conduct of a complete M&S project. Industry-sponsored projects are an option. Individual and team reports and oral presentations are required.

4. PROGRAM SPECIFIC OUTCOMES

Currently, the M&SE Program is evaluated under the ABET General Criteria only. Therefore, there are no specific ABET EAC Program Criteria for the M&SE Program. However, the MSVE Faculty took great care in developing a curriculum that would satisfy both ABET and possible future discipline-specific criteria for modeling and simulation engineers. Along with this curriculum was developed several discipline-specific student outcomes. These outcomes were assessed as to their level of attainment by our students along with the eleven general engineering student outcomes which can be found on the ABET website (www.abet.org). The eleven general engineering outcomes will not be discussed here but rather the discipline-specific outcomes for our M&SE Program are discussed below.

4.1. M&S Capabilities

Students graduating with a B.S. in M&SE are expected to be able to model a variety of systems from different domains using appropriate techniques and tools and communicate those designs to technical peers and non-technical managers or customers. Where available tools are lacking, students should be able to develop needed capabilities in software. Utilizing the experimental process, the M&S student should be able to generate and analyze simulations results after verifying and validating their models and simulations in order to reach an appropriate conclusion. These processes should be supported judiciously were possible with visualization. With these desired capabilities in mind, program-specific outcomes were created above and beyond the eleven ABET general outcomes.

4.2. M&SE Program-Specific Outcomes

Initially, there were 9 different program specific outcomes and those 9 outcomes were assessed as to the program's effectiveness in achieving those outcomes. Homework and test problems that were directly attributable to learning a particular outcome were assessed by the course instructor utilizing a rubric as to whether the work was in the (1) Unacceptable, (2) Marginal, (3) Good, or (4) Excellent category. Then, the results for all students in the class (and likely other classes) were averaged to determine a Student Outcome Category Average (SOCA) score. Our target for all program-specific outcomes was to have a SOCA quantified score of 3.2 out of 4.0 with an average of 75% of students in the Good or Excellent range over all courses assessed for a particular SO, which are reasonably high standards. Our assessment showed that only one program-specific outcome failed to meet either of the two targets namely, "An ability to select and apply appropriate simulation techniques and tools." The statistic for this outcome was a SOCA score of 3.13 with 70.8% at the Good or Excellent range. To address this slight underperformance, the MSVE Assessment Committee recommended changes to MSIM 320 that included an increase in the number of physical systems models and examples.

Another recommendation that came out of our assessment process was to reduce the high number of program-specific outcomes since many were able to be incorporated under the general ABET criteria outcomes. After careful consideration of desired capabilities and capabilities already contained within the ABET general engineering student outcomes [McKenzie 2015], the MSVE faculty combined and reduced the number of program-specific outcomes and developed the three M&SE program specific outcomes identified below.

1. An ability to model systems across different domains
2. An ability to design and develop appropriate simulation solutions
3. An ability to apply visualization techniques to support the simulation process

The attainment of these newly established outcomes will be measured against a rubric created for each outcome as before using student learning measures such as homework, reports, test questions, etc.

5. CONCLUSIONS

Modeling and simulation is now becoming a recognized discipline with a broad engineering appeal that can be harnessed to find creative solutions to a wide variety of problems. Underlying the techniques and tools is a foundation in mathematical and statistical theories. Such theories bridge the gap between science and engineering and enable the exploration of solution spaces for problems that may be too complex, too costly, or too dangerous to explore by utilizing the real systems themselves. We have presented an educational curriculum to provide students with a well-rounded foundation to apply such methodologies to virtually any domain. We believe this curriculum has shown its viability through its successful ABET accreditation as an engineering program.

ACKNOWLEDGMENTS

MSVE faculty and staff were instrumental in developing the successful department, curriculum, and overall program.

REFERENCES

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AUTHORS BIOGRAPHY

Frederic (Rick) D. McKenzie, Ph.D. is Professor and Chair of the Modeling, Simulation and Visualization Engineering (MSVE) Department and joint member of the Electrical and Computer Engineering Department at Old Dominion University where he currently serves as Principal Investigator (PI) and Co-PI on projects involving software architectures for simulation, behavior representation in simulations, and medical modeling and simulation. Dr. McKenzie received his Ph.D. in computer engineering from the University of Central Florida in 1994. Prior to joining ODU, he held a senior scientist position at Science Applications International Corporation (SAIC), serving as Principal Investigator for several distributed simulation projects. At SAIC he was a Team Lead on a large distributed simulation system. Before joining SAIC, Dr. McKenzie worked as a student researcher on research projects involving both NASA Kennedy Space Center and NASA Marshall Space Flight Center. He has several years of research and development experience in the software and artificial intelligence fields, including object-oriented design and knowledge-based systems. Both his M.S. and Ph.D. work have been in artificial intelligence - focusing on knowledge representation and model-based diagnostic reasoning.

APPENDIX

Table A-1. M&SE Curriculum Sheet with Pre-Co-requisites (1/2)

Course	Grade	Cr.	Sem.	Comments	Pre-/Co-Requisite
Freshman Year – First Semester					
MATH 211 – Calculus I		4			P-Placement Exam
ENGL 110C – English Composition I*		3			P-Placement Exam (Not satisfied by the associate's degree)
CHEM 121N – Foundations of Chemistry I Lecture		3			P-MATH 102M[c]
CHEM 122N – Foundations of Chemistry I Lab		1			C-CHEM 121N
ENGN 110 – Engineering and Technology I		2			C-MATH 162M
General Education (Oral Communication): COMM 101R		3			
Freshman Year – Second Semester					
MATH 212 – Calculus II		4			P-MATH 211[c]
CHEM 123N – Foundations of Chemistry II Lecture		3			P-CHEM 121N[c]
CS 150 – Programming I		4			P-MATH 102M
PHYS 231N – University Physics I		4			C-MATH 211
MSIM 111 – Information Literacy and Research for Modeling and Simulation Engineers		2			P- ENGN 110
Sophomore Year – First Semester					
Course	Grade	Cr.	Sem.	Comments	Pre-/Co-Requisite
STAT 330 – Probability and Statistics		3			P-MATH 211[c]
PHYS 232N – University Physics II		4			P-PHYS 231N
CS 250 – Programming II		4			P- MATH 162M, CS 150[c], C-CS 252
CS 252 – Introduction to Unix		1			P – CS 150[c], C-CS 250
MSIM 201 – Introduction to M&S		3			P/C-MATH 163 & CS 150
Sophomore Year – Second Semester					
MATH 307 – Differential Equations		3			P-MATH 212[c]
ENGL 231C – Technical Writing*		3			P-ENGL 110C[c] (Not satisfied by the associate's degree)
General Education "A" Course (Human Creativity)		3			
General Education "L" Course (Literature)		3			
MSIM 205 – Discrete Event Simulation		3			P-MSIM 201, P/C-STAT 330
MSIM 281 – Discrete Event Simulation Lab		1			C-MSIM 205

[c] Requires a grade of "C" or better in pre-requisite course in order to register

Table A-2. M&SE Curriculum Sheet with Pre-Co-requisites (2/2)

Junior Year – First Semester					
Course	**Grade**	**Cr.**	**Sem.**	**Comments**	**Pre-/Co-Requisite**
CS 330 – Object-Oriented Program & Design		3			P-MATH 163, CS 250[c] & CS 252
CS 381 – Discrete Structures		3			P-MATH 163 & CS 150[c]
MSIM 320 – Continuous Simulation		3			P – MSIM 201; P/C – MATH 307 (280) & PHYS 227N/232N
MSIM 382 – Continuous Simulation Lab		1			C-MSIM 320
General Education "S" Course (Human Behavior)		3			
Elective – Approved Program Elective		3			
Junior Year – Second Semester					
MSIM 331 – Simulation Software Design		3			P-CS 330 & CS 381 & MSIM 205; C-MSIM 383
MSIM 383 – Simulation Software Design Lab		1			C – MSIM 331
MSIM 451 – Analysis for M&S		3			P – MSIM 205 & STAT 330
MSIM 410 – Model Engineering		3			P – MSIM 205, P/C – MSIM 320
General Education "H" Course (Interpreting the Past)		3			
Upper Division General Education – Option D Course 1		3			

Senior Year – First Semester					
Course	**Grade**	**Cr.**	**Sem.**	**Comments**	**Pre-/Co-Requisite**
MSIM 441 – Computer Graphics & Visualization		3			P – CS 250
MSIM 487W – Capstone Design I*		4			P – MSIM 331, 410, 451; "C" or better in ENGL 231C
Upper Division General Education – Option D Course 2		3			
ENMA 401 – Project Management		3			C-Junior Standing
MSIM 4xx – Approved MSIM Elective 1		3			
Senior Year – Second Semester					
ENMA 480 – Engineering Ethics (Satisfies Philosophy & Ethics Gen. Ed. Req.)		3			C-Junior Standing
MSIM 488 – Capstone Design II		3			P-MSIM 487W and MSIM 441
Elective – Approved Program Elective		3			
MSIM 4yy – Approved MSIM Elective 2		3			P/C – MSIM 487W
General Education "T" Course (Impact of Technology)		3			Not necessarily met by the Associate's Degree

[c] **Requires a grade of "C" or better in pre-requisite course in order to register**

*Grade of "C" or better (or "TP"/"DP"/"MP"/"XP"/"DN") required in ENGL 110C, ENGL 231C and a "C" or better in MSIM 487W in order to satisfy University Writing Requirements for graduation.