Developing Instructional Content for Test & Evaluation: Introduction to Modeling and Simulation for Test and Evaluation

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1. Overall project description

This section provides background information on the overall project under which the course described in this paper was developed. The project's motivation, history, and process are described.

1.1 Motivation

The use of modeling and simulation (M&S) in defense acquisition and test and evaluation (T&E) is growing steadily due to both the escalating cost of testing and acquiring new military systems, and the increasing accuracy and fidelity of models and simulations. In acquisition, combat models are used to define and refine requirements for new weapons systems to be developed, and engineering models are used throughout the process of designing and developing new military systems. In T&E, models are used to explore the range of operational scenarios for a new system to identify the critical or preferred scenarios for live tests, to supplement live tests with simulated tests in non-critical scenarios, and to create a context or stimulus for live tests. In addition, the occasions are growing when the models and simulations themselves are the systems to be tested.

Because of this expansion of the role of M&S in defense acquisition and T&E, a need has been recognized to expand the knowledge of M&S in persons working in these areas. To that end, a project sponsored by the Modeling and Simulation Coordination Office and led by the Naval Postgraduate School (NPS) was initiated to develop education curriculum and content on the topic of using M&S in defense acquisition and T&E. The project's goal has been to develop a set of university courses that provide comprehensive coverage of this application of M&S, and considered as a group, constitute a Master's degree-level education on the subject.

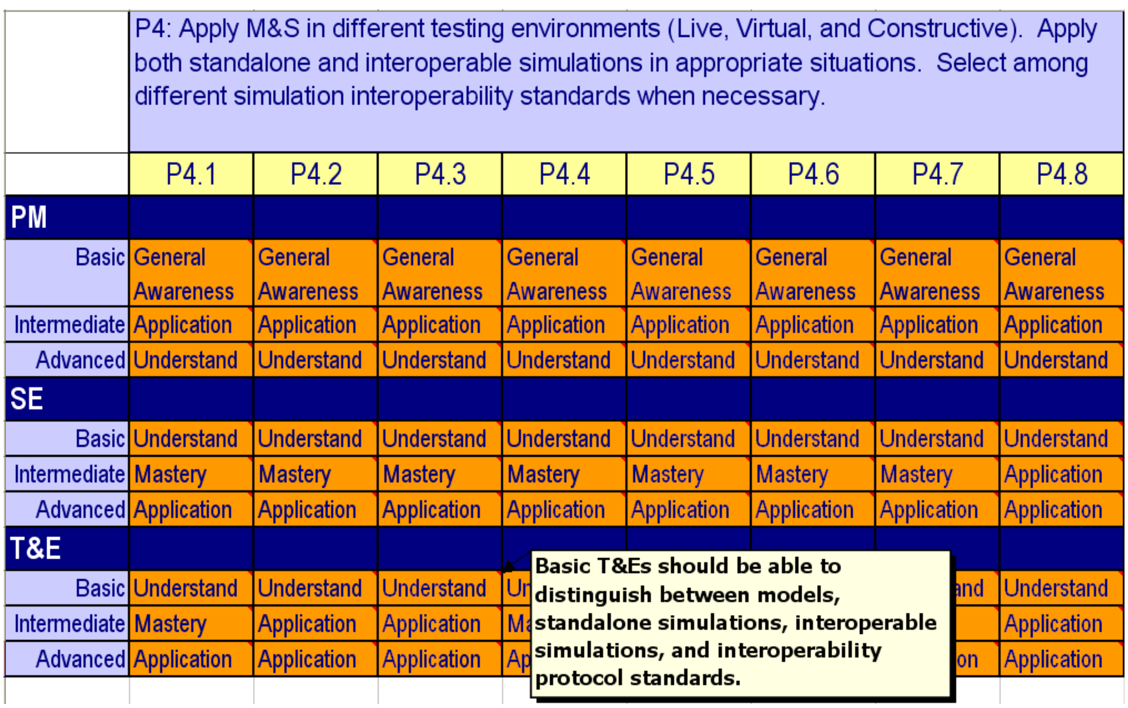
1.2 Instructional design

The first phase of the project, which took place in 2007, focused on instructional design. Working with a stakeholders group representing the different components of the education curriculum's target audiences, NPS developed a set of 42 overarching learning objectives for the curriculum, termed Educational Skill Requirements (ESRs). These ESRs specified, at a high level, the topics and concepts the curriculum should cover. A group of partner universities[1], all

[1] The partner universities during the instructional design phase included (in alphabetical order) George Mason University (GMU), Johns Hopkins University (JHU), Old Dominion University (ODU), the University of Alabama in Huntsville (UAH), the University of California San Diego (UCSD), and the University of Central Florida (UCF).

of whom had significant expertise in M&S, worked with NPS to refine these ESRs into more detailed learning objectives, termed sub-ESRs. By refining the ESRs into sub-ESRs, the topics included explicitly and implicitly in each ESR were identified and decomposed into a set of sub-ESRs, ranging in size from 3 to 42 and averaging 9 per ESR. The sub-ESRs were carefully defined so as to be relevant to the ESR, coherent in content, complementary with the other sub-ESRs of the ESR, and stated so as to be evaluable.

The education audience was divided into three groups (Program Managers, Systems Engineers, and T&E Engineers) and within each of the groups, three career levels were considered (Basic, Intermediate and Advanced). The educational audience was therefore partitioned into nine different sub-audiences. Then, for each of the sub-ESRs/sub-audience combinations, a required learning level was identified. The learning levels were General Awareness (lowest), Understanding, Application and Mastery (highest).[2] The learning level selected for each sub-ESR/sub-audience combination specified how much that sub-audience needed to know about the topic of that sub-ESR. The learning level assignments were made based on available literature on the subjects where possible, and on the professional expertise of the designers where necessary.



	P4: Apply M&S in different testing environments (Live, Virtual, and Constructive). Apply both standalone and interoperable simulations in appropriate situations. Select among different simulation interoperability standards when necessary.							
	P4.1	P4.2	P4.3	P4.4	P4.5	P4.6	P4.7	P4.8
PM								
Basic	General Awareness	General Awareness	General Awareness	General Awareness	General Awareness	General Awareness	General Awareness	General Awareness
Intermediate	Application	Application	Application	Application	Application	Application	Application	Application
Advanced	Understand	Understand	Understand	Understand	Understand	Understand	Understand	Understand
SE								
Basic	Understand	Understand	Understand	Understand	Understand	Understand	Understand	Understand
Intermediate	Mastery	Mastery	Mastery	Mastery	Mastery	Mastery	Mastery	Application
Advanced	Application	Application	Application	Application	Application	Application	Application	Application
T&E								
Basic	Understand	Understand	Understand	Ur			and	Understand
Intermediate	Mastery	Application	Application	Ma				Application
Advanced	Application	Application	Application	Ap			on	Application

Figure 1. Example ESR Matrix

At that point, the instructional design effort had produced a specification of what topics needed to be covered in the curriculum and how much different groups within the learning audience needed to know about each of those topics. Figure 1 is an example of one of the resulting "ESR matrices" which documented the instructional design at that stage. At the top, it shows the ESR

[2] Definitions of these levels from the instructional design literature were used.

(with its identifying code P4). On the horizontal axis, the matrix shows that ESR P4 has been decomposed into eight sub-ESRs, P4.1 through P4.2. The educational sub-audiences are arranged on the vertical axis. The entries in the cells give the required learning level for each sub-ESR/sub-audience combination. Associated with each cell is a justification for its value; one of those justifications is shown in the figure.

Next the ESRs were grouped, based on content, into sets termed "content modules." The intent was that the content modules would each form a self-contained and cohesive unit of instruction. Then the content modules were grouped, based on size and related prerequisite background knowledge requirements, into courses. These courses were intended to be 40-45 hours of instruction and suitable for development as a standard university semester course.

Finally, syllabi were developed for each of the university courses. The syllabi contained the standard information ordinarily found in university course syllabi, including course description, prerequisites, proposed texts, learning objectives and planned assignments. The syllabi connected the courses to the ESR-based instructional design by identifying the content modules and ESRs covered in the course. Finally, each syllabi included a detailed list of course topics, specifying material to be covered hour-by-hour in the course.

1.3 Courses

The set of course designs produced in the instructional design phase were presented to the stakeholders group; some adjustments were made to the course list and content based on the stakeholders' evaluation. Ultimately a set of sixteen courses was selected for further development. University partners were selected to perform the development of each course. Table 1 lists the courses and the course developers.

Course	Developer
M&S Environments	UAH
M&S Data Strategies	UAH
M&S for Test and Evaluation, Introduction	UAH
M&S for Test and Evaluation, Advanced	UAH
M&S in the Acquisition Life Cycle, Introduction	GMU
M&S in the Acquisition Life Cycle, Advanced	GMU
M&S Strategy and Support Plans	UCSD
M&S in Decision Risk Analysis and Mitigation	UCSD
M&S Requirements and Evaluating Proposals	ODU
Contracting for M&S	ODU
Best Practices for M&S	ODU
Introduction to Engineering M&S Applications	ODU
Physics-based M&S	NPS
Basic Engineering Concepts in M&S, Introduction	NPS
Basic Engineering Concepts in M&S, Advanced	NPS
Selected Topics in Application of Engineering M&S	NPS

Table 1. Courses and developers.

1.4 Course content development

In the second phase of the project, which took place in 2008, the university partners developed the courses. At UAH, that process proceeded, in general, as follows. The course topics defined in the first phase and documented in the ESRs, sub-ESRs, and syllabi, were carefully reviewed and a presentation sequence was planned. Then source materials, including chapters in the course textbook[3], research literature, and existing training materials, were identified and mapped to the topics. Then the course lectures were prepared; these consisted of complete presentation slides for all the course lectures. Approximately 600-700 slides were prepared for each of the four courses. The presentation slides were augmented with extensive instructor notes intended to be sufficient to allow someone other than the course developer to teach the class. Homework assignments and exams were also prepared.

Developing professional quality course content is time-consuming. At UAH, an average of six hours was required to develop the presentation slides and associated notes for each hour of instruction. This level of effort produced course materials that addressed the topics well and were reusable for future offerings.

1.5 Test offerings and course revisions

Each of the courses, once developed, was taught as a test of the new course. The specific circumstances of these "test offerings" varied by developer and course. Though the courses were intended to be university semester courses, many of the test offerings were conducted in short course format, with approximately 32-40 hours of instruction compressed into a single week and the course assignments also adjusted. Of the four UAH test offerings, two were taught in short course format and two as university courses. Table 2 gives the details of the UAH test offerings.

Course	Format	Dates	Location
M&S Environments	Semester	Summer 2008	UAH Huntsville AL
M&S Data Strategies	Semester	Fall 2008	UAH Huntsville AL
M&S for Test and Evaluation, Introduction	Short course	October 6-10 2008	SPAWAR Charleston SC
M&S for Test and Evaluation, Advanced	Short course	November 3-7 2008	SPAWAR Charleston SC

Table 2. Test offerings of UAH-developed courses.

At the conclusion of each of the test offerings, the students were asked to assess the course. The assessment included both a written survey instrument and an interview with someone other than the course instructor. Based on the results of the assessment, the course materials were revised and enhanced for future offerings of the course.

[3] Only one of the four UAH courses, M&S Data Strategies, had the benefit of a suitable textbook. The other three courses used other source materials. A textbook is expected to appear in early 2009 that could be suitable for future offerings of the M&S Environments course.

1.6 Continuous Learning Modules

Once the course materials had been revised for each of the courses, they were repackaged and reorganized as 6-hour online courses, using a format defined by the Defense Acquisition University for Continuous Learning Modules. These shortened versions of the courses, while necessarily covering less material due to the reduction from 45 to 6 hours of instruction, were carefully designed to present the key concepts of each course.

2. Course Design Requirements

The course content and supporting materials for *An Introduction to Modeling and Simulation for Test and Evaluation* were designed for a 16-week, entry-level graduate semester curriculum. The development team designed the introductory course to satisfy five requirements. These requirements included student pre-requisite knowledge, graduate content maturity level, student competency levels, educational skill objectives and domain specific knowledge. The team also conducted a course test offering. The test offering allowed the team to gather feedback for course revisions and to evaluate how well the design criteria were met. This section of the paper reports the details and rationale of the design requirements and the results of the test offering.

2.1 Course Pre-requisites

First, the team designed the introductory course to be self-contained with few background pre-requisites other than a baccalaureate degree. The team construed the baccalaureate degree requirement broadly to include the acquisition, technology and logistics (AT&L) skill sets likely to be held by the Department of Defense (DOD) acquisition workforce. In keeping with the Defense Acquisition Workforce Improvement Act (DAWIA) of 1990, the team designed the course to attract students seeking to improve a specialized knowledge base, analytic skills and good judgment routinely involved with managing the lifecycle acquisition process for complex systems. Targeted students included program managers, project managers, product managers, system engineers, test and evaluation specialists and modeling and simulation specialists.

2.2 Content Maturity Level

Second, the team developed the course content with a maturity level to satisfy a beginning graduate class. Components of the graduate maturity level requirement included reading breadth, writing, knowledge awareness, content understanding, numerical literacy, understanding of the scientific method and concept generalization and knowledge transfer to similar, as well as to different, problem domains. Reading material for the course was selected to include commercial, academic and DOD materials. The class textbooks selected included:

- Modeling and Simulation in Manufacturing and Defense Acquisition: Pathways to Success, National Research Council, 2002. Available at www.nap.edu/catalog/10425.html
- Systems Engineering, Alexander Kossiakoff and William Sweet, NY: Wiley, 2003.
- Test and Evaluation in Support of Systems Acquisition, Department of the Army Pamphlet 73–1, Washington DC, 2003.

2.3 Competence Levels

Third, the modeling and simulation working group and the course development team adapted Benjamin Bloom's (1956) categories for intellectual skill development to set the competence levels expected of students enrolled in the course. For the introductory course, the two learning categories selected were general awareness and understanding. General awareness corresponds to Bloom's knowledge category of cognitive development. General awareness or knowledge was defined as the ability to identify and recognize the data and information presented during instruction. This level of competence may be demonstrated by a student recalling the major steps involved in planning for a model design and development exercise. Another instance of a student exhibiting general awareness would be identifying the defining elements of a discrete event simulation. Understanding corresponds to Bloom's comprehension level of cognitive development. Understanding was defined by a student's ability to elaborate in one's own words the concepts, instructions and problems under discussion. An example of student understanding is describing the independent and dependent variables in an equation and applying the mathematical operations to the equation's terms. Throughout the content development cycle, the course team compared the selection of content and exercises to these competence levels to verify that the course materials were gauged to these performance requirements.

2.4 Educational Skill Objectives

Fourth, the course learning and educational skill objectives were formulated by the working group who designed the course suite for modeling and simulation education. The learning objectives were:

1. Demonstrate understanding of DoD policies and regulations related to modeling and simulation for system acquisition and test and evaluation
2. Demonstrate understanding of the types of modeling and simulation as well as the uses, benefits, limitations and risks for test and evaluation
3. Demonstrate understanding of the uses of modeling and simulation during developmental test and evaluation (DT&E), operational test and evaluation (OT&E), and live fire test and evaluation (LFT&E)
4. Demonstrate understanding of the uses of modeling and simulation for testing in a joint, interoperable environment
5. Demonstrate understanding of the process and importance of validation, verification, & accreditation (VV&A) for modeling and simulation
6. Demonstrate understanding of the strategies for planning, contracting and executing modeling and simulation in concert with test and evaluation
7. Demonstrate understanding of the existing modeling and simulation resources and test and evaluation facilities used within the DOD for a given program need

2.5 Course Content

Fifth, within the framework of these learning objectives, the development team selected the course content from three primary knowledge domains: modeling and simulation, system engineering and test and evaluation. The course material presents the requirements, benefits, and challenges of modeling and simulation planning and execution in support of systems acquisition and test and evaluation. The course content emphasizes how effective modeling and simulation plans and implementations return short-term and long-term benefits to program managers, project managers, system engineers, the test and evaluation community, decision-makers, and system users over the entire life cycle of a system.

The course explains how to use modeling and simulation as a complementary methodology for physical testing in support of system evaluation. The general relationships among modeling, simulating, testing, and evaluating are developed within the context of commercial and defense systems acquisition life-cycle management. Concepts for using models and simulation to support test planning, test execution, and systems analysis are described and illustrated with simplified real-world examples. Opportunities and issues are identified about integrating simulation and testing to optimize the allocation of scarce resources for system capability assessment.

The course development team analyzed the conceptual dependencies that existed for the core learning objectives. Using this analysis, the team developed the following outline for scheduling the semester lecture topics:

1) Introduction to system acquisition planning and process
   a) System engineering planning
   b) Specifying system requirements and capabilities
   c) DOD Milestones entrance and exit criteria
2) Introduction to test and evaluation
   a) Define developmental, operational and live testing
   b) Introduce different test strategies
   c) Define the various data types that occur in different forms of testing
   d) Describe test evaluation master plans
   e) Explain cross-walks and data sources
3) Introduction to modeling and simulation
   a) Modeling techniques and model types
   b) Simulation techniques and simulation types
   c) Modeling and simulation support plans
4) The scientific method
   a) Hypothesis formation and requirements specification
   b) Experimentation and testing
   c) Modeling and simulation as experimentation and testing
5) Verification, Validation and Accreditation
   a) Definitions, requirements and resources
   b) Methods of comparisons
   c) VV&A inheritance
6) Relationships of modeling and simulation to system design and production
   a) Identify the practices common to modeling and system design
   b) Establish how modeling and simulation are used in all phases of product life cycle management
7) Relationships of modeling and simulation to developmental, operational and live testing

   a) Describe the roles and features of different models and simulation techniques
   b) Identify the practices common to modeling and test and evaluation
   c) Identify data integration from a variety of sources (e.g., simulation data, live test data, historical data)
   d) Define the types of models and simulations used in test
8) Strengths and limitations of M&S for different kinds of testing
   a) Describe how modeling and simulation supports the evaluation process
   b) Identify how and where M&S are utilized in developmental testing
   c) Identify how and where M&S are utilized in performance testing
9) Mitigating risk to system acquisition using modeling and simulation
   a) Risks to performance, cost and schedule
   b) Risks involved in testing
   c) Risks involved in modeling and simulation
   d) Methods for assessing risk with modeling and simulation
10) Using modeling and simulation in test planning and execution
   a) Describe the evolutionary role of modeling and simulation in the test evaluation master plan and system engineering master plan
   b) Identify the required personnel and resources needed to integrate modeling and simulation, test and evaluation and system engineering
   c) Identify existing modeling and simulation and test and evaluation facilities used within DOD which address specific program needs
   d) Describe the missions of the facilities with regard to modeling, simulation, testing and evaluation
   e) Identify modeling and simulation resources and repositories
11) Introduction to distributed simulation and live, virtual and constructive simulation
   a) Hierarchy of models
   b) Defining live, virtual and constructive simulation
   c) Simulation development environments

2.6 Test Offering

The course test offering took place at the SPAWAR Systems Center in Charleston, South Carolina during the week of October 6-10, 2008. The test course differed from the original semester design in that the test offering was presented as a week-long, short-course. All topics were addressed, albeit in an abbreviated form for some topics. A total of 36 hours of instruction were completed.

The student recruitment strategy was organized internally at SPAWAR. A lead student at SPAWAR made an initial, general announcement about the course to the community. From that point forward, students recruited students by word of mouth and work unit contacts. Students self-selected the course and at least 8 different work units at SPAWAR were represented in the class.

The demographics of the test offering class matched well the target audience for which the course was designed. A total of 21 students attended the class. Most of the students were SPAWAR government employees. The distribution of gender in the class was 17 males and 4 females. The training backgrounds of the students included computer science, information management systems, engineering (mechanical, electrical, chemical and environmental), mathematics and biology. Most students had completed a baccalaureate degree, while others had masters and doctoral degrees. At least 6 students reported having taking course work through the Defense Acquisition University.

Numerous lessons were learned about the course design and content during the test offering. The test offering confirmed that concept-focused, simplified exercises and examples are valuable for assisting the students to reach the learning objectives. Simple examples clarify concepts while avoiding possible information overload from overly complex system descriptions. As a case in point, early in the course, an example of building a simple pendulum model was completed. This example served as a common reference for other course topics such as model verification.

The test offering also identified unnecessary redundancies in the course content. These issues along with other errors of spelling and sentence structure were recorded and used in the course revision effort. The test offering also revealed that students would benefit from computer access for the modeling and simulation modules. The test class also revealed that more emphasis was needed for decision making using data and statistical summaries of data.

The test offering confirmed that the order of topics and knowledge dependencies worked well for this student sample. The course was well received by the students and individual comments were positive. Multiple requests were made for distance learning options for degree and non-degree offerings for the course. Students expressed that the course content would be of immediate use to them for developing test and simulation plans. At the time of this writing, an independent, external course evaluation is still ongoing by Dr. Peter Kincaid from the Institute for Training and Simulation an the University of Central Florida.

2.7 Summary

In summary, the effort to develop an introductory course on the applied fundamentals of modeling and simulation has been rewarding and challenging. As for rewards, now a self-contained, comprehensive framework exists for teaching the applied dimensions of modeling and simulation for system acquisition and test and evaluation. The response of the students to the test offering confirmed the need for bundling this domain knowledge into a course. As for challenges, the breadth of material that must be covered for a course of this nature would definitely benefit from a textbook that integrates methods of modeling and simulation with applications toward system capability design, testing and evaluation. Apart from handbooks and textbooks on discrete event simulation, no textbook is yet available. However, several DOD publications can serve to fill this gap in the meantime. This course development project puts the community well on the way to identifying the needs and requirements of the class and of a future textbook.

3. References

Bloom B. S. (1956). *Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain.* New York: David McKay Co. Inc.

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4. Biographies

Anthony W. Morris is a Research Scientist at the University of Alabama in Huntsville's Center for Modeling, Simulation, and Analysis and an adjunct graduate faculty in the Department of Psychology. Dr. Morris received his Ph.D. in Psychology from University of Connecticut, specializing in Human Factors, Ergonomics and Performance Learning. He is currently working on projects with the US Army focusing on pilot performance modeling for utility rotorcraft and other vehicle operations. His expertise covers issues of information detection and action control for navigation and instrumentation operation. He also has experience with virtual and constructive simulations involving digital human models for life cycle management for manufacturing, maintenance, equipment operations as well as test and evaluation. Dr. Morris' research focuses on the role that an intention plays in the learning and maintenance of adaptive, goal-directed behavior. Research projects include eye-hand coordination tasks involving inter-limb coordination, visual illusions and the control of objects in virtual environments. His research has been published in Behavior, Biological Cybernetics, and Instructional Science. He has taught courses in experimental research design, statistics, learning, perception, human factors engineering, and industrial and organizational psychology at UAHuntsville since 2000.

Mikel D. Petty is Director of the University of Alabama in Huntsville's Center for Modeling, Simulation, and Analysis and a Research Professor in both the Computer Science and Industrial and Systems Engineering and Engineering Management departments. Prior to joining UAH, he worked at Old Dominion University's Virginia Modeling, Analysis, and Simulation Center and the University of Central Florida's Institute for Simulation and Training. He received a Ph.D. in Computer Science from the University of Central Florida in 1997. Dr. Petty has worked in modeling and simulation research and development since 1990 in areas that include simulation interoperability and composability, human behavior modeling, multi-resolution simulation, and applications of theory to simulation. He has published over 140 research papers and has been awarded over $12 million in research funding. He served on a National Research Council committee on modeling and simulation, is a Certified Modeling and Simulation Professional, and is an editor of the journals *SIMULATION* and *Journal of Defense Modeling and Simulation*. He was the dissertation advisor to the first two students to receive Ph.D.s in Modeling and Simulation at Old Dominion University.

Wesley N. Colley is a Senior Research Scientist at the University of Alabama in Huntsville's Center for Modeling, Simulation, and Analysis. Dr. Colley received his Ph.D. in astrophysical sciences from Princeton University in 1998. During his graduate work, Dr. Colley focused on gravitational lensing and cosmology. His team at Princeton monitored the brightness fluctuations of particular lensed-quasar system that allowed them to settle a decades-old controversy over the implied value of the Hubble Constant, which sets the size scale for the Universe. He used Hubble Space Telescope imaging of a gravitationally lensed-cluster system, to measure the mass of the very distant cluster of galaxies, and exploit the lens's magnification to realize Einstein's dream of a “gravitational telescope” in which the gravity of a foreground celestial body forms enhances our view of very distant background objects.

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