A model for multidisciplinary graduate education in modelling and simulation

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Abstract: Modelling and Simulation (M&S) is increasingly important in numerous disciplines. M&S also has gained acceptance as a discipline in its own right. There is growing demand for at least two different approaches to M&S graduate education, one path for users and another for developers of M&S. Thus, the traditional department-focused approach is no longer adequate for M&S education. This paper outlines the development of a multidisciplinary approach to M&S graduate education at Old Dominion University. The approach encourages development of a number of M&S programmes, coordinated by university-level oversight, in which all academic colleges participate.

Keywords: M&S; modelling and simulation; graduate education; multidisciplinary academic programmes; programme organisational model.

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1 Introduction

Over the past decade, the notion that computer simulation rivals in importance the more traditional aspects of scientific investigation, theory and experimentation, has gained wide acceptance. Several recent government-sponsored panels have accentuated these observations and have noted the urgent need to develop and enhance educational programmes in simulation. The NSF Blue Ribbon Panel on Simulation-Based Engineering Science (SBES) (2006) states that

> "seldom have so many independent studies by experts from diverse perspectives been in such agreement: computer simulation has and will continue to have an enormous impact on all areas of engineering, scientific discovery, and endeavors to solve major societal problems."

Regarding education in computer simulation, the report goes on to state:

> "The old silo structure of educational institutions has become an antiquated liability. It discourages innovation, limits the critically important exchange of knowledge between core disciplines, and discourages the interdisciplinary research, study, and interaction critical to advances in SBES."

The President's Information Technology Advisory Committee (PITAC) Report (Belytschko and Lazowska, 2005) concludes that

> "Universities must implement new multidisciplinary programs and organisations that provide rigorous multifaceted education for the growing ranks of computational scientists the nation will need to remain at the forefront of scientific discovery."

The enormity of the problem posed by these reports is visible even to casual observers of higher education. Universities historically are structured around traditional academic disciplines. Faculty are hired because their degrees, their research programmes, and their teaching interests all are focused on advancing their specific discipline. Most often, there is little interest in, or encouragement for, participating in teaching or research that crosses discipline boundaries. Within this structure, Modelling and Simulation (M&S) is claimed by many yet championed by none. The true significance of the problem is apparent when the time scales of the requirements are observed. We need enhanced multidisciplinary M&S educational programmes immediately; the time required to make lasting change in the organisational structures of our educational institutions is measured in years and perhaps even decades.

Old Dominion University (ODU) has proposed a novel approach to building academic programmes in M&S. In 1997, the University established the Virginia Modelling, Analysis and Simulation Center (VMASC), a university-wide research centre focused on modelling, simulation and visualisation. In 1998, an M&S master's programme was started; this was followed by the initiation of an M&S doctoral programme in 2000. These M&S academic programmes are administered through the Batten College of Engineering and Technology and are directed primarily at engineering and science graduate students interested in the fundamentals of M&S. However, since 2005, the University has hired 17 new faculty having special designation as M&S faculty. These individuals have expertise in traditional academic disciplines that represent 12 departments and cover all six academic colleges at ODU. In addition to the traditional department expectations, these faculty are charged with developing research activity through VMASC and seeding new M&S activities within their respective academic units. In many programmes, the M&S activities may begin as new academic courses. However, eventually they are expected to mature into certificate programmes and even emphasis areas and tracks within existing degree programmes. The University now is establishing several university-level committees to promote, guide, and oversee development of programme activities carrying the M&S label. The objective is to establish M&S programmes designed to meet the needs of multiple

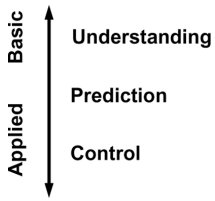
constituencies while simultaneously promoting the cross-disciplinary teaching and research interactions so necessary for the development of new knowledge in M&S and new applications for M&S. This is being done by overlaying a multidisciplinary structure for M&S on the traditional department structure of the university.

The objective of this paper is to describe the ongoing organisational development of the M&S academic programmes at ODU. The purpose of the paper is two-fold. First, the description may be a useful model for other universities considering the initiation of M&S programmes. Second, it is hoped that the paper will promote additional discussion in the literature concerning the development of M&S graduate programmes. In Section 2, two broad M&S student constituencies are described and their different educational needs are identified. This discussion is used to demonstrate that it is difficult to address M&S academic programme needs within the traditional department structure alone. The new approach at programme organisation being implemented at ODU is presented in Section 3. A definition of an M&S student is proposed, the various M&S programmes are identified by discipline and audience, and the high-level administrative structure for the M&S programmes is discussed. In Sections 4–7, the details of M&S programme activities in a sample of four academic colleges (Engineering, Sciences, Arts and Letters and Education) are presented. Concluding remarks are stated in Section 8.

2 Background and motivation

Historically, M&S has been viewed as an important research tool in numerous disciplines or application domains. Research in most domains often proceeds through a sequence of phases as shown in Figure 1. In the initial phase, we are interested in understanding how events or objects are related. An understanding of relationships among objects or events then allows us to begin making predictions and ultimately to identify causal mechanisms. Finally, knowledge of causality enables us to exert control over events and objects. Research moves from more basic to applied levels as we progress through these phases. For example, the Human Genome project was undertaken to understand the complete sequencing of chromosomal DNA in human beings. Knowledge of the human genome helps to make predictions regarding genetic variation and can lead to more reliable diagnostic tests and medical treatments applied at the genetic or molecular levels.

Figure 1 Progression of research phases along the basic/applied continuum



M&S is closely linked to all of these phases. At the more basic levels, research is guided heavily by theory. Models are often used to represent specific instances of theories, evaluate competing theories, or evaluate underlying assumptions. Likewise, simulations are used to test predictions under a variety of conditions or to validate theories against actual conditions. At the applied levels, simulations are also used to control events and objects. One of the primary uses for simulation is training where the goal is to control performance variability (i.e., minimise error) by improving operator reliability. Simulations in the form of mock-ups or prototypes are also used in the creation of products and systems to validate predictions regarding operational requirements, specifications, and user/customer satisfaction.

Although this description of the research process is admittedly simplistic, it does underscore three important points regarding M&S. First, M&S is intimately related to all phases of the research process. M&S is used to generate and refine the theories that help us understand our world as well as the technology we use to interact with the world. Second, the description is generic and highlights where M&S is (or can be) applied in any domain where individuals are engaged in research. Thus, biologists, chemists, sociologists, economists, and historians can all use M&S to help formulate research questions, conduct experiments, evaluate theories, and add to their respective bodies of knowledge. Third, the description also shows the different aspects of M&S emphasised along the basic/applied continuum. Thus, at the basic end, M&S is used more as a research tool whereas at the applied end, it is used either to create products or may be a product in and of itself.

In the mid-1990s, a second type of M&S professional began to emerge. Motivated by the rapidly growing use of simulation for training, analysis, and decision-support by industry and federal agencies, these individuals are more interested in learning about M&S rather than just using M&S to study something else. Coming from backgrounds in mathematics, computer science, and engineering, these individuals are interested in the fundamental principles and theoretical foundations of M&S. They are anxious to investigate some of the major challenges of M&S: multiscale and multiresolution M&S, interoperability of simulations, composability of models, verification and validation, distributed and real-time simulation, and representation of complex and data-intensive system problems. In short, this group views M&S as a discipline. Their objective is to obtain formal education in the M&S discipline and then to find employment opportunities as M&S scientists and engineers.

The growth of the view of M&S as a discipline is well documented in the literature. As early as 1997, Rogers (1997) reports on a workshop, having participants from industry, academia, and government, to discuss the desirable characteristics of an M&S professional. A similar study by Tucker and Fairchild (2000) focused on the M&S needs and requirements of industry. In 2001,

Sarjoughian and Zeigler (2001) published one of the several early papers suggesting that M&S be viewed as a discipline. Supporting this view, a number of additional papers address the development of an M&S curriculum (Crosbie et al., 2001), a code of ethics for M&S professionals (Oren et al., 2002), professional certification (M&SPCC, 2003), master's-level graduate programmes (Sarjoughian et al., 2004), and development of an M&S body of knowledge (Oren, 2005). More recent papers have started to discuss models for undergraduate M&S programmes (Roberts and Ghosh, 2004; Mielke, 2007).

The view of M&S as a discipline leads naturally to the development of educational programmes for students who wish to become practitioners of this discipline. These students first develop background in mathematics, computer science, and selected engineering topics, and then focus their core technical studies on the M&S body of knowledge. They emerge as technical specialists skilled in the design, development, and use of simulation technologies and methods. This educational path may not be attractive to those wishing to utilise M&S in the investigation of another discipline because of the extensive background requirements and the absence of an opportunity to focus on a particular application area. Thus, it is clear that M&S educational programmes cannot be developed with a "one-size-fits-all" approach. Comprehensive educational programmes in M&S must be designed to accommodate the needs and requirements of all potential M&S students. A new multidisciplinary approach to M&S education that spans the breadth of the university community is being developed at ODU. This approach is described in the next section.

3 A new approach to M&S programmes

ODU's approach to M&S graduate education is based on two assertions. The first is that M&S is a multidisciplinary academic programme. M&S is used in, or can have an impact on, nearly every traditional academic programme at the University. For this reason, participation in the M&S programme must have broad representation from all academic colleges. The second is that there are two primary student constituencies in M&S, the user constituency and the developer constituency. The user constituency consists of students who utilise M&S as a tool to investigate another discipline. They need to know enough about M&S to select the best methodologies for their specific problem and then to apply these methodologies in an appropriate way. In the following sections, examples of programmes in the College of Education and the College of Arts and Letters that focus on the user constituency are presented. The developer constituency consists of students who wish to study M&S as a discipline. Their focus is to learn about the technical aspects of M&S and then to develop new M&S methodologies and enhanced M&S technologies. Upon graduation, these students will seek employment in the M&S professional community as scientists, engineers and technical managers. In the following sections, examples of programmes in the College of Engineering that focus on the developer constituency are presented. Last, the College of Sciences has programmes that address both the user and developer constituencies. Specific examples from this College are also presented.

3.1 M&S academic programmes

Two levels of M&S academic programmes are being established, graduate certificate programmes and graduate degree programmes. An M&S graduate certificate programme consists of a minimum of four three-credit graduate courses. These courses must include two required M&S core courses and two or more M&S-related courses specified by the host academic department. The two core courses are broad overview courses designed to introduce students to the M&S body of knowledge. The courses specified by the host department must be designed to expand on the coverage of the M&S body of knowledge topics or to demonstrate the application of M&S in the discipline of the host department. Course content must include an introduction to models and modelling techniques, and examples of the use of simulation, in the host discipline. Graduate certificate programmes are open to non-degree seeking students as well as degree-seeking students. These programmes often are attractive to students who desire to enhance their knowledge of M&S for job-related purposes or who are interested in previewing a potential graduate degree programme. Up to 12 credits taken in a non-degree seeking status may later be applied towards a graduate degree.

The term M&S graduate degree programme is used to refer to any graduate degree programme titled M&S or any concentration, emphasis, or track, offered within another degree programme, that is titled M&S. The degree requirements for these programmes must include or exceed the requirements for the graduate certificate programme.

Two university committees, the M&S Steering Committee and the M&S Executive Committee, have been established by the Provost's Office. The M&S Steering Committee consists of M&S faculty representing all six academic colleges. This committee is responsible for recommending policy and procedure and for operational issues spanning all M&S programmes. The M&S Executive Committee consists of the Dean or Associate Dean from each academic college. This committee is responsible for approving policy and procedure spanning all M&S academic programmes. Together, these committees oversee and coordinate all M&S programmes and control the distribution of resources that support M&S programmes.

An ODU graduate student is considered an 'M&S Student' if

- the student is enrolled in an M&S graduate certificate programme
- the student is enrolled in a graduate degree programme titled M&S.

Full-time, degree-seeking M&S students are eligible to apply for M&S Graduate Assistantships provided by the University to help expand the M&S workforce. The number of enrolled M&S students, and the number of students who complete M&S certificate programmes and M&S degree programmes, will be used to measure the impact and productivity of the University's M&S educational activities.

3.2 M&S core courses

The required M&S core courses are composed of a two-course sequence designed to introduce students to the M&S Body of Knowledge (Oren, 2005). The courses are taught at an overview level, but care is taken to ensure that students do learn to apply useful and practical M&S techniques. A content outline for the two core courses is presented in Figure 2.

The prerequisites for the core course sequence include mathematics (college algebra), familiarity with personal computers and standard computer applications (word processing, spreadsheets), and graduate standing. Students who have achieved Certified Modelling and Simulation Professional (CMSP) status are excused from this requirement and are allowed to substitute other approved M&S courses in place of the core courses.

Figure 2 Core course sequence content outline

Introduction to Modelling and Simulation

I. Introduction to M&S
- A. History
- B. M&S Terminology
- C. M&S Characteristics and Applications
- D. M&S Academic and Research Communities

II. M&S Paradigms
- A. System Classification
- B. Monte Carlo Simulation
- C. Continuous Simulation
- D. Discrete Event Simulation
- E. Simulation Tools

III. M&S-Related Disciplines
- A. Probability and Statistics
- B. System Modelling
- C. Analysis Techniques
- D. Computer Visualisation
- E. Human Factors
- F. Project Management

IV. M&S Methodologies
- A. Modelling Techniques
- B. Verification and Validation
- C. Distributed Simulation
- D. Interoperability and Integration
- E. Research Challenges

V. Applications of M&S
- A. Engineering
- B. Science
- C. Health Science
- D. Business
- E. Arts and Letters
- F. Education

A single semester version of this course has also been developed for students having undergraduate degrees in engineering and science. The prerequisites for this course are mathematics, including two courses in introductory differential and integral calculus and one course in ordinary differential equations, and computer science, including algorithmic problem-solving, a high-level programming language, and data structures. This course covers the same content, but progresses at a faster rate because of the student's enhanced preparation.

4 M&S programmes in engineering

The Batten College of Engineering and Technology (BCET) offers M&S programmes of study appropriate for both the user and developer student constituencies. The user student constituency is supported through certificate programmes developed in the College's traditional engineering degree programmes. The developer student constituency is supported through several degree programmes organised and administered as the M&S Graduate Programme within the College. A brief description of these certificate and degree programmes is presented in this section.

4.1 User student constituency

M&S has long been an essential component in the engineering design process. Most system design problems begin with a statement of need and the identification of system requirements. These specifications are used to formulate an initial system conceptual design or model, a first cut at a system to address the identified needs and requirements. The conceptual model is implemented in computer code as a simulation model. The simulation model is run on a computer with various inputs and different anticipated environmental conditions to assess the performance of the system. Based on an analysis of system performance, the system design is modified to improve performance, and the modelling, simulation, analysis, and redesign cycle is conducted again. This process is repeated until a system design that has the desired performance is achieved. It is only at this point that a physical system prototype, or perhaps the actual system, is constructed. The use of conceptual and simulation models, as contrasted with the use of physical models or prototypes, has been shown to reduce significantly the cost and time required for system design.

Each of the traditional BCET engineering programmes – Aerospace Engineering, Civil and Environmental Engineering, Electrical and Computer Engineering, Engineering Management and Systems Engineering and Mechanical Engineering – agreed to offer M&S certificates within their existing degree programmes. Motivation for establishing M&S certificates comes primarily from two sources. First, the University has established a limited number of graduate assistantships that are available only to M&S students. Participation in a BCET M&S certificate qualifies a student to compete for these new assistantships. Thus, the M&S certificate programme presents a new source of student financial assistance to the engineering departments. Second, the traditional departments recognise the growing importance of M&S as a tool in their respective disciplines. The development of an M&S certificate enhances and adds breadth to the formal M&S instruction a student receives. In addition, the certificate provides a

formal recognition of this achievement and may prove an asset to the student when it is time to graduate and seek a job.

The engineering certificates are designed in accordance with the university rules for M&S certificates. Each certificate requires completion of 12 credits. In engineering, the one-semester overview course, MSIM 601: Introduction to M&S is used as the common required course. This course covers in a survey fashion the M&S body of knowledge and thus adds breadth to the student's perspective of M&S. The remaining three courses are specified by the host department and must include a course that covers models typical to the discipline and another course that demonstrates the application of simulation in the discipline. Several of the engineering departments have focused their M&S certificate on specialised sub-areas within their discipline where M&S is especially important. For example, Civil and Environmental Engineering has developed a special set of certificate courses for transportation M&S while Mechanical Engineering has developed a special set of certificate courses for bio-medical M&S.

4.2 Developer student constituency

Responding to requests by local industry and government organisations, BCET initiated degree tracks in M&S at both the master's and doctoral levels. These tracks are designed for students having undergraduate degrees in engineering or science who wish to become developers of M&S technology and methodology. Prerequisites for admission include courses in undergraduate mathematics – two courses in differential and integral calculus and one course in calculus-based probability and statistics, and undergraduate computer science – algorithmic problem-solving, knowledge of a high-level programming language, and data structures. Additionally, undergraduate courses in linear algebra and ordinary differential equations are recommended at the master's level and required at the doctoral level.

The master's programme is designed to prepare students for careers as simulation professions in government and industry, teachers of M&S at the high school or junior college levels, and for advanced graduate study in M&S or other related disciplines. The programme can be completed in 1–2 years of full-time study. The Master's Programme is available as a thesis option (MS) or non-thesis option (ME); both programmes require completion of 30 graduate credits. The programme of study includes 15 credits of core courses addressing M&S fundamentals, 9 (thesis option) to 15 (non-thesis option) credits of approved elective courses addressing applications of M&S, and six credits of thesis research (thesis option only). The core courses include an Introduction to M&S, Discrete Event Simulation, Systems Modelling, Analysis and Operations Research, and Computer Visualisation.

The PhD Programme focuses on developing the knowledge and skills required to evaluate and conduct independent, original research in an area of M&S. Completion of this programme prepares students for careers as simulation professionals and researchers in government and industry and for research and teaching at the university level. In addition to the general prerequisites, students are expected to have completed the core master's level M&S courses. The programme of study consists of 72 credits of course work including 24 credits of M&S background from the master's level, 12 credits of doctoral core courses, 12 credits of approved doctoral elective courses, and 24 credits of dissertation research. The required core courses include: Continuous and Real-time Simulation, Theoretical Foundations of Simulation, Analysis II, and Visualisation II. Formal examinations include the Diagnostic Exam taken near the beginning of the course work, the Qualifying Exam taken near the end of the course work, the Dissertation Proposal taken at the beginning of the dissertation research, and the Dissertation Defense taken at the completion of the dissertation research. The PhD Programme can be completed in 3–4 years of full-time study.

Recently, a new professional doctoral programme called the Doctor of Engineering was established. This degree is designed for advanced practitioners of M&S who wish to direct or manage M&S development teams. The programme of study consists of 72 credits course work including 24 credits of M&S background from the master's degree, 18 credits of professional technical management courses, 12 credits of doctoral core courses, 6 credits of approved electives, and 12 credits of advanced project work. The D.Eng. Programme can also be completed in 3–4 years of full-time study.

5 M&S programmes in sciences

Science certificate and degree programmes offer educational opportunities appropriate for both the developer and user student constituencies. Modelling is a fundamental component of science used in explanations and concrete representations of theories. Scientific models help us understand complex dynamic systems and allow us to quantify empirical observations of objects and events. Scientific models are used to obviate assumptions, generate the math and logic needed to run simulations, and to validate results.

Obviously, programmes in computer science and mathematics provide some of the building blocks for an M&S curriculum. Mathematics departments offer courses in computational statistics, probability theory, time series analysis, and finite element models. In computer science, students learn about computer graphics, visualisation methods, computational geometry, optimisation techniques, artificial intelligence, and intelligent agents.

At ODU, students enrolled in doctoral or master's programmes in computer science and mathematics can satisfy their M&S certificate requirements early in their training and may choose to substitute an existing and more rigorous introductory-level M&S course for the two-course core sequence. The certificate requirement would then be fulfilled with courses that provide a more comprehensive

treatment of advanced topics (e.g., applied numerical methods, computer graphics, distributed systems, etc.).

Aside from the role of mathematics and computer science in M&S development, there are many other areas within the sciences that are oriented more towards the user constituency. Obviously, modelling is fundamental to physics, from quantum mechanics to cosmology. However, M&S is equally important to anthropology, biology, chemistry, cognitive and neuroscience, as well as the ocean and atmospheric sciences. In this section, the Psychology programme at ODU is presented as an example.

Psychology is a broad discipline largely concerned with human thoughts and behaviour. Major areas of study include: attention, clinical assessment and treatment, cognition, emotions, learning, motivation, personality, physiological bases of behaviour, sensation/perception, social interactions, and changes across the lifespan. Studying psychology helps us to understand who we are and how we interact with each other and the world around us. Thus, it is no surprise that many people in the M&S community are working in areas that draw upon some aspect of psychology.

One specialty area within psychology, human factors, is particularly relevant for M&S. Human factors, itself, is a broad discipline that focuses on designing systems and tools for the end-user (Sanders and McCormick, 1993). Although many human factor professionals work in areas associated with industrial engineering (e.g., anthropometrics and biomechanics), from the psychological perspective emphasis is placed on human information-processing capabilities. As such, human factor psychologists are interested in how knowledge of attention, decision-making, memory processes, problem-solving, sensory processes, skill acquisition, stress, and workload can help create more effective equipment and systems (Wickens and Hollands, 2000).

Graduate students in the human factors programme must obtain a master's degree as a prerequisite for the PhD Required courses at the master's level include cognition, human factors, and sensation and perception in addition to standard courses in quantitative methods and research design. Any two of the content courses would satisfy the M&S certificate requirements. In our programme, however, we do not offer a terminal master's degree in human factors. Thus, M&S students in human factors must satisfy doctoral-level requirements.

At present, human factor students interested in M&S must formally declare this focus as a concentration area in their doctoral plan of study. Consequently, the student and his or her guidance committee establish the formal course work and research experiences needed to meet this requirement. Thus, the training needed to satisfy an M&S concentration in human factors is substantially more rigorous than that for the M&S certificate. In fact, students must satisfy the M&S certificate requirements as a prerequisite to an M&S concentration in human factors.

As an example, in addition to the M&S certificate requirements a student pursuing an M&S concentration in human factors can take advanced seminars in cognition, aviation psychology, human–computer interaction, human performance, and perception in real and virtual environments. In addition, students are required to take one doctoral-level course in an M&S area outside of the Psychology Department to enhance their interdisciplinary experiences in M&S. Further, students are expected to be engaged in research in an M&S topic area (e.g., cognitive task analysis, cognitive modelling, display design, training design or assessment, user–simulator interaction, virtual reality, etc.) throughout their training and also are expected to do their dissertation work in an M&S area. Thus, graduates from the human factors programme with an M&S concentration should be prepared to enter the M&S industry and contribute to either the developer or the user constituencies.

6 M&S programmes in arts and letters

M&S has become central to the cutting edge in a number of areas of the social sciences, and has begun playing a significant role in the humanities as well. Nonetheless, the developing academic field of M&S has largely been conceptualised as an engineering discipline. There are important connections that need to be made between M&S as a discipline and the social sciences and humanities. These critical connections go in both directions: There are contributions to be made from the humanities and the social sciences to M&S and there are contributions that M&S can make to the social sciences and the humanities. These links highlight the importance of an integrative and multidisciplinary approach to both the teaching and research dimensions of M&S.

In the social sciences, the behavioural revolution opened the way first for statistical and then formal and most recently simulation modelling.[1] Modelling has now become central to all of the major social science fields. In turn, each of them has made critical contributions that need to be incorporated into the body of knowledge that constitutes the core of M&S as a discipline. Quick examples would include the contributions of economics to game theory, the advances in social network modelling in sociology, and the preference aggregation models that have been developed in political science.

M&S is a newer technology in the more traditional humanities fields, but the increasing digitisation of creative works has opened significant new territory for these applications.[2] Modelling is already being used for a broad range of textual and linguistic analysis as well as in the creation and analysis of music and visual arts.

The humanities and the social sciences are also critical to M&S because of the human element that is at the centre of many of the most important things we need to model. Increasingly, the essential challenges of M&S are at the interface of physical and social phenomena, or are purely in the social realm. Consider, in this regard, the problems of the war on terrorism, transportation management, global warming, or the effective provision of healthcare.

In each case, accounting for the human element is at the centre of the analytic challenge. Developing more integrative and effective training in the social dimension is essential to the M&S agenda.

The humanities are also critical on several of these fronts. The effective communication of the results of M&S analysis requires skills that are fundamentally enhanced by work in the humanities. And where humans are involved values inevitably come into play. Input from the humanistic disciplines will be important for identifying the priorities and values relevant to the modelling endeavour.

Some of this integrative challenge can be met by building cooperative relationships between scholars with M&S expertise and subject area experts in human social behaviour. Ultimately, however, there also needs to be explicit work to build M&S expertise within the social sciences. This has been an area of considerable intellectual growth over the past 25 years across the social sciences, but it has been largely isolated from the parallel developments in the growing field of M&S per se. A multidisciplinary, university-wide approach to M&S offers an opportunity to develop a more integrative M&S approach to human social behaviour. Such an approach will help develop a common M&S language and will allow the advances in each field to more quickly propagate to the others and ensure that the most effective tools are available for M&S work across the disciplines.

6.1 The ODU model

The integrative approach to a multidisciplinary M&S programme being pursued at ODU provides an example of how some of these critical synergies might be tapped. In the case of the College of Arts and Letters at ODU, the beachhead for M&S has been the Graduate Programme in International Studies (GPIS). This example points to both the strong potential and the important challenges in bringing an explicit M&S perspective into the social sciences. The GPIS programme already takes a broadly based multidisciplinary social sciences approach that integrates political science, history, geography and economics. Over the past several years, faculty have been added with expertise in game theory, formal and spatial modelling, geographic information systems, simulation modelling, and advanced statistical modelling.

The M&S programme is set to begin as a certificate programme. Within a few years, it is expected to lead to regular tracks within both the MA and PhD programmes. The M&S emphasis in the GPIS programme will be built on a foundation of two interdisciplinary university-wide core courses that cover the basic M&S body of knowledge. Students will then have a choice of several electives that focus on the different strains of M&S work in the social sciences. A set of elective courses oriented around international studies applications will be offered within the GPIS programme. These will include: Formal Modelling and Game Theory, Geographic Information Science (GIS), Simulation Modelling, Social Network Models and Advanced Statistical Modelling. Students will also be able to draw on course work from the other M&S programmes across the whole university as they are developed.

The interdisciplinary nature of the international studies programme will help create a community of people working with M&S tools across several disciplines. As the M&S component in the international studies programme reaches critical mass, it should be possible to begin developing M&S specialisations in other social science and humanities programmes as well.

Student and employer response to the new programme has been very strong. The local military planning community is very interested in students who combine a substantive understanding of political and social processes and have the tools to situate that understanding within the military's M&S practices. Other employers in the shipping and medical industries have also expressed strong interest in these approaches. Students, meanwhile, have a clear sense that adding these tools to their skillset can give them a significant advantage in the marketplace.

6.2 Challenges for integration

There are several challenges in bringing M&S into the social sciences curriculum that are worth noting. In the first place, it is important to acknowledge that modelling human and social behaviour is a 'grand challenge'. Modelling the decision-making of humans at either the individual or the aggregate levels is exceedingly difficult. As a science, this area of modelling is still in its infancy. It is unlikely to ever provide the concrete and targeted kinds of predictions that are possible in the modelling of kinetic phenomena.

Both the engineers and the more traditional social scientists need to appreciate these formidable challenges. While there are already important insights being derived from the modelling approach, there also needs to be support for basic science that helps push forward the technology of M&S even if it is not yet generating the kinds of point predictions that end-users anxiously await.

A second challenge is that social science education at the undergraduate level, except to a degree in economics, is relatively non-technical. This means that social science students often need some level of remedial work to get up to speed with the math needed to work at the frontier in M&S. Despite these challenges, there is considerable enthusiasm among both students and potential employers for the integrative M&S programmes in the social sciences.

These challenges are important, but at the multidisciplinary level, they are not significantly different from the challenges that M&S have faced within these fields themselves. There has been varying resistance to the incorporation of modelling technology across the social sciences and the humanities. In economics, it has quickly become a part of the mainstream. It is still very much at the fringes of the humanities. Political science, and international studies are good examples of a domain where acceptance has been more reluctant. While considerably controversy remains, we have moved over the past 20 years from outright skepticism and hostility towards the use of

M&S to an environment in which most major graduate programmes have to have some formal modelling expertise and the top journals all publish a significant number of modelling papers.

As we have argued in this paper, the next important step in this progression is improving the integration of M&S to build a common language and set of understandings that will enhance analytic leverage across these many disciplines.

7 M&S programmes in education

Education and training historically are among the most universal users of M&S. Classroom teachers, university faculty, and corporate and military trainers alike use modelling, simulation, and their closely related counterpart, games, as methods to impart knowledge, skill, and meta-cognitive experiences to learners of all ages. All three methods provide unique features that facilitate learning and are considered by many to be important to Science, Technology, Engineering, and Mathematics (STEM) education aimed at improving scientific literacy, workforce proficiency, and competitiveness to meet the nation's future workforce challenges (National Science Board, 2007).

Instructional simulations and simulators provide learners with an efficient and effective method to experience situations, view phenomena, or practice procedures not possible with more traditional approaches. Features such as time frame compression, multiple levels of visualisation, immediate feedback and unlimited repetition provide both individuals and groups of learners the ability to interact with content and environments in ways that are logistically impossible or unsafe otherwise. One need only look at the ease of using physics or biology lab simulations, the safety of a flight or gunnery simulator, or experience interactions with avatar-based counselling simulation to understand the instructional benefits of simulations and simulators (Alessi and Trollip, 2000).

While modelling is a basis for simulation, it is a very powerful instructional tool in and of itself. Creating models requires learners to analyse phenomena, form associations, derive algorithms, test hypotheses, and reformulate. Modelling is a particularly well-suited tool for constructivist learning environments where learners explore, experiment, construct, collaborate, and reflect on real-world problems (Jonassen et al., 2003).

Finally, instructional games often build on simulation technology and provide the complexity and challenge to engage learners in complex scenarios, across multiple domains of knowledge, and over multiple sessions to use, reinforce, and build complex knowledge structures and strategies important for learning. The unique capabilities of games have lead groups such as the American Federation of Scientist to recommend their increased use for K-16 instruction (Federation of American Scientists, 2006).

These are just a few of the features that make modelling, simulations, and games powerful learning technologies. Whether using existing models, simulations and games as instructional resources or allowing the learner to create their own model, simulation, or game, learning is enhanced through interaction and manipulation of the content parameters. The challenge for educator and trainers is facilitating the most comprehensive learning with each technology by fitting it most effectively to the learner and content of interest. These elements form the theoretical and applied basis of the M&S in education.

To address these efforts, the Darden College of Education placed the initial M&S curriculum in the Instructional Design and Technology Programme (ID&T). ID&T is a logical programme for this effort as it is traditionally responsible for technology courses within the College and, as a field, focuses on the design and development of instruction, instructional materials, and software tools for all levels of instruction including K-12, adult education, and industry- and military-based training. ID&T is grounded in cognitive science, psychology, and systems theory resulting in design and development models that transcend the specific content of instruction. The field has a long history in development and use of simulator-based training technologies.

The ID&T programme is positioned to begin with the immediate offering of a certificate in instructional simulation and gaming with the intent of offering a related concentration in the ID&T PhD programme and potentially other STEM areas in the near future. The certificate requires four courses of which two are the interdisciplinary course sequence covering required for all certificates. These courses provide the basis of M&S concepts and applications across all disciplines and are considered necessary for instructional designers who often work in large, diverse software or hardware development teams. To complete certification requirements, students have a choice of several electives in the College of Education. Two such courses are: Theory and Design of Instructional Simulations and Instructional Gaming Theory and Practice. These courses focus on the theoretical basis, design, and evaluation of instructional simulations, simulators, and games. Students design and develop instructional products and integration plans for training and educational settings. The ID&T programme anticipates offering additional M&S courses on advanced design and development, measurement, and research in simulation and gaming, and special topics as the concentration area is developed. Students also have the option of taking M&S courses in other colleges that may fit their individual career interest or goals.

Several challenges exist for the M&S effort in education. First, courses must be efficacious for a diverse set of students without requiring considerable prerequisite courses. It is anticipated that undergraduates and graduate students from a variety of disciplines, as well as working professionals in the areas of training and education, will pursue this certificate. Covering the theory and research foundations with such a wide audience may prove challenging, especially when ranges include

the traditional education student with an extensive background in teaching and learning but little or none in development, as well as the technical student with an extensive background in computer programming but little or no knowledge in cognition, learning, or instructional design.

Another challenge is that a significant number of students may be distance learners taking classes remotely. This scenario creates a number of technical challenges including acquiring affordable programming software, resolving technical problems at individual sites, and testing simulations and games within the course. Future considerations may include remote access for students to lab facilities, student-based technical exchange hosted on the class website, and requirements for students to purchase software packages for project completion.

Finally, fundamentals of the more sophisticated training technologies overlap with other areas and will need careful consideration to ensure appropriate coverage for the educator or trainer without the need for prerequisites in engineering or computer science. Despite these challenges, the programme is encouraged by the considerable interest in the certificate expressed by public school teachers, professional instructional designers working in industry and military settings, and graduate students from technical fields interested in an emphasis in educational or gaming applications.

8 Conclusion

A new approach to organising graduate education in M&S is presented. The approach recognises that there are two primary student constituencies in M&S education, those within the traditional M&S community who wish to focus their studies on the discipline of M&S and those from other disciplines who wish to use M&S as an investigative tool in their respective endeavours. As a result, M&S education is being organised as a true multidisciplinary activity in which all academic colleges participate. Several new graduate certificate programmes, as well as degree programmes or tracks, are being established across the university. These programmes are coordinated at the university level by committees of M&S faculty from each college as well as college-level administrators. The approach essentially superimposes a multidisciplinary structure over the more traditional departmental structure of the university.

There are several advantages of this new approach. First, and most important, the new approach better serves the needs and objectives of our students. Those students wishing to become M&S scientists and engineers can do so by focusing their full attention on mastering and enhancing the M&S body of knowledge. On the other hand, those students wishing to utilise M&S as a tool of their discipline can do so with knowledge that they will learn enough about M&S to be competent users. Indeed, the examples from social sciences and education highlight the increasing importance that M&S plays in advancing knowledge and understanding in these domains as well as the challenges faced by educators to ensure that their future work force achieves a degree of M&S literacy.

The second advantage of this approach is the opportunity to promote the broadest possible use of M&S. Efforts to formalise M&S education within one or two departments in a college provide examples to others interested in incorporating M&S into their curricula. Moreover, the core M&S courses and multidisciplinary administration of the curricula both encourages and facilitates cross-discipline interchange of ideas and concepts.

The approach also faces several significant challenges. Encouraging broad participation is difficult. It requires M&S users to acknowledge that the wise use of M&S requires knowing more than how to use a single specific modelling methodology or a particular simulation software package. It also requires programmes to make room in their curricula for M&S courses outside their major discipline. Supporting the development of a broad multidisciplinary initiative in M&S is expensive, both in human capital and in educational resources. As in all such initiatives, these activities are viewed as positive developments only if they do not diminish the already scarce resources available to existing programmes and activities. This requires an aggressive administration that is willing and able to raise additional funds to support the added activities.

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Notes

[1]There are important precursors, of course, that make this story less linear than implied here. Condorcet's voting paradox, for example, was discovered at least three times, the first in the Middle Ages (McLean, 1987).

[2]See, also, the work of the Humanities, Arts, Science, and Technology Advanced Collaboratory at www.hastac.org