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PRELUDE TO THE PANEL ON WHAT MAKES GOOD RESEARCH IN MODELING & SIMULATION

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ABSTRACT

Modeling and Simulation (M&S) is a unique field, which has been and continues to be influential in the development and growth of numerous science and engineering disciplines. From basic research and concept formulation to diffusion of innovations, M&S rests on fundamental strategies that not only provide guidance to scientists, but also provide explanations for the society and institutions that have stakes in the produced knowledge. We explore the essential components of the professional realm of M&S research to (1) gain better insight about the characteristics of successful and creative M&S research, (2) identify the major components of the M&S profession that need to be nurtured to enable growth and sustainment of its vitality, and (3) help facilitate explanation of the character of simulation discipline to other engineers and scientists at large.

1 INTRODUCTION

As indicated in (NSF 2006), a recent National Academy of Engineering report (NAE 2006) warned: "Leadership in innovation is essential to U.S. prosperity and security. In a global, knowledge-driven economy, technological innovation – the transformation of new knowledge into products, processes, and services – is critical to competitiveness, long-term productivity growth, and the generation of wealth." To raise awareness about the role and significance of simulation in revolutionizing science, engineering, and technology, NSF instituted a panel on Simulation-based Engineering Science (SBES), which organized two workshops, one in April 2004 and the other in September 2005 (SBES 2005). The findings and recommendations of these earlier workshops helped facilitating a consensus on the utility of simulation in advancing the computational sciences and engineering fields. This panel aims to promote the recognition of modeling and simulation (M&S) as its own *discipline*, which has its own core research domain with implications to the broader context of science and engineering. This view is in contrast to the more traditional view of simulation as simply a "research tool or instrument" to support research in a variety of diverse fields. The distinction between these views and the growth and sustainment of M&S as a discipline is critical for the growth and expansion of the field.

1.1 Background on Scientific and Societal Role of Simulation

M&S is a different type of discipline in that it interacts strongly with other fields and draws much of its vitality from serving the needs of other diverse communities of science. Dramatic improvements in the capability and capacity of computational models in empirical and normative understanding of artificial and natural information processes are enabling the creation of vast archives of knowledge of significant value to scientists. For example, the particle physics community is considering computational virtual experiments on super symmetric particles, which may shed light on the dark matter problem of cosmology. Similar opportunities are emerging in medicine, where the promise of artificial organs is being explored via computation-based simulation of natural and artificial organ functions.

Numerical simulations are providing new modes of computational science where supercomputers act as the central power plants in a scientific Grid. The increasing prominence of simulation and data-driven science is also driving experimental science by introducing and integrating new apparatus into the scientific problem-solving process. For instance, the earthquake engineering community is deploying telepresence capabilities that allow participants to remotely design, execute, and monitor experiments without traveling to the actual experiment facilities. The Network for Earthquake Engineering Simulation (NEESGrid) is using Grid technologies to link earthquake engineering across the US with shared engineering research equipment, data resources, and leading edge computing resources. Other resources that focus on the role of simulation in engineering and science include the Presidents Information Technology Advisory

Committee (PITAC) Report (Benioff and Lazowska 2005), which emphasizes the development of computational science for national competitiveness; the (SCiDAC 2000) and SCaLeS reports (Keyes, Colella, Dunning, and Gropp 2003, **?**), which emphasize opportunities for scientific discovery at the high-end of todays simulation capabilities and the need for a new scientific culture of interdisciplinary teamwork to realize them; and the Cyberinfrastructure report (Atikins 2003), which outlines a diverse program of inter-related research imperatives stretching well beyond simulation into communication and computational virtual experimentation.

1.2 Motivation: The Need for a Panel on the Modeling and Simulation (M&S) Profession - What Makes Good M&S Research?

This panel is based on the observation that the significant potential benefits and advances in the realm of simulation-based engineering and science require explicit understanding of basic and applied research in the scientific components of M&S itself. Physics, biology, medicine, as well as human and social sciences have well-refined public explanations of their research processes and modes of scientific inquiry and knowledge production. These explanations provide guidance as to what constitutes good and innovative research. Despite its broad impact on science and technology, M&S does not yet have this sort of explicitly delineated, well-understood and communicated guidance. However, if M&S is going to transform 21st century science, engineering, and technology, and continue to be relevant as new challenges and critical fields such as global climate change mitigation, energy restructuring, genetic engineering impacts on society emerge, then the characterization of the science and technology of modeling and simulation must also be explicitly delineated and documented. Understanding research strategies, guiding principles, and criteria for evaluating good and creative innovations in M&S will not only help scientists in developing next generation simulation technologies and designing research plans using computational models, but will also facilitate explaining the *character* and importance of M&S research to other engineers and scientists at large.

2 SUSTAINING THE GROWTH AND VITALITY OF M&S

What is necessary for a scientific field to form and develop? What are its underlying guiding principles, research strategies, and criteria for evaluating good and creative innovations? From basic research and concept formulation to diffusion of innovations, scientific fields rest on fundamental strategies that not only provide guidance to scientists, but also provide explanations for the society and institutions that have stakes in the produced knowledge. The theme and the issues addressed by this panel leverage an extended version of a generic model (Gardner, Csikszenthmihalyi, and Damon 2001) of creative research depicted in Figure 1. The elements of the framework are the researchers, the field, the discipline, and the stakeholders. The field is comprised of experienced scientists, who decide on the novelty of contributions, as well as other contributors and apprentices. The discipline has three dimensions (problems, ethics, and knowledge) that depict the knowledge, skills, practices, and values of the professional realm. Stakeholders refer to other engineering and scientific fields that use simulation, as well as general society and institutions, which benefit from the scientific and technical production of the M&S field.

The relations between the elements of the model pose challenging issues. The dependency between the domain and researchers in M&S suggest exploring the following questions pertaining to nature of scientific production:

- What kinds of issues (methods for analysis, generalization, feasibility, empirical understanding, normative understanding, theory generation etc.) are interesting and worthy of allocating limited resources for exploring in scientific, technological, and applied M&S research and why?
- What research methods can help attain these results? (abstraction, empirical models, analytical models, procedure or technique). What are strengths and limitations of existing methods and how can existing weaknesses be mitigated?

Considering the novelty relations between the researchers, the field, and the discipline, as well as the competitive nature of M&S research:

- What types of evidence are required to demonstrate the credibility and novelty of research results in M&S (e.g., persuasion, analysis, experience, evaluation, example)?

The social conditions that stimulate research are captured through the culture imposed by the field on the researchers, who are practicing to grow and extend the scope of the M&S body of knowledge. Hence:

- What are the desirable characteristics of the M&S field to stimulate community-building and alignment of the expectations of the stakeholders and the discipline, the field, and the researchers?

As pointed out by the NSF SBES panel (SBES 2005), as well as the National Research Council report on Defense Modeling, Simulation, and Analysis, the changing landscape in science and engineering (e.g., industrial and defense application, medicine, predictive homeland security, energy and environment) introduces new types of problems and

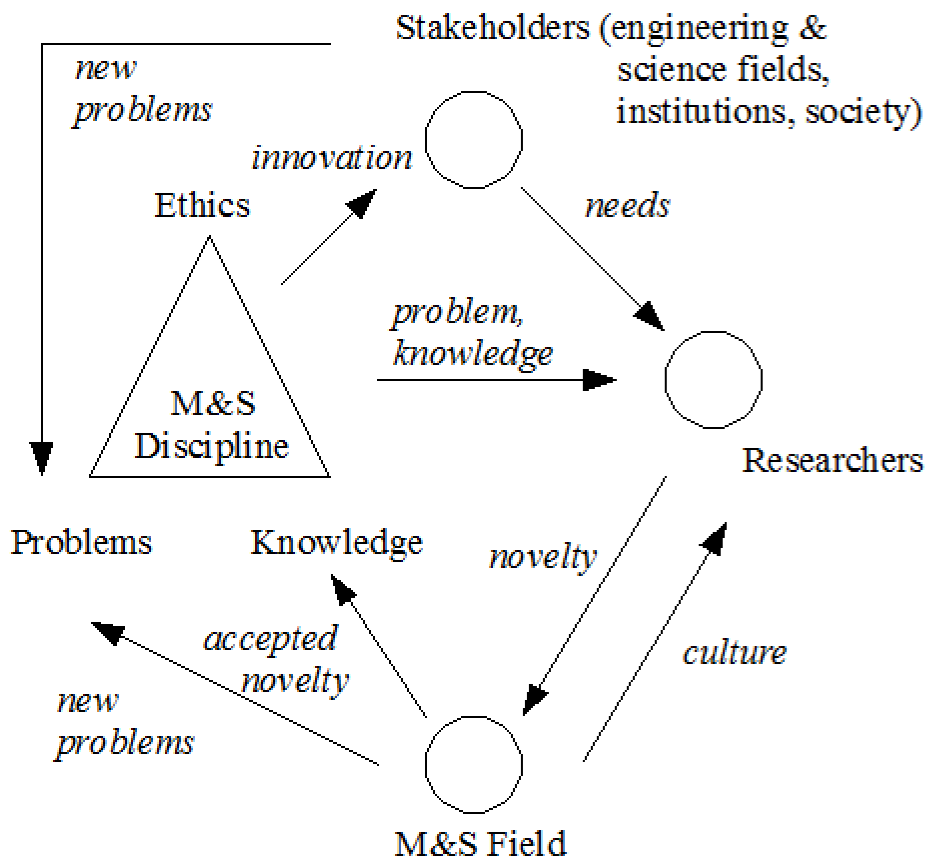

Figure 1: Components of M&S Profession and Research

challenges into the M&S domain. In light of these emergent needs:

- How can M&S stay relevant as new critical fields such as global climate change mitigation, energy restructuring, genetic engineering impacts on society, universal health care, etc. emerge and come into prominence? Surely the systems point of view and the tools that M&S brings to the table are key to these new directions. So, how does M&S play its rightful role in these?

As depicted in the model, a discipline and its domain needs to contain more than just knowledge and problems. In addition, there has to be an ethical dimension reassuring that knowledge and skills will not be used against the common interest shared by the stakeholders. Given the significance of ethics and institutional support for the sustained growth of a scientific field:

- What are the ethical concerns that are peculiar to M&S and its relation to society?

The issues above suggest exploring the M&S dicipline under the umbrella of 4 major dimensions. The first dimension focuses on the scientific discourse by exploring the nature of scientific and technical knowledge production and application. The second dimension recognizes the significance of evaluation of knowledge leading to its certification, which is the result of a process of competition. The next two dimensions acknowledge M&S profession as a socio-cultural practice. Hence, desirable characteristics of the social and institutional organization, as well as ethics in M&S are considered as important levers to sustain growth and further development of the professional realm of M&S.

3 ALIGNMENT OF THE DISCIPLINE, FIELD, AND INDIVIDUAL RESEARCHER

Recognizing the significance of the proper alignment of the discipline, the field that represents the social context, expectations of the stakeholders, and personal backgrounds of individuals, we take a close look at each one of these components and raise questions and hypotheses pertaining to their impact on the M&S profession.

The *discipline* component as shown in Figure 1 represents a symbolic system that indicates the codification of specialized knowledge, practices, and norms for transmission to new practitioners. Besides the ethics dimension, a discipline embodies ideas, practices, knowledge, as well as new problems worthy of exploration. Unless the M&S profession convinces its stakeholders that its practices (procedures) and ethical standards are valuable, support for its advancement is likely to find resistance.

The M&S field constitutes the social context of the professions by enacting the symbolic system depicted by the M&S discipline. More specifically, the field constitutes the engineers and scientists that practice the skills and knowledge embodied by the discipline. Great majority of the field is represented by experts. Vitality of the M&S profession requires a second group, called the apprentices or students, to facilitate growth and continuity of the profession. A small minority of the members of the field are categorized as evaluators that decide which contributions are worthy of expanding the domain of the discipline. Finally, the scientists and engineers who select to enter to profession represent the individuals who receive training to be enculturated in the norms and practices of the discipline to make contributions to further extend its depth, as well as scope.

The alignment of the field, the culture represented by the discipline, and the expectations of the stakeholders is critical to enable the growth of the profession. Furthermore, to sustain the vitality of the profession, the field has to pay attention to emergent challenges and, if necessary, revisit assumptions regarding the discipline, field, and practitioners. Tables 1, 2, and 3 suggest issues that are worth revisiting to examine the desired characteristics of discipline, field, and practitioners to sustain the relevance and vitality of the M&S research and profession, respectively.

4 CONCLUSIONS

The panel aims to raise awareness about the nature of scientific knowledge production in M&S, as well as its application as a scientific instrument in the broader context of science and engineering. As such, the panel will contribute to both the development of the M&S profession and to its recognition within the scientific/technical community at large. A better understanding of the M&S discipline based on the types of problems, the research methods adopted by the members of the discipline, and the evaluation criteria used by the field should help researchers design research plans and report results clearly, while helping to explain the character of modeling and simulation research to other scientists and engineers. The workshop will also make recommendations to (1) evaluate the current capabilities of M&S to support transformation of 21st century science, engineering, and technology, (2) identify leverage points for M&S research based on the observation of the changing scientific landscape and emergent new problem areas, and (3) suggest techniques to frame M&S products to decision makers in R&D management.

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Table 1: Issues Pertaining to the Influence of Discipline and Domain on M&S Profession - adopted from (Gardner, Csikszenthmihalyi, and Damon 2001)

1. How is knowledge stored and disseminated? - Permanency and ease of access of knowledge facilitates assimilation of knowledge, as well its future growth.
2. How is knowledge protected? - Does new copyright mechanisms such as Open Access Data Protocol improve diffusion of innovations? - Accessibility improves participation in M&S research.
3. How differentiated is the discipline? - Differentiation improves specialization, which then enables advancement.
4. Is the knowledge within the discipline sufficiently integrated so that advances in one subdomain become relevant for the overall discipline,while avoiding rigid or tight integration that inhibits innovation?
5. Is the discipline open enough to facilitate interdisciplinary, as well as transdisciplinary research to make the profession vital during rapid advancement of science and technology for emergent new application domains?

Table 2: Issues Pertaining to the Influence of Context on M&S Profession - adopted from (Gardner, Csikszenthmihalyi, and Damon 2001)

1. Does the M&S field encourage innovation?
2. What is the extent of mobility and internal conflict in the field?
3. Is the field balanced in term of integration and differentiation to facilitate generation of innovations, as well as their adoption.
4. To what extent is the field independent of its stakeholders (e.g., institutions, other science and engineering fields)?
5. Is there an agreement and consensus on the what constitutes novelty? - Too much or lack of agreement may inhibit innovation and meaningful growth.
6. What is the extent of institutionalization in the field?
7. Is the field open and supportive of change? - Higher field receptivity in conjunction with bold individual contributions are likely to result in innovations.

Table 3: Issues Pertaining to the Influence of Personal Qualities on M&S Profession - adopted from (Gardner, Csikszenthmihalyi, and Damon 2001)

1. Does the practitioner exhibit the talent and skills needed to succeed?
2. What is the impact of curiosity and intrinsic motivation on generating novelty?
3. Do practitioners exhibit divergent, yet meaningful and useful thinking that is conducive to discovery?
4. What are the requisite personality traits relevant to successful research? Do certain personality traits bring advantage in generating novel contributions?