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Modeling, Virtual Environments and Simulations (MES)

The Future of Modeling and Simulation

Findings Report | Year 1 | 2023 - 2024

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Modeling and Simulation: A rich and diverse field with deep historical roots and far-reaching applications evolved to meet the demands of an ever-changing world shaping our understanding of complex systems and driving innovation across various industries.

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Introduction

In an era defined by interconnected systems and rapid technological advancement, the field of modeling and simulation (M&S) stands as a crucial pillar for understanding and optimizing complex systems. M&S increased accessibility and can serve as an enabler to a broader community aiding in problem solving, decision making and training. With the increasing demand for skilled professionals in this domain, it is crucial to not only develop robust curricula but also to raise awareness and delineate the study of modeling and simulation.

This report is the outcome of extensive research into the core content, best practices, and necessary skills required to design curricula and corresponding documentation for the Modeling, Virtual Environments and Simulation Diploma (8 month certificate). Through existing research, live experiences and data analysis our objective is to provide insights that will help shape the future of modeling and simulation instruction.

This report is a compendium of diverse aspects of Modeling and Simulation. It highlights the importance of curriculum design, and expanding awareness initiatives through content experts. As we investigate and create, we also engage with a wider audience through site visits, blogging, and other mixed media sources to foster a deeper understanding of modeling and simulation.

Furthermore, the establishment of a task force comprising experts in various areas necessary for achieving the project objectives will play a pivotal role in expanding awareness and further defining the study of modeling and simulation.

History

Modeling and simulation (M&S) constitute a **multidisciplinary field employing mathematical, statistical, and computational techniques to construct models of real-world systems**, as cited by Brigas (2019), Singleton (2020), and Jaiswal and Karabiyik (2022). *These models serve the purpose of studying system behavior, predicting responses to changes, and testing novel ideas and concepts.*

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The roots of modeling and simulation trace back to ancient times and have played a pivotal role in education and training. Dating as far back as the 3rd century BC, historical accounts mention the use of melons for learning bandaging techniques and incisions. In the 18th century, an obstetrical mannequin was crafted in Paris, while the Middle Ages saw the utilization of animals to enhance surgical skills, a practice persisting until the 19th century when nursing students turned to anatomical models for practice (Singleton, 2020).

The application of modeling and simulation gained further traction during World War II when mathematicians developed techniques to address complex problems (Introduction to Modeling and Simulation Systems, n.d.). Subsequently, in the 1960s, simulation languages were introduced and refined. A milestone in the field occurred in 2001 when Laerdal introduced the first fully automated, lifelike SimMan, enhancing the ability of medical and nursing faculty to recreate real-world scenarios within the safety of the learning lab (Singleton, 2020).

M & S Education

Modeling and simulation are indispensable methodologies for depicting and analyzing real-world systems and scenarios. Participation in scenarios empowers learners to swiftly evaluate situations, identify the most effective course of action, and carry out necessary procedural steps. This approach allows professors to assess students' grasp of the subject matter and their capacity to apply acquired knowledge in practical situations. Notably, modeling and simulation-based activities provide students with potent opportunities to acquire practical skills and enhance their conceptual understanding in modeling and simulation courses, as emphasized by Alinier (2007), Brigas (2019), and Baily (2018).

Engaging with simulation tools offers students hands-on experience in applying theoretical modeling knowledge to construct computational representations of intricate phenomena. The process of building, running, and evaluating models not only encourages deeper learning but also allows students to test assumptions, employ problem-solving techniques, and bridge the gap between abstract concepts and tangible applications. This integrated approach facilitates the teaching of mathematics, science, and technical skills, aligning with the objectives of the Modeling and Simulation Certificate Program (Brigas, 2019; Jackson et al., 2009; Niu, 2022).

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Through thoughtfully designed modeling projects, instructors can involve students in activities mirroring real-world engineering practices. The iterative nature of developing, testing, and refining models, culminating in a critical refinement process, forms the core of modeling. Analyzing simulation results equips students with the skills to interpret data and extract valuable insights. Collaborative group modeling fosters teamwork, communication, and project management skills, emphasizing the multifaceted benefits of modeling and simulation in education (Brigas, 2019; Jaiswal & Karabiyik, 2022).

Actively addressing open-ended modeling problems empowers students to develop their intuition, enhance critical thinking skills, and integrate knowledge across disciplinary boundaries. Exposure to professional modeling software not only imparts relevant technological skills but also enhances the practical application of theoretical concepts. Successfully linking theory to practical use cases not only improves students' long-term retention but also enhances their ability to apply knowledge in real-world scenarios, aligning with the overarching goals of the Modeling and Simulation Certificate Program (Brigas, 2019; Jaiswal and Karabiyik, 2022).

As crucial as technical competencies are, the development of transversal competencies is equally vital for the success of students, enabling them to adapt to the evolving demands of modern society and scientific advancements. Transversal competencies encompass various classifications, including cognitive, methodological, linguistic, individual, and interpersonal skills. Cognitive skills involve understanding and applying thoughts and concepts, while methodological skills encompass areas such as time management, learning techniques, decision-making, and problem-solving. Language skills cover both verbal and written communication. Individual skills relate to expressing feelings or viewpoints on a subject, while interpersonal skills involve working effectively in a team and expressing ethical or social commitments in a socially appropriate manner.

The cultivation of these competencies is pertinent not only to individual citizenship but also to successful employment in the diverse and unpredictable trajectories of modern professions. Students need to adapt to the dynamic demands of contemporary society and scientific progress. Acquiring these skills can enhance employment opportunities by influencing the

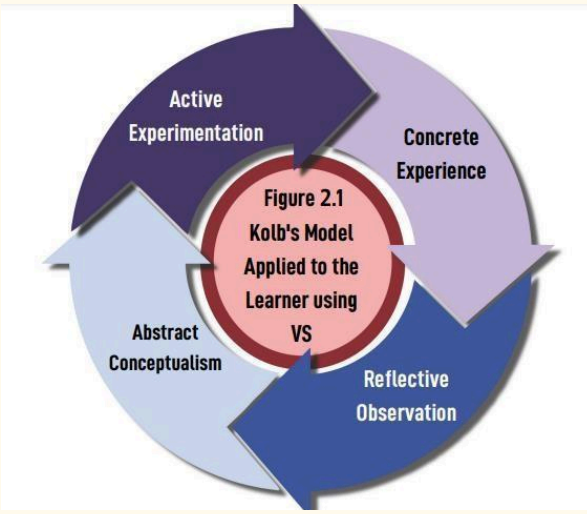
selection of candidates in the labor market, aligning with the overarching goals of the Modeling and Simulation Certificate Program (Cervera et al., 2010; Economou, 2016).

In the realm of higher education, transversal competencies can be effectively imparted through a collaborative approach, incorporating: a) Integration of teaching methodologies that foster the development of these competencies within the curriculum of each subject or module; b) Internships and work opportunities within the industry; and c) Simulated situations of professional environments facilitating the transfer of knowledge and attitudes to professional practice, as highlighted by Cervera et al. (2010). The use of technological simulation tools in "real" environments allows decision-making in real-time, thereby adding value to higher education. Competency-based learning, as supported by research, is particularly effective when linked to transfer processes, active exploration, and social environments, making simulations that replicate work environments conducive to this learning approach (Economou, 2016).

Suñer Martínez & Carballeira Morado's (2023) study further reinforces the effectiveness of simulations for experiential learning, particularly in a mechanical engineering course where modeling and simulation projects were integrated into the syllabus assignments. The research found that simulated environment assignments, analysis of results, and overall course organization provide significant opportunities for the development of cross-cutting competencies. Their evaluation using a rubric affirmed the suitability of simulation environments for academic work and the enhancement of cross-cutting competencies.

The most effective learning involves active engagement, including testing, building, experimenting, decision-making, and problem-solving. Simulations, due to their similarity to work environments and versatility, prove valuable for teaching transversal competencies. Operating in "real" environments through technological simulation tools allows real-time decision-making, facilitating the competency-based learning process. Professional competencies are acquired through action, requiring a demonstration of knowledge, understanding of theory (foundational competence), the ability to apply that knowledge in a practical way (practical competence), and the capacity to apply knowledge, understanding, and practical skill in a constantly changing environment (reflective competence).

Moreover, in the field of modeling and simulation, the foundation for effective education rests on the thoughtful integration of educational theories:



From *Kolb's Model Applied to the Learner using Virtual Simulation* (VS) by M. Verkuyl, S. Goldsworthy & L. Atack, Using Virtual Gaming Simulation: An Educator's Guide 2022. https://ecampusontario.pressbooks.pub/vgsguide/front-matter/authors/

- Experiential Learning Theory: Developed by David A. Kolb, this theory underscores the significance of experiential learning and emphasizes the integration of theory and practice. Simulations, as synthetic experiences, actively engage learners in domain-relevant tasks, aligning with the principles of experiential learning (Baily, 2018; Shin & Rim, 2023; Verkuyl, 2022). Active Learning and Multisensory Learning enhance experiential learning by providing hands-on, engaging experiences that involve multiple senses, aligning with Kolb's emphasis on learning through concrete experiences and reflective observation.
- Andragogical Learning Theory: Also known as adult learning theory, this approach prioritizes learning experiences for adults, focusing on self-directed learning, problem-solving, and critical thinking (Baily, 2018).
- Constructivist Learning Model: Simulation-based learning embodies a constructivist learning model, providing learners with experiences in a simplified simulated world or system. This approach allows learners to construct their own knowledge and skills through interactions with the real world, emphasizing active engagement and contextualized learning (Jong, 2023).
- Situated Cognition Theory: Knowledge acquisition and skill mastery are most effective when immersed in the situation where they will be applied. Simulations, by recreating contextualized environments, align with the principles of situated cognition (Lui & Goel, 2022).
- Deliberate Practice Theory: Emphasizing deliberate practice beyond proficiency to mastery through structured metrics-based training, simulations provide a platform for repeated practice, contributing to skill enhancement (Mitchell & Boyer, 2022).

- Cognitive Load Theory: Developed by John Sweller, this theory suggests that learners have limited working memory capacity. When designing simulations, it is crucial to consider expectations and the amount of new information, managing working memory load through well-designed simulations that simplify tasks and provide scaffolding tailored to learners' experience levels.
- Social Cognitive Learning: Developed by Albert Bandura, this theory highlights the role of social experiences and modeling in learning. It underscores the importance of observing others and learning from their behaviors, as well as the influence of social interactions on cognitive growth. Multi-user simulations further enhance collaborative learning by facilitating interaction with peers, coaches, and teams (Verkuyl et al., 2022).

The integration of these educational theories enhances the effectiveness of modeling and simulation in fostering a comprehensive and dynamic learning environment.

Curriculum

Educational programs preparing individuals for roles in modeling and simulation typically emphasize the following key areas:

a. Advanced Mathematical Modeling and High-Performance Computing: This entails advanced mathematical modeling and computing specifically related to high-performance Modeling and Simulation (M&S) systems.
b. Human Systems in M&S: This encompasses a range of topics such as human modeling, situation awareness, decision-making, knowledge representation, intelligent architectures, human learning, human behavior, team training and performance, and human-computer interaction.
c. Interactive Simulation: Focuses on the requirements, design, development, and utilization of interactive simulation systems for knowledge transfer and training purposes.
d. Networking and Computing Infrastructure: Covers advanced, high-performance networked testbeds, integrator architectures, and related technologies supporting distributed and large-scale simulation.
e. Simulation Management: Involves logistics, management, cost-effectiveness analysis, and simulation-based product acquisition and development.

f. Simulation Modeling and Analysis: Encompasses simulation optimization, random phenomena, experimental design, environmental modeling, and the simulation of biological phenomena.
g. Computer Visualization in M&S: Addresses visual representation and computer graphics, including virtual environments and various aspects of computer graphics.

M&S is defined as a multidisciplinary program, emphasizing its diverse and interconnected nature (Kincaid & Westerlund, 2009; Mielke et al., 2009).

Demonstrating competence in an occupationally oriented vocational qualification involves showcasing knowledge and understanding of theory (foundational competence), applying that knowledge and understanding practically (practical competence), and exhibiting the ability to apply knowledge, understanding, and practical skills in a constantly changing environment (reflective competence). This understanding aligns with the cognitive domain ascending levels of learning and underscores the importance of the M&S Program's curriculum in preparing individuals for positions of need in industry or public administration.

As a result, the development of contemporary university-level academic programs in modeling and simulation has manifested in three distinct paths, yielding three distinct types of programs: (1) Modeling and Simulation (M&S) programs, (2) Computational Science and Engineering (CSE) programs, and (3) Computational Media (CM) programs. Despite each degree program having a distinct concentration, all three programs engage with information typically associated with modeling and simulation (Sokolowski & Mielke, 2017).

However, the emerging academic field of M&S has primarily been conceptualized as an engineering discipline. Despite this, there exist fundamental links between this discipline and the social sciences and humanities. Examples include economic contributions to game theory, advancements in social network modeling within sociology, and the creation of preference aggregation models in political science (Mielke et al., 2009; National Center for Simulation, 2023). The humanities and social sciences play a crucial role in M&S due to the fundamental human element that is paramount in modeling the critical aspects we aim to understand (Sokolowski & Mielke, 2017).

Education and certification serve as assurances of authority and credibility for individuals both within and outside the professional community.

Similarly, as modeling and simulation gain increasing importance, the demand for training, education, and certification of practitioners, researchers, and educators in this field is on the rise (Loper et al., 2011). Various efforts have been employed to meet the need for creating modeling and simulation professionals, taking the forms of academic training, non-university professional training, and professional certifications. In this context, academic degrees encompass certifications, bachelor's, master's, or doctoral degrees; non-university professional training involves the acquisition of skills and knowledge for promotion through facilitated learning; and professional certification is a designation earned to ensure qualification for specific job roles or tasks.

While only a few universities offer modeling and simulation as an academic discipline at the bachelor's degree level, these programs typically adopt an academic approach. Students enroll in a program and undertake a series of courses leading to a degree, with the curriculum often grounded in the theory and science of the underlying subject matter. The culmination of these programs typically involves a formal project, thesis, or dissertation. Examples of universities offering modeling and simulation as a degree-granting academic discipline include the University of Central Florida, Old Dominion University (ODU), the University of Alabama in Huntsville (UAH), and the Naval Postgraduate School (NPS) (Tolk & Ören, 2017; National Center for Simulation, 2023).

An alternative form of modeling and simulation training is vocational (or continuing) education. In contrast to academic degrees, these courses emphasize applied learning rather than theory and may focus on specific areas of study. Vocational courses are offered by universities and industry with varying levels of accreditation. Examples of institutions providing such courses include the Georgia Tech Research Institute, George Mason University and the Army Simulation and Modeling School, Massachusetts Institute of Technology.

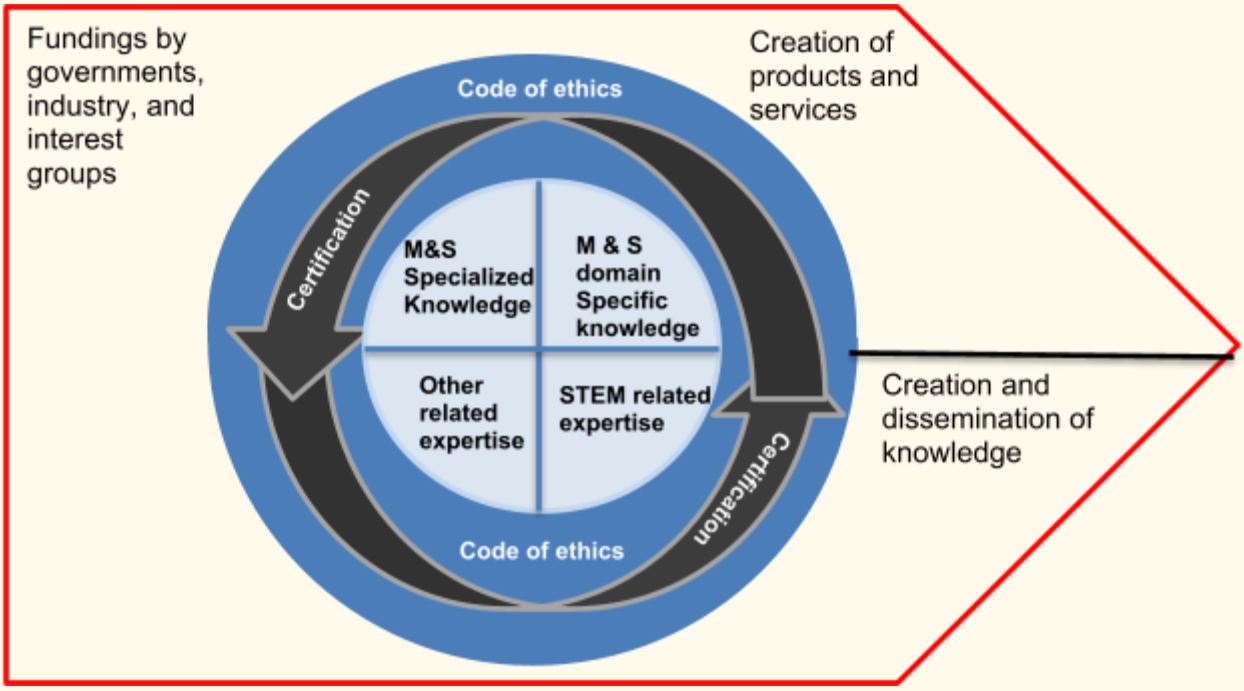
Body of Knowledge (BOK)

A Body of Knowledge (BOK) for modeling and simulation (M&S) proves invaluable, offering a comprehensive and cohesive understanding of the discipline. It serves multiple purposes, including the evaluation of professionals and organizations, conducting self-assessments, and guiding the development of curricula for academic and professional development courses and degree programs (Ören, 2005).

The recognition of the need for an M&S BOK dates back to 1997 when a consortium of M&S professionals from academia and industry convened to discuss the future of M&S as a profession. At that time, M&S was an emerging field with significant potential, and only a few academic programs offered advanced degrees in response to industry demand (Ören, 2016). The stakeholders in M&S encompass simulation theorists, methodologists, technologists, tool/environment developers, systems engineers, analysts, software engineers, programmers, industrialists, customer/sales representatives, users, and individuals potentially impacted by simulation results.

In 2008, the Department of Defense published the M&S Workforce Body of Knowledge (BOK) to support a range of professionals requiring M&S training. Funded by the Modeling and Simulation Coordination Office (M&S CO), the BOK's purpose is to provide a standardized language and knowledge base for users, developers, managers, and leaders to effectively apply M&S to DoD requirements. It serves as the foundational reference for defining the core knowledge and skills essential for members of the DoD M&S workforce. The M&S BOK is categorized into five main areas: (a) Training; (b) Decision Support; (c) Understanding; (d) Education and Learning; (e) Entertainment (Lord, 2019; Ören, 2016; Tolk & Ören, 2017).

A BOK for M&S proves highly beneficial, offering a comprehensive and integrative perspective on the discipline, facilitating self-assessment, evaluating professionals and organizations, and guiding the development of curricula for academic and professional development programs.



Adapted from M&S Body of Knowledge by T. Ören (2011). A Basis for a Modeling and Simulation Body of Knowledge Index: Professionalism, Stakeholders, Big Picture, and Other BoKs. *SCS M&S Magazine, 2*(1),40-48.

Institution | Industries| Organization	Course Description
Georgia Tech Research Institute	This course offers a comprehensive curriculum that spans diverse subjects, including advanced systems engineering tools, human systems integration, high-performance computing architectures, open architectures for software and hardware applications, aerodynamics research, and energy systems analysis. Students engage in applied research, design, development, and prototyping across these fields, providing a well-rounded education in systems engineering, computing, aerodynamics, and energy systems.
George Mason University	This course focuses on imparting foundational knowledge in modeling and simulation, equipping students with essential skills for constructing computational models of real-world systems. The curriculum places a significant emphasis on programming languages commonly employed in computational model development. The initial portion of the course introduces fundamental concepts of the Python programming language,

Institution | Industries| Organization	Course Description
	laying the groundwork for its application in the latter part of the course for developing computational models. The second half of the course delves into specific modeling techniques, including dynamical systems, Monte Carlo simulation, and discrete-event simulation.
Army Modeling & Simulation School - Simulation (s7) Course-Distance Learning	This course will provide trained personnel with an understanding of the concept of training using simulations, unit requirements to support training, an understanding of the weakness of each training venue (live, virtual, and constructive), an understanding of the importance of proper use of the after-action review process and lessons learned program.
Massachusetts Institute of Technology-Machine learning, modeling and simulation Principles	This course provides a comprehensive exploration of key concepts. Participants engage in creating simulations for intricate physical processes, employing discretization methods and numerical algorithms. The curriculum emphasizes the critical role of optimization techniques in machine learning and guides students in implementing real-world prediction and risk assessment through probabilistic methods. Furthermore, students gain insights into the limitations of machine learning and MIT researchers' proposed solutions. The course also offers a unique opportunity to stay abreast of current machine learning research at MIT CCSE, fostering awareness of its potential impact on participants' professional endeavors.
National Training & Simulation Association	The M&S Professional certification (CMSP) provides the Modeling & Simulation (M&S) industry with its own professional certification that remains valid for four years before recertification is required. Apprentice: The CMSP Apprentice level certification identifies individuals who have demonstrated an awareness of basic M&S concepts, methods, and applications. Practitioner: The CMSP Practitioner level certification designates professionals who possess applied knowledge of M&S principles and practices in a variety of domains. Master:The CMSP Master level certification is designed for M&S professionals who have a demonstrated understanding of the M&S body of knowledge and its application in a variety of context
National Center for	The content includes but is not limited to practical experiences in

Institution | Industries| Organization	Course Description
Simulation Modeling & Simulation (M&S) Certificate Program	modeling and simulation conceptualization, design, storyboarding, development methodologies, essential programming techniques, prototype development, production processes and implementation challenges. Science, Gaming and Animation, Robotics and/or Geospatial/Geographic Information Systems Technology, Computer Programming, Math, 2D and 3D Art are embedded throughout the program to emphasize the relationship between these areas and the field of Modeling and Simulation.

The effectiveness of education and certification lies in the public's perception of their alignment with professional standards. It is imperative for employers, academia, government, industry, and other stakeholders to have confidence in the quality of education and certification, as it serves as a cornerstone for establishing subject matter authority among professionals and adds credibility to the overall process (Tolk, 2017). Education plays a pivotal role in shaping the cultural mindset of future scientists and engineers. Achieving this requires a collaborative effort among academia, government, and industry to forge a shared understanding of the knowledge needed for the body of expertise in Modeling and Simulation as a profession (Mielke, 2009; Tolk & Ören, 2017). This collaborative approach ensures a robust foundation for M&S professionals, instilling trust in their capabilities and fostering a unified commitment to excellence.

Assessment at M&S

In the field of modeling and simulation,a well-crafted certification program serves as a confirmation of an individual's knowledge, skills, and readiness for professional practice. Therefore, the importance of the assessment is that it serves as a proof of knowledge, where theoretical understanding and practical application merge to validate an individual's preparation for the demands of the work ahead. The intended purpose of an assessment is to determine whether an assessment tool gives valid and reliable results that are wholly attributable to the learner (Urbina & Monks, 2023). This rigorously tests one's depth of learning and ability to apply acquired concepts in real-world situations. When establishing mechanisms for assessment, instructors should keep the simulation's core learning objectives and the targeted skills in mind.

Assessment methods should be chosen depending on what is most suited to assessing the students' desired learning goals. In some studies, we can conclude that simulation was more robust when used as an assessment in combination with other assessment tools and when more than one simulation scenario was used (Fullana & Urquia, 2009; Ryall & Gordon, 2016). Also, authentic assessments are realistic and iterative, and they require students to perform a task and apply their knowledge. They should present an interesting problem that can be visualized and understood, and they should require creativity, ingenuity, and resourcefulness.

The purpose of modeling and simulation includes performance assessment, proof, prediction, discovery, training, entertainment, and education. Simulation techniques are utilized in a wide range of research fields, such as computer systems, manufacturing processes, societal systems, business organizations, government systems, ecology, environmental systems, and other complex processes and systems. Modeling and simulation methods have been applied to interdisciplinary research fields, including decision-making mechanisms in design systems, integrated product team management, new product development processes, and organizational management (Yin & McKay, 2018).

In addition to their wide-ranging applications across research fields, modeling and simulation techniques are instrumental in education for assessing student knowledge, skill development, and interpersonal abilities. These tools not only facilitate performance assessment, proof, prediction, and discovery but also serve as effective training aids. In educational settings, modeling and simulation enhance engagement and understanding, making complex concepts more accessible. They provide a dynamic platform for interactive learning, enabling students to apply theoretical knowledge to practical scenarios. This educational approach fosters creativity, problem-solving skills, and collaboration, preparing students for diverse professional environments.

Measurement	*Assessment*	*Example*
Student Knowledge	Examinations	A post-simulation exam can be used to assess how much knowledge students have gained on the content of the simulation (Bray, 2011: O'Flaherty & Costabile,2020). Alternatively, a take-home exam can ask students to undertake a detailed analysis of certain topics or issues central to the simulation. Examinations can assess both content and the ability of the students to connect their personal experiences in simulation with the broader learning objectives of the course (Landricina,2013; Shin & Rim, 2023).
Assessment of Applied Skill Development	Writing exercises	This strategy can take a variety of forms. Students can be assigned to write an introspective paper in which they must reflect on what they learned throughout the simulation. This type of reflective writing encourages students to explore how the exercise might have differed in the real world, if it met their expectations, and to engage in broader self-reflection on their own performance and learning (O'Flaherty & Costabile,2020; Wu, 2015b). If the instructor intends to stimulate reflection on topics during the simulation, regular diary entries can also be employed.
	Task-specific exercises	Students can be given a number of tasks of varying difficulty to perform levels during or after the simulation to demonstrate competencies acquired. Students are assessed based on their performance, as well as follow-up reflection or explanation (Trundle & Bell, 2010). For example, medicine students were tasked with demonstrating their surgical skills in animal models (Sidhu, 2005) while tourism management students were asked to demonstrate their tour-guiding skills by conducting mini-tours around the campus (Ryall & Gordon, 2016; Jong,2023).

	Discussion	In role-play simulations, students can be assessed through a facilitated discussion. During the discussion, the students can be asked to explain their in-role stance, reflect on what transpired during the simulation, and explore alternative outcomes. Students are graded on the depth of their self-reflection and their ability to connect knowledge gained through the exercise with real-world practice (Moore et al., 2014).
	Debriefing and reflection:	After the simulation, learners engage in a debriefing process, where they discuss their experiences, identify areas for improvement, and reflect on their learning (Bertiz & Moreno, 2022),
	Case study	The use of interactive cases is another tool for the assessment of students' problem solving and critical thinking skills. Here, specific cases representing different complex situations are integrated in the simulation. The students have to explore the cases and come up with acceptable solutions for the problems (Wu, 2015a; Wu, 2015b; O'Flaherty & Costabile,2020).
	Validation of assessment tools:	Validation of assessment tools is essential to ensure that they are valid and reliable (Bertiz & Moreno, 2022; Urbina & Monks,2023).
Assessment of Interpersonal Skills and Professionalism	In-person feedback	This can take the form of a semi-structured interview where service users and students are given the opportunity to discuss their experiences in front of the instructor. Students are assessed based on the feedback as well as their response to it (McMahon-Parkes et al., 2016). This kind of assessment is important for those disciplines where the students will have to directly interact with the service users as part of their professional careers.

It is imperative that assessment materials align with learning objectives, with developers maintaining direct control over all aspects of delivery and evaluation. The content should be closely tied to the learning objectives, and the test itself should be sufficiently comprehensive to yield reliable scores. The assessment process is crucial for curriculum development, feedback,

and learning. Simulation instructors should ideally reflect on the purpose of the simulation to determine if the focus is on teaching or learning (Nazar et al., 2019). If the focus is on teaching, then assessments should focus on performance criteria with exercises for a series of skill-based experiences; this evaluates the effectiveness of the instructional method in task training. If the simulation aims to assess higher-order learning, the assessment should measure multiple integrated abilities, including factual understanding, problem-solving, analysis, and synthesis (Urbina & Monks, 2023). To optimize learning outcomes and return on investment (ROI), it is crucial to select the appropriate category of simulation, develop simulation-based training with clear training objectives, facilitate the measurement of the training process and outcomes, and incorporate formative evaluation throughout the training.

The purpose of model verification and validation is to ensure that the simulation model is meaningful in a real-world context. Therefore, the modeling and simulation procedure includes model verification and validation in addition to model design and development. Verification is the process of determining whether a model implementation accurately represents the developer's conceptual description and specifications. Validation is the process of determining the accuracy of a model in representing the real world for its intended uses. Accreditation is the official certification that a model, simulation, or federation is acceptable for a specific purpose (Yin & McKay, 2018).

Ensuring that simulations generated by educational program student’s pass the verification and validation process involves several key steps. First and foremost, it is crucial to provide students with a clear understanding of the concepts and principles behind model verification and validation. This includes imparting knowledge about the importance of accurately representing real-world phenomena, aligning simulations with intended purposes, and ensuring the reliability of the simulation outcomes.

Practical training is essential, and students should be guided through the process of designing, developing, and refining their simulations. Emphasizing the significance of thorough documentation and transparent communication in the modeling process can contribute to successful verification and validation. Encouraging students to articulate their conceptual descriptions and specifications explicitly will enhance the accuracy of the model implementation.

Moreover, integrating real-world data and scenarios into the simulation projects can enhance their authenticity and applicability. This involves guiding students in selecting appropriate input

parameters, refining their models based on empirical data, and aligning simulation outcomes with observed real-world behaviors.

Regular feedback and iterative refinement are essential components of the learning process. Simulation creators learners should be encouraged to engage in peer reviews, seek input from instructors or mentors, and iteratively refine their simulations based on validation results and feedback received. This iterative approach allows students to learn from the verification and validation process, enhancing their skills in developing accurate and reliable simulations.

Ethical behavior

In the realm of modeling and simulation, ethical considerations play a pivotal role given the diverse purposes they serve, including decision making, training to enhance decision and/or communication skills (gaming simulation), training to enhance motor skills (simulators), understanding and education (Links-EdSim), and entertainment (simulation games and animation of dynamic systems). Because M&S is computer-based, various ethical issues of computerization, software engineering, the Internet, and artificial intelligence apply to modeling and simulation. Ethics are important considerations in the modeling and simulation profession. Modeling and simulation for scientific and engineering purposes necessitates consideration of scientific and engineering ethical norms. Although modeling and simulation are commonly used in research, it is important to adhere to ethical standards to prevent fabrication, falsification, and plagiarism of data, language, and ideas, as well as other forms of misconduct.

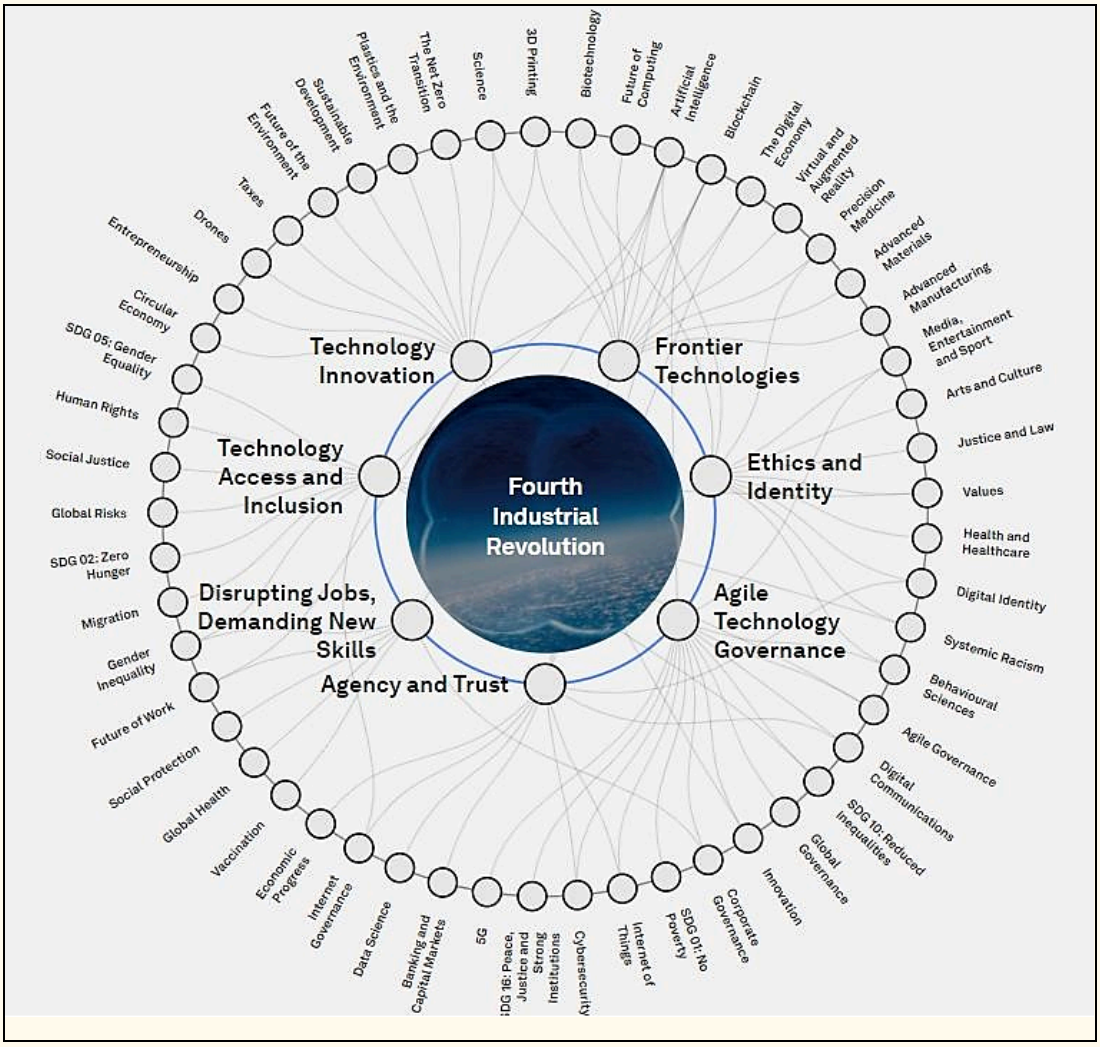
Ethical issues in business also apply to modeling and simulation. In defense settings, additional business ethics for the military sector are desirable. During the development and implementation of simulation activities, it is crucial to take into account the code of ethics, which consists of five sections: personal development and the profession; professional competence; trustworthiness; property rights and due credit; and compliance with the code. Some of the societies that have adopted the code of ethics include the National Training and Simulation, the Society for Modeling and Simulation International (SCS), McLeod Modeling and Simulation Network (M&SNet), the Simulation Interoperability Standards Organization (SISO), SISO Canada, and Alabama M&S Council (AMSC) (Ören, 2005).

This ethical framework ensures that modeling and simulation practitioners uphold the highest standards of integrity, promoting responsible conduct in both research and business applications. As the field continues to evolve, the commitment to ethical practices remains essential for fostering trust, credibility, and the responsible use of modeling and simulation technologies.

Competencies in Industry 4.0

Industry 4.0 marks a transformative phase in human development. This revolution is enabled by advances and fusions of technologies, as well as increasing harmonization and integration between research disciplines, where research breakthroughs leverage technological and digital capabilities. In addition, Industry 4.0 is merging the physical, digital, and biological worlds (World Economic Forum, 2019).

The advent of Industry 4.0 brings about significant changes in the employment landscape, shaping job profiles and necessitating a broad spectrum of competencies in graduates. According to the World Economic Forum (2018), the ten essential skills or competencies required for success in Industry 4.0 include complex problem solving, critical thinking, creativity (out-of-the-box thinking skills), time management, people management, coordination with others, emotional intelligence, judgment and decision-making, service orientation, negotiation and cognitive flexibility, growth mindset, and adaptability. These competencies collectively empower individuals to navigate the dynamic challenges and opportunities presented by the evolving landscape of Industry 4.0.



From *Fourth Industrial Revolution* by World Economic Forum, 2023
https://intelligence.weforum.org/topics/a1Gb0000001RIhBEAW?tab=publications. CC BY-NC-ND 4.0

Types of models

As a result, hands-on simulation experiences enable students to think, collaborate, and problem-solve like real modelers. Instructors can leverage these high-impact activities to equip students with modeling competencies and prepare them for future careers in this growing field. In addition, because of their many advantages, modeling and simulations are now frequently used for education in a variety of fields.

Modeling and Simulation: A rich and diverse field with deep historical roots and far-reaching applications evolved to meet the demands of an ever-changing world shaping our understanding of complex systems and driving innovation across various industries.

Therefore, M&S can encompass various forms, such as virtual simulations and physical simulations. Virtual simulations use computer technologies to create interactive scenarios and realistic environments, allowing participants to participate and respond as they would in real life. Physical simulations, on the other hand, involve the use of physical models or replicas to simulate real-world situations. These may be medical procedures simulated with mannequins or flight simulators that mimic the experience of pilots in the cockpit. Likewise, for example, engineers can use models to design new products and systems. Doctors can use models to study the human body and develop new treatments for diseases. Models may help businesspeople make better decisions in marketing, finance, and operations. Models can also be used by military officials to plan operations and test new weapons and tactics (Brigas, 2019; Dauer et al., 2019; Niu, 2022; Shan et al., 2023).

There are various types of models that can be used in M&S. The most common types of models are physical, mathematical, and computational models. **Physical models** are physical representations of real-world systems and can be used to study their behavior in a controlled environment. **Mathematical models** are mathematical representations of real-world systems and can be used to predict how systems will respond to changes. **Computational models** are simulations of real-world systems that can be used to test new ideas and concepts (Menner, 1995; Brigas, 2019; Niu, 2022).

The type of model used depends on the application. For instance, a physical model may be utilized to examine the aerodynamics of a new aircraft design. Physical modeling is a fundamental aspect of modeling and simulation because it provides a tangible, visual representation of complex, real-world systems. *In the context of MSP curriculum design, we explore the world of physical models to provide students with the knowledge and skills needed to create, analyze, and effectively use these practical representations*. Physical models, which can range from scale replicas to intricate prototypes, are valuable tools used in various industries, including engineering, architecture, physics, and environmental science. An example of a model is a printed map or a mock-up. An integration of physical and virtual simulations is observed. The digital model of a terrain has an analogous version in maps that represent the same variables but encode them on a physical support through graphic conventions (Felicísimo, n.d.).

Similarly, mathematical models are an essential tool in a modeling and simulation course, as they allow students to represent and analyze complex systems using mathematical equations and relationships. Mathematical models play a fundamental role in identifying the essential skills and knowledge needed for a modeling and simulation course. These models enable students to understand the quantitative aspects of complex systems and develop analytical and problem-solving skills. They encourage a structured approach to modeling, emphasizing the need for accuracy, data analysis, and critical thinking. By working with mathematical models, students can discern patterns, make predictions, and test hypotheses—all fundamental skills in the field of modeling and simulation (Shan, 2023). An example of a mathematical model can be used to predict the spread of a disease (Sarkar et al., 2020).

Mathematical modeling provides students with a diverse set of mathematical tools and techniques, preparing them to handle the quantitative aspects of modeling various systems. It establishes a robust foundation for students to acquire the skills and knowledge essential for success in a modeling and simulation course, enabling them to create, analyze, and apply models across different fields. For instance, a mathematical model can be created for a production plant. This model should consider various factors such as the arrival of raw materials, different shifts of operators, production orders for different products, and availability of spare parts for parts that tend to fail, among other variables. The modeling is then transferred to a computational environment to observe the impact of decisions over time, streamlining processes (Shan et al., 2023).

Computational models provide a platform for hands-on experience, but they also require a deep understanding of mathematical concepts, programming, and data analysis. Students working with computational models learn to translate real-world systems into a digital format, cultivating problem-solving skills, critical thinking, and the ability to effectively create and modify models (Dauer et al., 2019). In addition, these models expose students to a variety of simulation software and programming languages, ensuring that they gain proficiency in the technical aspects of modeling and simulation. By engaging with computational modeling, students develop a comprehensive set of skills and a knowledge base that are essential for success in a modeling and simulation course, equipping them to tackle complex real-world problems and

analyze diverse systems across numerous domains. In addition, the professor continually enhances their practice by developing an understanding of computational thinking and its application as a cross-cutting skill. The professor develops a working knowledge of the basic components of computational thinking, such as decomposition, data collection and analysis, abstraction, algorithm design, and the impact of computer science on people and society (Brigas, 2019; Dauer et al., 2019; Zhang, 2022; Shan et al., 2023).

Modeling and simulation applications

Modeling and simulation applications have a significant impact on diverse organizational and operational systems, spanning manufacturing systems, industrial production processes, business service systems, complex problem-solving processes, business organizations, socio-technical systems, human systems, and automotive assembly systems.

M&S programs were primarily developed to meet the needs of the U.S. Department of Defense (DoD) and the manufacturing industry. The Department of Defense employs modeling and simulation to develop and evaluate doctrine, assess the effectiveness of proposed new systems, and conduct training more efficiently. Similarly, the manufacturing industry uses modeling and simulation to improve their processes and products. Simulation is used to design and develop new manufacturing processes and systems, monitor, and control the manufacturing supply chain and production facilities, and evaluate the business case for investing in new production methods and technologies (Tolk & Ören, 2017). Both of these sectors require modeling and simulation professionals with the capabilities to conduct extensive studies and make recommendations based on the results. The World Economic Forum's Future of Jobs Report predicts widespread disruption to business models and labor markets due to the "Fourth Industrial Revolution" unleashed in part by the advances in fields such as artificial intelligence, machine learning, and robotics (World Economic Forum, 2023).

Modeling and simulation serve as valuable assets for various industries, offering insights into material behavior, cost efficiency in materials and process designs, and tools to reduce time, cost, and risks associated with material design processes by minimizing expensive or hazardous experiments. Well-documented models formalize knowledge, preventing its loss over

time, and contribute to avoiding mistakes and repetition. Additionally, these methodologies are crucial for scaling up production and reducing time-to-market through efficient process design.

Use of Modeling and Simulation

Modeling and Simulation (M&S) find extensive applications across diverse fields, playing a pivotal role in solving real-world problems. Its utility spans engineering, medicine, business, and military operations, with examples of applications in each domain:

Engineering: M&S is used in engineering to design new, more efficient, and safer products and systems, test the performance of existing products and systems, and improve the safety of products and systems (Blaykin, 2022; Scotti et al., 2023).

Medicine: M&S is used in medicine to study the human body, develop new treatments for diseases, and improve the safety of medical procedures. Physicians can use modeling and simulation to develop new, more effective, and less costly treatments for diseases. For example, several studies have concluded that students who participate in this simulation teaching method increase their clinical skills, knowledge, safety, and communication skills in an interdisciplinary team. The implementation of simulated environments allows for the generation of a patient safety policy that minimizes the occurrence of incidents or adverse events, thus increasing their clinical experience and improving their clinical care processes (Blaykin, 2022; Duaer et al., 2019; Kincaid & Westerlund, 2023).

Business Industry: Modeling and Simulation is used in business to make better marketing, financial and operational decisions that lead to higher profits. For example, a company's goal may be to satisfy the customer, using a simulation model, this requirement can be translated into the time to respond to a customer's request, which can be designated as the performance measure to satisfy the clientele. Simulation measures the strengths and weaknesses associated with the design of a new product or service and allows further analysis on parameters such as time to market, service levels, market requirements, transportation costs, etc. (Fullana & Urquía, 2009).

In the military: They are used to train soldiers, plan operations, and test new weapons and tactics. Modeling and simulation (M&S) are essential tools in the defense field. M&S offers a

versatile and cost-effective means to enhance training, planning, decision-making, and overall military preparedness. M&S supports all defense missions, including concept exploration, analysis, acquisition, test and evaluation, planning, doctrine and tactics development, operations, and training, both within each service and the Joint commands. The Department of Defense (DoD) is requesting $842 billion for the fiscal year 2024, including funding for enterprise-level capabilities for modeling and simulation (M&S) (DoD, 2023), according to the FY 2024 budget request overview book.

In the military industry, the utilization of Modeling and Simulation (M&S) stands as a cornerstone for enhancing training, strategy development, and operational planning. This approach mirrors the core objectives of the VirtualEd-MES project, which seeks to leverage M&S in educational contexts for improved learning outcomes. The participation of our task force in the I/ITSEC 2023 event within the military industry was a transformative experience that enriched our understanding and approach to modeling and simulation (M&S) in education.

At the event, sessions highlighted the transformative impact of M&S on military training and operations. For instance, the session "How the Marine Corps is using the Digital World to support Training Today and into the Future" showcased innovative uses of M&S for enhancing training effectiveness and operational readiness. Additionally, the session "Driving Proficiency through Mobile, Immersive, Hands-on eXtended Reality (XR) Training" underscored the role of immersive technologies in revolutionizing military training approaches.

Another learning experiences from the I/ITSEC 2023 event:

- Attending tutorials on Conceptual Modeling, which emphasized the importance of establishing robust conceptual models in simulation development to avoid unnecessary expenses.
- Exploring innovative applications of modeling and simulation in academic program development, such as the presentation on "Rise of the Resistance" at Walt Disney World, which showcased how simulation can revolutionize educational experiences.
- Engaging with the latest technologies and practices in simulation, particularly in flight and healthcare simulators, to broaden technical expertise and comprehension of simulation applications in fields like medical training and flight simulation.

- Attending a session on the use of virtual reality (VR) in medical training, which highlighted successful implementations of simulation in formative settings, such as recreating complex surgical procedures for medical students.
- Participating in a workshop on simulations driven by artificial intelligence (AI), which showcased successful implementations of AI in formative settings, such as dynamically adjusting simulation parameters based on user performance to optimize learning outcomes.
- Engaging in a panel discussion on simulation-based crisis management, which revealed successful implementations of simulation in preparing professionals for real-world emergencies, such as training first responders and healthcare personnel in simulated disaster scenarios.

By drawing parallels between military applications and educational contexts, our project aims to adapt these successful strategies to create immersive and impactful learning environments.

Moving forward, the insights gained from I/ITSEC 2023 will serve as a guiding light for our project's future endeavors. The event highlighted the importance of immersive technologies and advanced AI techniques in optimizing training outcomes, which aligns perfectly with our project's focus on integrating these elements into educational simulations. By leveraging the lessons learned from the military industry, we aim to create a transformative learning experience that prepares students for success in the digital age.

Areas of opportunity:

Industry 4.0

In the context of Industry 4.0, the primary objective is to enhance production flexibility, quality, safety, and customer responsiveness through the integration of digital industry technologies. Industry 4.0 organizations embrace a range of emerging technologies to achieve these goals, including:

(a) Robotics and Autonomous Machines: Implementing robotic and autonomous systems to streamline manufacturing processes.

(b) Advanced Visualization: Incorporating technologies such as augmented reality, virtual reality, and mixed reality for enhanced visualization.

(c) Sensor Technologies and Industrial IoT (IIoT): Utilizing sensors and IIoT to gather data and facilitate connectivity within industrial settings.

(d) Cybersecurity: Ensuring the security of digital systems and networks within the industrial environment.
(e) Cloud Computing and Software as a Service: Leveraging cloud-based computing and software services for improved efficiency.

(f) Big Data Analytics: Employing analytics to derive insights from large volumes of data, enhancing decision-making processes.

(g) Additive Manufacturing: Integrating 3D printing and additive manufacturing techniques for innovative production.

(h) Vertical and Horizontal Integration of Systems: Enhancing connectivity and collaboration between different systems within the industrial ecosystem.

(i) Simulation: Utilizing simulation technologies for modeling and testing operational scenarios.

These digital technologies are being adopted by various industries. These technologies are used for increased production quality and diversity, optimizing processes, and decreasing costs in manufacturing systems using smart systems. Data collected on supply chain management, customer behavior, marketing campaign performance, and workflow procedures, among others, are also widely available virtually. Although digital industry technologies are prominent and contribute to Industry 4.0, they remain a growing area of development.

Advancements in simulation-related hardware and software over the past decade have rapidly upgraded. As large volumes of data can be continuously provided in real time or semi-real time through simulation modeling, operational logic can be described in detail at any desired level (Economic Forum, 2023; Gaku et al., 2019; González Hernández & Granilla Macías, 2021). A report published by Gartner predicted net job creation through the use of artificial intelligence by 2020 and two million net-new jobs as a result of the technology by 2025 (World Economic Forum, 2023).

M&S and Artificial Intelligence

Modeling and Simulation (M&S) and Artificial Intelligence (AI) are intricately connected, with AI being constructed upon a programmed "model" that simulates how humans represent knowledge, process data, and make decisions. AI, particularly its subfields of machine learning (ML) and natural language processing (NLP), plays a crucial role in M&S due to their shared objectives, including knowledge representation, prediction, understanding, and decision-making.

Machine Learning (ML): ML is a fundamental aspect of AI, and its integration with M&S enhances the capabilities of predictive modeling, pattern recognition, and decision support. ML algorithms can analyze data, identify patterns, and adapt their models based on new information, contributing to more sophisticated and accurate simulations.

Natural Language Processing (NLP): NLP, another subfield of AI, focuses on the interaction between computers and human language. In the context of M&S, NLP holds significant potential. One notable application is its ability to translate conceptual models into accessible text, making them more understandable for a diverse audience, including subject matter experts. This can facilitate collaboration and engagement in the modeling process.

The synergy between M&S and AI is evident in their complementary goals. Both fields aim to represent knowledge, predict outcomes, understand complex systems, and support decision-making processes. As AI technologies continue to advance, their integration with M&S will likely evolve, contributing to more sophisticated simulations and improved accessibility for a

broader range of stakeholders. This convergence opens up new possibilities for enhancing the effectiveness and inclusivity of modeling and simulation practices.

M&S Quantum computing

Although quantum computing is not yet widely accessible, it has the potential to revolutionize fields such as chemistry (e.g., drug discovery and development, the development of new materials) and cybersecurity (breaking or improving encryptions). Modeling and simulation practices can support this potential by aiding in the design and experimentation of new quantum computing methods.

Advantages of modeling and simulation

M&S offers a number of advantages, including:

- **Risk reduction:** M&S can be used to reduce the risk of making bad decisions. By testing new ideas and concepts in a simulated environment, M&S can help us identify potential problems and make better decisions.
- **Improving efficiency:** M&S can be used to improve the efficiency of operations. By simulating the performance of systems, M&S can help us identify areas where we can improve efficiency.
- **Increased safety:** M&S can be used to increase the safety of products and systems. By simulating the behavior of systems, M&S can help us identify potential hazards and design safer products and systems (Future of Modeling and Simulation, 2023).
- **Evaluation tool:** It is used as a methodology to evaluate psychomotor and communication skills. It has also been successfully used to evaluate the development of competencies. It allows systematic and repeated training of practical skills and competencies; it allows students to make mistakes and learn from them; the learning process is based on practice and reflection, achieving a greater transfer of training from theory to practice (Brigas, 2019; Dauer et al., 2019; Niu, 2022; Shan et al., 2023).

The application of M&S is multifaceted, providing practical solutions to complex problems across diverse domains.

Challenges of modeling and Simulation

M&S also faces a number of challenges like:

- **Complexity**: M&S models can be very complex. This can make their development and use difficult (Sakar et al., 2020; Scotti et al., 2023; Shan et al., 2023).
- **Accuracy:** The accuracy of M&S models depends on the data on which they are based. If the data are not accurate, the model will not be accurate either (Sakar et al., 2020; Scotti et al., 2023; Shan et al., 2023).
- **Cost:** M&S can be expensive. The cost of developing and using M&S models can be a barrier for some organizations (Sakar et al., 2020; Scotti et al., 2023; Shan et al., 2023).
- **Teaching M&S versus the commercial educational environment:** In the academic world, one of the challenges is to ensure that participants (i.e. students) acquire the general knowledge necessary to understand the concept of M&S. On the other hand, in the commercial sector, it is necessary to ensure that participants (i.e., employees) acquire the necessary skills to solve specific problems (Mielke et al.,2009); Ören, 2017).
- **Emerging and disruptive technologies:** M&S needs to be rethought, from how it conceptualizes and executes their models and simulations, to how they use M&S to understand reality. It requires that the M&S community connects with other research and development communities (including academia and industry)that are also looking at these disruptive technologies. This interdisciplinary perspective will consider not only the technology, but more importantly its users and how their advanced activities like decision-making with fast simulation prototyping (Future of Modeling and Simulation, 2023).

At the I/ITSEC 2023 event some of the challenges presented were shape simulation capabilities, enable the transformation of operations, training, testing, erratic budget, complex threats, sustaining a global force in a digital world and that all economy enterprises needs new technology workers with training in state-of-the-art technologies so they can work in a short period of time.

Despite the challenges, modeling and simulations are valuable tools that can improve our lives. As M&S technology continues to develop, we are likely to see even more applications of M&S in the future.

To overcome the challenges of modeling and simulation, it is important to use the right tools and techniques. For instance, complex models can be decomposed into smaller, more manageable models, and inaccurate models can be improved by using better data and more sophisticated modeling techniques.

The expense of modeling and simulation can also be decreased by utilizing open-source software and cloud-based computing resources.

By overcoming the challenges of modeling and simulation, we can make this powerful tool even more accessible and useful.

Conclusion

In summary, the development of an evidence-based curriculum for Modeling and Simulation (M&S) not only addresses the current needs of academia, industry, and government but also advances the field itself. By integrating educational theories, incorporating practical design, aligning with professional knowledge, and adapting to emerging technologies, this curriculum sets a new standard for M&S education.

This research contributes to the advancement of the M&S field by providing a comprehensive framework for curriculum development. It emphasizes the importance of stakeholder collaboration, educational theory integration, and practical application, ensuring that M&S professionals are equipped with the necessary skills and knowledge to excel in their field.

Furthermore, this curriculum's adaptability to emerging technologies ensures that it remains relevant in the rapidly evolving landscape of the Fourth Industrial Revolution. By staying abreast

of changes and incorporating new technologies, this curriculum prepares students to tackle the challenges of tomorrow.

In conclusion, this research not only provides a roadmap for developing an effective M&S curriculum but also contributes to the advancement of the field itself. It sets a new standard for M&S education, ensuring that graduates are well-prepared to make significant contributions to their respective fields.

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