Learning Theory Foundations of Simulation-Based Mastery Learning

William C. McGaghie, PhD;
Ilene B. Harris, PhD

Summary Statement: Simulation-based mastery learning (SBML), like all education interventions, has learning theory foundations. Recognition and comprehension of SBML learning theory foundations are essential for thoughtful education program development, research, and scholarship. We begin with a description of SBML followed by a section on the importance of learning theory foundations to shape and direct SBML education and research. We then discuss three principal learning theory conceptual frameworks that are associated with SBML–behavioral, constructivist, social cognitive–and their contributions to SBML thought and practice. We then discuss how the three learning theory frameworks converge in the course of planning, conducting, and evaluating SBML education programs in the health professions. Convergence of these learning theory frameworks is illustrated by a description of an SBML education and research program in advanced cardiac life support. We conclude with a brief coda.
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This article addresses the intellectual foundations of simulation-based mastery learning (SBML). Our purpose is to point out that SBML is grounded in multiple theoretical models that operate together to produce short-run and translational learning outcomes. A practical example about advanced cardiac life support (ACLS) education illustrates the convergence of learning theory foundations of SBML.

SIMULATION-BASED MASTERY LEARNING

Simulation-based mastery learning is expanding rapidly in scope and impact in health professions education.[1] Scores of SBML research studies have been published in a variety of discipline-specific, simulation, and health professions education journals for the past two decades. These research reports chiefly address skill acquisition studies in the health professions for individuals and teams across a range of learning outcomes. Examples include core clinical skills;[2,3] invasive procedural skills;[4–9] communication with peers, patients, and families;[10,11] management of complex clinical conditions, eg, pediatric status epilepticus;[12] intensive care unit patients on ventilators;[13] complex obstetrical deliveries;[14] and surgical maneuvers.[15,16] At least seven integrative reviews demonstrate the power and utility of SBML to achieve short-run results in the simulation education laboratory and also “downstream” results expressed as better patient care practices and improved patient outcomes.[17–23] Strong evidence shows that SBML is an effective education strategy to help health professions learners acquire foundation knowledge, clinical skills and acumen, communication skills, and attributes of professionalism.

What is mastery learning? Mastery learning is a form of competency-based education in which all learners acquire essential skill and knowledge measured rigorously in relation to high and fixed achievement standards without restricting learning time to a uniform interval to reach the outcome.[24] Mastery learning outcomes indicate a much higher level of performance than competence alone. In mastery learning education, *results* are uniform, with little or no variation, whereas education *time* to achieve mastery may vary among trainees. The education goal of mastery learning is “excellence for all learners,” without exception.[25]

Mastery learning is operationalized as an integrated bundle of seven blended features that together express its education structure and processes. The seven features of the mastery learning bundle and their purposes are presented in Table 1.[26,27]

Conducted in a health sciences education simulation laboratory learning environment, mastery learning with rigorous deliberate practice[28–30] produces SBML—a powerful approach for the acquisition of knowledge, skills, and professionalism attributes among learners in the health professions.

LEARNING THEORY FOUNDATIONS

Simulation-based mastery learning has theoretical roots that not only shape and define its principles but also set its boundaries and operations expressed as curriculum development, formative and summative learner assessment, and outcome evaluation research. We endorse the perspective of Kauffman and Mann[31] who describe theory generally as, “… a set of assumptions and ideas that help to explain some phenomenon.” Fred Kerlinger[32] provides a more expansive definition of theory for education and the social sciences, commenting: “A theory is a set of interrelated constructs (concepts), definitions, and propositions that present a systematic view of phenomena by specifying relations among variables, with the purpose of

From the Department of Medical Education and Northwestern Simulation (W.C.M.), Northwestern University Feinberg School of Medicine; and Department of Medical Education (I.B.H.), University of Illinois College of Medicine, Chicago, IL.

Reprints: William C. McGaghie, PhD, Department of Medical Education and Northwestern Simulation, Northwestern University Feinberg School of Medicine, McGaw Pavilion Suite 1-200, 240 East Huron St, Chicago, IL 60611 (e-mail: wcmc@northwestern.edu).

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TABLE 1. Seven Features and Purposes of the Mastery Learning Bundle[26,27]

Feature	Purpose
1. Baseline, ie, diagnostic testing	Establish learning point-of-departure; provide specific, actionable feedback for learner improvement
2. Clear learning objectives sequenced as units with increasing difficulty	Logical curriculum plan moving from simple to advanced challenges and achievements
3. Engagement in educational activities, eg, deliberate practice, coaching, data interpretation, reading, focused on the learning objectives	Planned, active education activities designed to help learners achieve learning goals. Faculty are also engaged actively.
4. A set minimum passing standard (MPS), eg, checklist score, test score, for each education unit	A high and fixed learning expectation for each educational unit. All learners are expected to reach each MPS.
5. Formative testing with actionable feedback to gauge unit completion, or the need for more practice at the preset MPS	Assessment for learning, feedback, and coaching aimed toward constant learner improvement.
6. Advancement to the next education unit given measured achievement at or above the MPS	Learner meets or exceeds the MPS, time needed to achieve the unit MPS may vary among learners
7. Continued practice or study of an educational unit until the MPS is reached	Deliberate practice and study are needed for each learner to achieve the unit MPS

explaining and predicting phenomena." Theories underlie all conceptual, educational, and empirical work and science in SBML, even if the theories are tacit and not made explicit.

Scientific work begins with hypotheses, ie, conjectures, that are derived from theory to predict relations among concepts. As hypotheses achieve empirical support by being robust to refutation or falsification, they slowly become established principles.[33] Sustained and productive empirical research can make principles thematic and coherent as a body of knowledge matures and becomes unified. This line of reasoning provides at least the following four insights: (*a*) theory has several parts—concepts, definitions, assumptions, and generalizations; (*b*) the purpose of theory is to describe and explain; (*c*) theory is an aid to learning, discovery, and problem-solving because it stimulates and guides new knowledge production; and (*d*) strong theories can withstand repeated challenges to their substance, structure, and sustainability.

Theories are not strictly true or false. Carl Hempel[34] states this simply, commenting: "… we can never establish *with certainty* that a given theory is true, that the entities it posits are real." Instead, theories are either useful or not useful. Theories are useful to the degree that they inform, frame, and energize scientific work such as experiments that lead to new knowledge and understanding. This concept is summarized in Lewin's Maxim,[35] an aphorism expressed by social psychologist Kurt Lewin in the mid-20th century, who commented: "There is nothing as practical as a good theory."

Psychologist Kenneth Hammond[36] has also articulated the importance of theoretical coherence and transparency for scholarly progress in the behavioral sciences and education. Hammond[36] gives particular attention to the research methods that are used in scientific work. Hammond[36] states, "Every [research] method…implies a methodology, expressed or not; every methodology implies a theory, expressed or not. If one chooses not to examine the methodological base of his or her work, then one chooses not to examine the theoretical context of that work and thus becomes an unwitting technician at the mercy of implicit theories."[36] A similar argument could be made about the theoretical foundations of other facets of SBML science and technology including curriculum development, assessment of learner achievement, and program outcome evaluation in immediate and translational categories. Progress in the behavioral sciences, including simulation research in the health professions, depends on scholars being mindful of the theoretical grounds of all phases of investigation as psychologist and philosopher Paul Meehl[37] taught four decades ago.

Another important point is that SBML in health professions education resides in a broader historical context of learning grounded in workplace apprenticeship experiences. Laboratory-based SBML complements but does not replace the situated learning and professional socialization that occurs in clinical settings. The difference is that in SBML the singular focus is on individual learners and teams under conditions that can be standardized, controlled, and predictable—good conditions for learning and instruction. By contrast, the focus in clinical workplace settings is properly on patients, in an uncontrolled environment, with many distractions—imperfect conditions for learning and instruction. However, we acknowledge that today, "In education for the professions, learning in the practice settings of the workplace is the signature pedagogy. It is in these milieus that novices experience professional socialization as they enter into a community of practice; develop professional skills through observation, coaching, mentoring, and supervision; and develop specialized professional knowledge as the situations of practice provide meaning and motivation for abstract learning."[38]

LEARNING THEORY TRADITIONS

Here we address the learning theory foundations that are associated with practical applications of SBML in health professions education. The foundations of SBML are grounded chiefly, but not exclusively, in the following three learning theory traditions: (*a*) behavioral, (*b*) constructivist, and (*c*) social cognitive. The three learning theory traditions are complementary, not rival, frameworks that together inform and shape curriculum design; instruction, deliberate practice, and faculty coaching; formative and summative assessment; feedback and its interpretation; and short-term and long-term learning outcomes (Fig. 1). The figure suggests that the behavioral, constructivist, and social cognitive learning theory foundations of SBML are neither mutually exclusive nor exhaustive. There is common ground among the three conceptual frameworks.

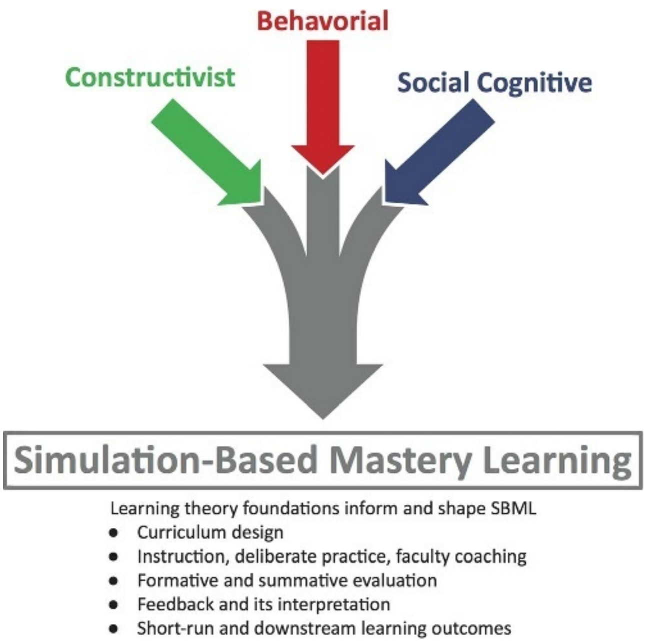

FIGURE 1. Theoretical foundations of SBML.

In addition, several other learning theory models can also be used to conceptualize SBML and the education technologies it may employ.[31,39–42]

Behavioral Learning Theory

The behavioral learning theory framework has roots in a positivist philosophy associated with specific, discoverable, natural laws. In education, its focus is on behavior change and improvement. Behaviorism focuses on behavior and behavior change as evidence of knowledge, learning, and competence acquisition, and the strategies that influence behavior change. This framework originated in early scientific psychology and found its peak in the science and writing of B. F. Skinner in the mid-20th century.[43,44] Practical expressions of behaviorism in SBML and health professions education include behavioral learning objectives; deliberate practice with supervision and coaching; rigorous, reliable measurement of observable behavior; and immediate, specific, and actionable feedback in the service of performance improvement. Behavior change, testing, teaching, and coaching in this framework are complementary education activities that not only boost clinical competence among learners but also enhance cognitive enrichment, especially memory formation—which is called the mnemonic effect of testing.[45] For example, citing a SBML retention study of ACLS published by Wayne and colleagues,[46] Larsen and colleagues[45] state, "…teaching cardiac life support through a simulation prevents forgetting of this knowledge over time. This finding could be interpreted as a testing effect because the simulations serve as hands-on tests."

Constructivist Learning Theory

Professional competence is far more complicated than responding correctly to serial order checklist items, even though use of checklists and other learning and clinical practice aids can reduce clinical complexity and boost patient safety.[47] Knowledge, understanding, service, and professionalism are in many ways socially constructed realities mediated by language and shared meanings that are open to multiple interpretations. The constructivist learning theory framework focuses on the perceptions, interpretations, mental processes, conceptual constructs, understandings, and practical knowledge of learners that influence their decision-making and action. Constructivism also encompasses the strategies that influence development of learner cognitive processes. Medical experts, for example, disagree frequently about the best approaches and solutions to clinical problems because most clinical problems have more than one right answer. Learning, from the constructivist perspective, accounts for such differences in relation to active processes of perception, interpretation, and constructing meaning, motivated by authentic problems. Constructivist learning goals not only include knowledge, skill acquisition, and data interpretation but also self-direction, mindfulness, and reflective practice. The constructivist perspective conceptualizes teachers as facilitators rather than coaches.[48–50]

To illustrate the constructivist framework in simulation research, Cheung and colleagues[51] recently reported an SBML study that included an observational practice component phase before hands-on deliberate practice of central venous catheter insertion skills. The observational practice feature was intended to help learners acquire a mental model of the clinical task to prime skill learning and enhance learner motivation. Observational practice greatly improved the efficiency and effectiveness of the behavioral skill acquisition central venous catheter SBML curriculum. This finding is consistent with recent writing by Ericsson and Pool[52] who comment, "The purpose of deliberate practice [a core principle of SBML] is to develop effective mental representations… mental representations in turn play a key role in deliberate practice." Ericsson and Pool continue, "The more effective the mental representation is, the better the performance will be."[52] Finally, they comment: "In any area… the relationship between skill and mental representations is a *virtuous circle:* the more skilled you become, the better your mental representations are, and the better your mental representations are, the more effectively you can practice to hone your skill."[52]

Social Cognitive Learning Theory

The social cognitive theoretical perspective frames learning and professional development as situated events because learning and behavior occur in context. The emphasis is on learning in real or simulated social settings and, more broadly, socialization into communities of practice through observation in communities and then more central participation in communities. Engagement in a real or simulated community of practice contributes to learner knowledge, competence, and personal and professional development. A substantial proportion of learning in the health professions, including professional socialization, is situated in the clinical workplace in addition to controlled laboratory settings. This makes the social cognitive conceptual framework a useful model for curriculum development and especially for authentic outcome evaluation using both objective and subjective methods to deliver "just-in-time" feedback because learners and teachers are engaged in real clinical education and work in authentic workplace settings.[31,53]

TABLE 2. Convergence of Learning Theory Foundations in ACLS Simulations Using SBML[56–61]

Learning Theory Foundations	ACLS Skills Acquired and Assessed Using SBML
Behavioral	Obtain patient history; perform physical examination; establish airway; request invasive and noninvasive monitoring; order and administer medications, procedures, and tests; perform chest compressions correctly; use defibrillator correctly
Constructivist	Situation awareness; recognize, discriminate, and interpret clinical signs and symptoms in ACLS scenarios: asystole, ventricular fibrillation, supraventricular tachycardia, ventricular tachycardia, symptomatic bradycardia, pulseless electrical activity; evaluate data to reach a correct diagnosis; patient management decisions under changing conditions
Social Cognitive	Fluidity of individual and team roles in team simulations; adapt to role changes within and between simulated ACLS events; lead and coordinate a team arrest response; fill a subordinate role in a team arrest response; increase clinical S-E about individual and team ACLS responses.

A key concept in the social cognitive conceptual framework is the formation and maintenance of self-efficacy (S-E), the belief in one's capabilities to organize and execute the courses of action needed to manage prospective situations. Self-efficacy relates to believing in oneself to take action.

Albert Bandura is a thought leader in social cognitive learning theory. Two of Bandura's seminal books *Social Foundations of Thought and Action: A Social Cognitive Theory*[54] and *Self-Efficacy: The Exercise of Control*[55] provide detailed accounts of the social cognitive perspective in general and S-E in particular. Bandura and other social cognitive scholars view people as self-organizing, proactive, self-regulating, and self-reflecting, not just reactive organisms shaped by environmental forces or driven by inner impulses.

In health professions education, S-E is a *product* of mastery, not a *source* of mastery. As an education outcome, S-E refers to a learner's confidence to participate in activities that will help achieve clear goals. Self-regulation as a consequence of SBML helps individuals set future goals and manage behavior and plans to reach them: goal setting, self-monitoring, and self-assessment. Research evidence shows that there is an increase in clinical S-E as learners acquire clinical skills and sharpen their mental representations in a SBML environment. This has been reported in SBML studies where intensive care unit nurses master central line maintenance skills,[9] pediatric residents master clinical management of childhood status epilepticus,[12] and internal medicine residents acquire ACLS skills to a mastery standard.[56] Behavioral skill improvement; cognitive advancement, conceptual understanding, and richer mental representations; and affective growth including S-E, professionalism, and socialization occur simultaneously, consistent with Ericsson and Pool's *virtuous circle*.[52]

SBML THEORETICAL CONVERGENCE

Skill and knowledge acquisition, formation of mental models and enriched cognitive representations, and development of S-E in a real or simulated professional learning contexts do not occur in isolation. Learners in the health professions do not acquire a complicated skill set such as ACLS by focusing on motor behavior (eg, frequency and depth of chest compressions) alone. Instead, mastery of ACLS requires individuals and teams to acquire and display a variety of perceptual, psychomotor, cognitive, affective, social, and professional responses simultaneously, for example: recognize an acute, life-threatening situation; mobilize the "code" team; start effective chest compressions; discriminate cardiac arrhythmias; choose and administer medications; respond to clinical urgency; be cool under time pressure; demonstrate teamwork; and show professional responsibility. Thus we disagree with Anders Ericsson because SBML does not focus solely on behavioral skill acquisition at the expense of "the cognitive processes mediating the acquired performance."[30] Mastery learning of critical clinical entities in the health professions, in simulated or real clinical settings, is best represented by an array of measured professional outcomes grounded in multiple theoretical frameworks operating "in sync."

Convergence of the behavioral, constructivist, and social cognitive learning theory frameworks is illustrated from a Northwestern University program of SBML research studies on internal medicine residents' acquisition of ACLS skills. The research program on ACLS skill acquisition begins with a report on SBML curriculum development, implementation, and short-run outcome evaluation;[56] continues with reports about setting the mastery MPS;[57] checklists development[58] and later checklist refinement[59] due to changes in American Heart Association (AHA) cardiac resuscitation guidelines; and reports documenting the translational outcomes of residents' learning ACLS to a mastery standard in terms of residents' responses to real in-hospital "codes."[60,61]

Examples of theoretical convergence from these studies, expressed as skills acquired and assessed, are presented in Table 2. The tabular entries show that mastery of ACLS involves a complex set of behavioral, perceptual, interpretive, decision-making, and teamwork responses that simply cannot be captured by a single learning theory framework. Multiple learning theories working in harmony are needed to frame and explain the ACLS mastery learning education and research program.

The mastery learning bundle described earlier in this article calls on health professions educators to be informed, thoughtful, and rigorous in all phases of curriculum development and management;[27] formative and summative learner evaluation; learner feedback based on reliable data toward goals of constant improvement; faculty preparation and coaching; standard setting; and clarity about short-run individual and team outcomes while anticipating and measuring downstream clinical effects.[23] The quality and character of this education work are enhanced from solid grounding in its theoretical foundations.

CODA

Simulation-based mastery learning in the health professions has broad and deep theoretical roots that are frequently tacit and rarely discussed even in academic circles. Our intent in this article has been to briefly describe three of the most prominent learning theory foundations that underlie SBML and to argue that they function together to yield strong learning results. Readers are encouraged to study the theoretical perspectives advanced by well-recognized experts in these research traditions and reflect on how theory might be better integrated into health professions simulation education and research.

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