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SIMULATION-BASED MEDICAL EDUCATION: THEORY AND PRACTICE

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Abstract— Simulation-Based Medical Education (SBME) gained popularity because it can expose novice healthcare professionals to a variety of situations in a completely safe environment. This keeps both practitioners and potential patients from facing potential safety problems. Beyond the most obvious benefit of safety, SBME is also a sound instructional method. This paper explores recent developments in the field of SBME, as well as surveys the multiple delivery modalities for SBME, including human-based and computer-based simulation options. The benefits of using SBME will be highlighted. In addition, this paper will examine the instructional pedagogy behind SBME and explore the theories of learning and teaching that inform SBME design. Specific and explicit focus will be given to the areas of cognitivism and constructivism, and especially how these influence the successful delivery of SBME. There will also be a focus on how SBME can be utilized, including for assessment.

Index Terms— Simulation-Based Medical Education, pedagogy, constructivism

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1 Introduction

Although it has had a long history in non-medical high-risk industries such as aviation (Gaba, 2004; Ziv et al., 2000), simulation is a relatively new approach to teaching and learning that continues to grow rapidly throughout different spheres of medical education (Gaba, 2004; Issenberg, Ringsted, Østergaard, & Dieckmann, 2011; Kneebone, 2005; McGaghie, Siddall, Mazmanian, & Myers, 2009; Murphy, Cremonini, Kane, & Dunn, 2007; Piquette & LeBlanc, 2015; Ziv, Ben-David, & Ziv, 2005; Ziv, Small, & Wolpe, 2000). The purpose of using simulations in high-risk fields including aviation, power generation, and the military has been to "plan, reduce risk, and increase control" (Ziv et al., 2000, p. 490). These industries share with healthcare professions, "intrinsic hazard and complexity" (Gaba, 2004, p. i2). Here lies the area of rapid growth and interest in simulation-based medical education.

Like several traditional methods of clinical medical education such as lectures, simulation-based medical education (SBME) has a significant purpose: improving the quality of patient safety and patient care (Gaba, 2004; Issenberg et al., 2011; Ziv et al., 2005; Ziv et al., 2000). SBME has been used as a pedagogical methodology that results in "demonstrable learning outcomes" (Issenberg et al., 2011, p. 155). Given the fact that there is widely growing interest in simulation as an approach that facilitates learning in every healthcare profession, this paper will explores the theories of learning and teaching that inform SBME design and practice.

To do so, I will examine three questions: 1) What is simulation and what is SBME, 2) why should SBME be used, and 3) how can SBME be used? The answers to these questions will predictably highlight the theories of learning and teaching influencing the design and practice of SBME.

2 What is Simulation? What is Simulation-Based Medical Education?

According to the online Merriam-Webster dictionary, simulation is "something that is made to look, feel, or behave like something else especially so that it can be studied or used to train people." That is, simulation can help individual learners demonstrate a situation by submerging them in an artificially created environment that "offers credible opportunities for learning" to enable them "explore behavior of the systems" (Harper, Squires, & McDougall, 2000, p. 117). In other words, it is "the technique of imitating the behavior of some situation or process…for the purpose of study or personnel training" (Bradley, 2006, p. 254). These definitions also agree with Gaba (1997) who defines simulation as "the artificial replication of sufficient components of a real world situation to achieve certain goals" (as cited in Ziv et al., 2000, p. 490). Within these definitions lies the importance of using simulation in education, which "emphasizes conceptual knowledge, basic skills, and an introduction to the actual work" (Gaba, 2004, p. i3). Admittedly, simulation has become an integral part of medical education, where medical educators have recognized it as an important instructional tool.

According to Chiniara, Cole, Brisbin, Huffman, Cragg, Lamacchia, & Norman (2013), SBME has been defined as "an instructional medium used for education, assessment, and research which includes several modalities that have in common the reproduction of certain characteristics of the clinical reality" (as cited in Piquette & LeBlanc, 2015, p. 470). Examples of simulation modalities include human simulations and computer-based simulations (more detailed description of modalities will be discussed in "How Can SBME Be Used? section). SBME has been used to teach and train generations of health professionals through "simulative aids…to gain full control over a pre-selected clinical scenario, without distressing patients or encountering other unwanted aspects of learning on real patients" (Ziv et al., 2005). In more detail, McGaghie (1999, as cited in McGaghie et al., 2009) defines SBME as

> A person, device, or set of conditions which attempts to present 'education and' evaluation problems authentically. The student or trainee is required to respond to the problem as he or she would under natural circumstances, frequently the trainee receives performance feedback as if he or she were in the real situation. (p. 63S)

In SBME, simulative tools, including human simulations and computer-based simulations, are integrated to facilitate and mediate learning (Piquette & LeBlanc, 2015) and assess technical and professional skills (McGaghie et al., 2009). In a later section of the paper, I will highlight the different modalities of simulation and the effectiveness of integrating various simulation forms in healthcare education. Before addressing simulation modalities and application, the drives to SBME should be first highlighted.

The next section of this paper will examine why SBME should be used in an attempt to explore the rationale behind the rapid growth and interest of simulation in medical education.

2.1 Why Should Simulation-Based Medical Education be used?

Medical simulation has emerged as an important tool to achieve a major driving force: patient care and safety. In addition, there are three main factors that have influenced the growth of interest in SBME: 1) prevention of medical errors, 2) possibilities for instruction and assessment of knowledge and skills, and 3) availability of new technologies (Ziv et al., 2000)

3 Prevention of Medical Errors

Making mistakes and errors in any field, including medical education, is inevitable. Indeed, "total prevention of mistakes is not feasible" (Ziv et al., 2005). However, there should always be attempts to reduce mistakes, especially when dealing with human beings. A mistake in healthcare can be lead to patient harm and in some cases be fatal. The NIOM (Neurological Intraoperative Monitoring) report illustrated the amount of fatal medical mistakes occurring during medical care and thus called for interventions to "confront the problem and reduce medical errors" (as cited in Ziv et al., 2005, p. 194).

These mistakes can be made by both novice and expert health professionals. Some medical errors occur as a result of insufficient preparation for less experienced health professionals (Bradley, 2006). Other errors are "rooted in unsafe systems rather than individual caregivers" (Murphy et al, 2007, p. 6). Therefore, SBME is considered as one of the effective methodologies to help reduce medical errors (Gaba, 2004; Piquette & LeBlanc, 2015; Murphy et al., 2007; Ziv et al., 2005, Ziv et al., 2000). Simulation can help inexperienced trainees practice common and uncommon medical cases without putting patients at risk. A simulated environment is a risk-free environment and there cannot be any harm to real patients. In brief, the use of simulation offers a safe, supportive learning environment (Bradley, 2006) to meet some needs in medical education.

4 Possibilities for Instruction & Assessment of Knowledge and Skills

As indicated above, simulation is a tool for instruction and assessment. In the past, the method to teach was merely modeling; there was no explicit teaching of clinical skills. Rather, experienced professionals, such as physicians, would do their routine practice at the "patient's bedside" while the trainee would experience his/her clinical skills through "incidental exposure to clinical cases…in unplanned medical contexts" (Ziv et al., 2005, p. 198). However, simulation today is used to link the actual medical practices to medical education, where explicit teaching occurs and enables both inexperienced and experienced health professionals to "practice and develop skills with the knowledge that mistakes carry no penalties or fear of harm to patients or learners" (Bradley, 2006, p. 259). That is, novice and expert health professionals can acquire skills through simulated experience. Medical educators can use different, simple tools to help trainees acquire knowledge and skills. These tools such as "manikins, organ models, animals and cadavers" (Ziv et al., 2000, p. 490) are used in authentic healthcare environments that allow health professional students to "immerse themselves into the simulated scenario as if it were and, consequently, to maximize their learning from the situation" (Ziv el a., 2005, p. 195).

It is more likely to demonstrate the targeted skills in the presence of: a physical environment that "reflects the reality of healthcare delivery locations, including hospitals;" a human environment that encompasses "patients and medical staff;" and medical tasks that the trainees would perform, including "procedural" such as physical exam, "diagnostic" such as interpretation of X-ray, "management" such as being a leader of a trauma event; and "communicative" such as interactions with patients and their families (Ziv et al., 2005, p. 195).

In addition to being a tool for teaching "knowledge, skills, and attitudes," (Piquette & LeBlanc, 2015, p. 471) SBME can be used to assess what has been taught and studied while performing the different modalities of simulation. For instance, simulation is considered a high-stakes assessment (Gaba, 2004; Piquette & LeBlanc, 2015, p. 471) where it is included in licensure and certification examinations (Piquette & LeBlanc, 2015). It can also be used to assess integrative team performance and technical performance (Murphy et al., 2007), as well as "performance and competency of individual clinicians and teams" (Gaba, 2004, p. i3). That is, simulation-based assessments can also highlight strengths and weaknesses of trainees while working either individually or as part of a team. In addition, the trainees themselves can provide feedback in regards to their "simulative experience" when making errors. This is a type of self-assessment through which the trainees' awareness of certain aspects of performance is raised (Ziv et al., 2005, p. 196).

5 Availability of New Technologies

Simulation technology has witnessed a rapid growth and interest in medical education. It is able to facilitate the creation of clinically realistic situations in a safe learning environment (Murphy et al., 2007). Admittedly, medical educational technology has shaped the way to teach and assess health professionals, for example, doctors (McGaghie, Issenberg, Petrusa, & Scalese, 2010). Not all complex tasks can be "recreated" with technological means (Gaba, 2004). In fact, the majority of simulators in use today are low technology (Bradley, 2006). An example of complex tasks is "practicing the dynamic management of life threatening clinical situations that include risky or noxious interventions (such as intubation or defibrillation)" (Gaba, 2004. p. i5). Such tasks require the use of technological advances as they "permit the accurate reproduction of simulated clinical events with sufficient fidelity to reproduce physiologically accurate clinical scenarios" (Murphy et al, 2007, p. 1).

Fidelity refers to the level of realism and simulations come in three levels: low, medium, and high. Low-fidelity simulations use low-tech simulators such as partial manikins to "train and assess basic life support maneuvers," that is, simple proce-

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dures such as chest compression (Ziv, 2000, p. 490). At this level, computer-based simulators may include the use of materials less similar to real ones. Medium-fidelity simulations, on the other hand, use materials that are somewhat similar to real ones through a computer-based simulated environment. In such an environment, the trainee will interact with the system and upon completion of the task the system will provide feedback. An example of a medium-fidelity simulator is virtual reality (VR). VR allows for the creation of virtual environments in which objects are computer-generated (Bradley, 2006; Gaba, 2004; Ziv et al., 2000). High-fidelity simulations use realistic materials, such as "a full-length manikin, a computer workstation, and interface devices that actuate manikin signs and drive actual monitors (Ziv et al., 2000. p. 492).

In the following section, I will examine how SBME can be used in an attempt to highlight the major simulation modalities and applications, and explore the theories of learning that inform SBME practice and design.

6 How Can Simulation-Based Medical Education Be Used?

Knowledge and understanding of the importance of simulation in medical education needs to be complemented by a third component; the ability to do simulations. Simulations can be used in different applications including "the professional development of individuals, as well as in supporting professional practice and continuing professional development" (Bradley, 2006, p. 259). In these applications, medical educators can use SBME in several modalities.

With McGaghie's (1999) description of a simulator as "a person, device, or set of conditions" in mind, SBME practical implementations include the use of human simulations (e.g. standardized patients), computer-based simulations (e.g. computer-based manikins), and simulated clinical immersion (e.g. task trainers) in several modalities, with or without different kinds of technologies. With the existence of a variety of modalities, I will use three types of modalities of Piquette and LeBlanc (2015): part-task trainers, human simulation, and computer-based simulation.

First, task-trainers simulation is referred to as "interactions with a physical or virtual model requiring the use of specific psychomotor skills to complete procedures" (Piquette and LeBlanc, 2015, p. 470). It is sometimes called part-task trainers—that is, simulators are used to replicate a specific body part of a real patient such as a limb (Bradley, 2006; Stanford Medical School, 2015). Part-task trainers are used to help trainees acquire procedural or psychomotor skills (Bradley, 2006; Murphy et al., 2007). These are basic skills that trainees must learn; before performing them on real patients, some trainees can try them on their own through a simulation. For instance, a trainee may learn how to do an injection by practicing on an orange (Stanford Medical School, 2015). According to Stanford Medical School (2015), task trainers can aid trainees not only in learning how to do a task but also in practicing communication with patients.

Second, human simulation is defined as "interactions with a simulated or standardized patient" (Piquette and LeBlanc, 2015, p. 470). Standardized patients are those who have received special training to portray the role of a patient or a patient's family (Murphy et al., 2007; Stanford School of Medicine, 2015). They are well trained to provide "a consistent and pre-defined account of their condition" and to respond to any questions posed by a healthcare practitioner (Stanford School of Medicine, 2015). According to Stanford School of Medicine (2015), the standardized-patients simulation can help trainees practice their clinical and communication skills with patients and their families. Interestingly, standardized patients have been integrated into medical school curriculum and assessment (Ziv et al., 2000, p. 490). For instance, it has become a mandatory experience that medical undergraduate students must go through since it is part of the Objective Structured Clinical Examination, a licensure assessment in the United Station, (Murphy et al., 2007, p. 2) and in other licensure exams (Reznick et al., 1996; Sutnick et al., 1993, as cited in Ziv et al., 2000).

Third, computer-based simulations, that is, "interaction with a screen-based interface," (Piquette & LeBlanc, 2015, p. 470) have begun to "proliferate" in medical education since the emergence of personal computers in 1980s to "train and assess clinical knowledge and decision making as a result of their [screen-based simulations] dropping acquisition cost and low maintenance" (Ziv et al., 2000, p. 491). According to Stanford Medical School (2015), computer-based simulations can be also be found as a desktop simulator where interactions occur not only with a screen but also with a mouse or trackball. In the computer, medical educators can upload all or part of a task/patient where trainees can see and interact in different forms (e.g. drawing or videos).

Moreover, these modalities can be "combined into hybrid simulations to facilitate the simultaneous and integrative practice of complementary skills" (Piquette & LeBlanc, 2015). An example of a hybrid simulation is the combination of a computer-based simulation and standardized patients; standardized patients can be put in a computer where trainees can see and interact with them. An alternative approach that is more advanced can be to set up multiple participants who would "interact simultaneously with the same patient in a common 'virtual world,' perhaps linked through the Internet from many different sites" (Stanford Medical School, 2015).

These modalities of simulation relate to theories of learning and teaching. Bradley (2006) asserts that SBME is "theory rich and such an abundant conceptualization of learning should help us understand how learning is taking place and how it can be supported through simulation" (p. 259). Therefore, the following section will highlight some theories of learning and teaching that are related to SBME and that have informed the design and practice of simulations used in medical education.

7 THEORIES OF LEARNING INFORMING MEDICAL SIMULATION

Bradly (2015) suggests the learning theories—behaviorism, constructivism, social constructivism, reflective learning, situated learning, and activity theory—are related to the field of SBME. The three types of modalities of Piquette and LeBlanc (2015) are part-task trainers, human simulations, and computer-based simulations. The design and practice of these modalities, I can infer, are drawn from two theories of learning and teaching: cognitivism and constructivism. Simply stated, cognitivism, namely cognitive load theory, "seeks to understand ways in which information is perceived, processed, stored, and acted on" (Reedy, 2015, p. 355). On the other hand, constructivism, namely social constructivism, argues that learners "develop personally meaningful and transferable knowledge and understanding" (Harper et al., 2000, p. 117).

First, cognitive load theory can contribute to medical simulation in specific and appropriate learning opportunities. For instance, since SBME occurs in a risk free environment, healthcare practitioners can ask questions about a problem and provide as many answers as they could to a problem "rather than specifying the form and shape of an answer (Reedy, 2015, p. 357). That is, trainees would not be anxious when making mistakes in a safe environment. With more repetitive practice by presenting a variety of cases and challenges, trainee would "monitor their learning experience and correct strategies and errors of level of understanding" (McGaghie et al., 2009, p. 55). Keeping in mind what the cognitive load theory is based upon, trainees should be provided with more simple tasks before moving toward move complex ones, where trainees "must master simple constituent tasks before moving on to more complex and holistic ones that are more reflective of actual clinical practice (Gagne, 1962, as cited in Reedy, 2015, p. 257). That also implies to begin with low-fidelity simulators, then to medium fidelity, and finally to high fidelity simulators. It is, in other words, a gradual progress for trainees to reduce the cognitive load.

Cognitive load theory can contribute to medical simulation in specific and appropriate learning opportunities. For instance, since SBME occurs in a risk-free environment, healthcare practitioners can ask questions about a problem and provide as many answers as they could to a problem "rather than specifying the form and shape of an answer" (Reedy, 2015, p. 357). That is, trainees would not be anxious when making mistakes in a safe environment. With more repetitive practice by being presented with a variety of cases and challenges, trainees would "monitor their learning experience and correct strategies and errors of levels of understanding" (McGaghie et al., 2009, p. 55). Keeping in mind cognitive load theory, trainees should be provided with simple tasks before moving toward more complex ones. Trainees "must master simple constituent tasks before moving on to more complex and holistic ones that are more reflective of actual clinical practice" (Gagne, 1962, as cited in Reedy, 2015, p. 257). This also suggests beginning with low-fidelity simulators, then moving to medium fidelity, and finally to high fidelity simulators. It is, in other words, a gradual progress for trainees to reduce the cognitive load.

Social constructivism can also contribute to medical simulation in specific and appropriate learning opportunities. One prominent social constructivist theorists is Lev Vygotsky (1978) whose sociocultural theory stressed that learning is inherently social. Indeed, his theory emphasized "the role of social interaction in the development of cognition" (McLeod, 2007). In SBME, trainees interact with one another and with their instructors to make meaning. They can begin with procedural or psychomotor tasks that may be accomplished independently. However, they would need an expert to clarify more and go further on what they have done and on what they cannot do by themselves. In other words, they need assistance from more knowledgeable sources.

This is a notion known as the zone of proximal development, another tenet of Vygotsky's sociocultural theory. With his theory in mind, a trainee can make progress in problem solving "in collaboration with more capable peers even if unable to do so unassisted" (Wertsch, 1985, as cited in Kneebone, 2005, p. 550). The learning support "scaffolding" by an expert or a peer is a "two-way, responsive relationship between learner and teacher" (Burner, 1967; Wood, 1998, as cited in Kneebone, 2005, p. 550).

8 CONCLUSION

Simulation has been used as an instructional technique in medical education. The increased interest in simulation-based medical education (SBME) is a result of the reality that simulation can prevent and/or reduce medical errors. It creates a safe, risk-free environment where novice healthcare professionals can acquire knowledge, skills, and attitudes. Not only can SBME be used as an instructional method but it can also be an assessment tool. There are several modalities of simulations. These include human simulations, such as standardized patients and computer-based simulations, and desktop/screen-based simulations. These modalities have been designed to achieve the overall objective of SBME, which is improving the quality of patient treatments and increasing safety. Research shows there are several theories of learning and teaching that are related to SBME. These learning and teaching theories, including cognitivism and constructivism, play a role in informing the design and practice of simulations in medical education.

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