Developing and Implementing a Simulated Electronic Medication Administration Record for Undergraduate Nursing Education

Using Sociotechnical Systems Theory to Inform Practice and Curricula

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Knowledge and skills related to medication administration are a fundamental element of nursing education. With the increased use of electronic medication administration technology in practice settings where nurses work, nursing educators need to consider how best to implement these forms of technology into clinical simulation. This article describes the development of a simulated electronic medication administration system, including the use of sociotechnical systems theory to inform elements of the design, implementation, and testing of the system. Given the differences in the medication administration process and workflow generated by electronic medication administration technology, nursing educators should explore sociotechnical theory as a potentially informative lens from which to plan and build curricula related to simulation activities involving clinical technology.

KEY WORDS: Barcode medication administration, Computerized provider order entry, Electronic medication administration, Informatics, Nursing, Nursing education, Simulation, Sociotechnical

A significant element of any nursing curriculum is the instruction of safe and effective medication administration practices drawing upon nursing knowledge.[1] During basic undergraduate nursing education, students generally receive both theoretical courses related to pharmacology and clinically focused experiences in the pragmatics of medication administration. Prior to students administering medications to real patients, learners are also typically provided simulated learning opportunities within classroom and clinical simulation settings.[2–4] In a clinical simulation environment, students are able to practice skills and further develop their theoretical knowledge of pharmacology with professional practice skills related to medication administration.

The recent introduction of electronic medication administration (eMAR) and computerized provider order entry (CPOE) systems in many healthcare and hospital environments has fundamentally changed how nurses administer medications.[5–7] Electronic medication administration systems are electronic health (eHealth) technologies that clinicians use to record and validate the administration of medications, whereby a nurse is required to scan a patient identification bracelet barcode and prescribed medications in order to confirm that the medications being provided to the patient are correct in terms of timing, dose, and route. Given the high frequency and rate of adverse medication events in healthcare,[8] some have proposed that eMAR/CPOE technology is essential to reduce medication prescribing and administration errors.[9–11]

Although eMAR systems appear simple to operate, medication administration using these systems is a subtle, yet significant progression from the processes found in traditional paper-based medication administration activities (eg, record keeping, workflow, and methods of instruction).[12] Within nursing education, there has been little development or research toward evidence-based approaches to implement eMAR technology into curricula or education practices related to teaching eMAR. Currently, the majority of the nursing research literature exploring the integration or teaching of these forms of clinical technology has focused on electronic medical records (EMRs) and other related technology.[13–15] Medical education literature has reported more experiences in relation to the integration and teaching of eMAR/CPOE technology into curricula, including exploring medical students' abilities to write orders,[16] learning and supervision implications of using CPOE in clinical education,[17] and student preferences and attitudes toward using CPOE technology.[18]

In light of the lack of nursing education literature regarding eMAR technology, it is important for nursing educators to explore and develop teaching-learning practices that are

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sensitive to the dynamic human-technical interface requirements of an eMAR system. A long sequence of research in the health informatics literature has demonstrated that eMAR and related systems have the potential to facilitate unintended consequences throughout the medication administration process, including the generation of new types of medication errors, human-technical interface difficulties, and a redefining of workflow and administration processes.[19–21]

Therefore, in an effort to generate usable insights for nursing educators, the purpose of this article is twofold: (1) to report details regarding the development and implementation of a simulated eMAR platform, designed and built to operate within the school's clinical simulation suite (CSS); and (2) to offer recommendations related to the development and implementation of an eMAR system in clinical simulation, informed through the lens of a sociotechnical systems theoretical perspective.

THE DEVELOPMENT AND THEORETICAL CONSIDERATIONS OF IMPLEMENTING A SIMULATED eMAR SYSTEM IN NURSING EDUCATION

The addition of an eMAR system into nursing education represented a significant change in how medication administration was both taught to and conceptualized for student populations. To undertake this curriculum evolution, the development team conducted a review of existing practices related to eMAR medication administration. Included in this review were training materials developed for clinical staff at the university affiliated hospital system,[22] academic literature related to CPOE and eMAR technology,[14,23–27] and insights from other clinically active faculty. In order to draw together these recommendations and research, the theoretical lens of sociotechnical systems theory[28–30] was selected to both inform the development of the simulated eMAR system and its subsequent implementation into the university CSS and nursing education.

SOCIOTECHNICAL SYSTEMS THEORY

Sociotechnical systems theory is a body of literature that explores the dynamic relationship between humans and material (ie, technology) objects in the generation of action. In the case of healthcare, sociotechnical perspectives are generally used to explore how humans and health technology interact and operate within health environments, since all work practices are conceptualized as larger, interconnected networks of peoples, tools, objects, and routines.[29] A sociotechnical lens enables an educator to question the role, importance, and influence of material objects such as technology in the learning or operation of specific tasks, including within clinician simulated education.[31–34] From a clinical simulation perspective, appreciating the various human and technical forces present in a learning experience involving eHealth technology such as eMAR is argued to be an important, yet sometimes overlooked, consideration. For instance, the transposition of teaching methods related to medication administration using a paper-based eight medication rights[35] (right patient, medication, dose, route, time, documentation, reason, and response) process to a computerized eMAR methodology must appreciate the new workflows and relationships generated between both human and technological entities. As outlined by Novak et al,[36] CPOE and eMAR technology commonly forced "rigid interpretation"[36(pe333)] of medication rights processes. In their study, they found that the rigid, stepwise interpretation mandated by eMAR technology forced nurses to generate adaptations and workarounds to complete the medication administration process. Furthermore, eMAR technology and its prescribed processes failed to appreciate the workflow flexibility commonly required during nursing care. Subsequently, implementation of eMAR technology in nursing education requires educators to understand the various sociotechnical implications generated by this new form of clinical technology and ensure this knowledge is meaningfully translated into teaching methods. Although other informative theoretical models exist, sociotechnical systems theory was deemed by the development team to be a conceptual perspective that adequately addressed the complex relationships among several elements of technology use in nursing practice, including the environmental and social context, and related technological infrastructure. Models such as the Technology Acceptance Model,[37] Unified Theory of Acceptance and Use of Technology,[38] and DeLone and McLean Information Systems Success Model[39] were not seen by the development team to be reactive enough to capture the multifaceted simulation context; furthermore, these other models have also been critiqued within the nursing literature for their lack of specificity and sensitivity toward elements of the nursing role.[40–42]

In the following sections, the development of the Simulated Medication Administration Record Technology (SMART) eMAR and the way sociotechnical systems theory was used to guide all elements of the eMAR creation and implementation are described. The Sittig and Singh[43] Eight Dimensional Model was selected as the guiding sociotechnical framework to assist in all elements of the conceptualization and development of the SMART eMAR system. Further discussion and description of the Sittig and Singh model and its related dimensions are provided in the following sections (Table 1).

DESIGN AND DEVELOPMENT OF THE eMAR SYSTEM

As part of ongoing curriculum and innovation development, nursing faculty and researchers developed a simulated eMAR system for learning purposes. Known as the SMART eMAR system, the technology was developed to operate within a modern university CCS and be used by nursing students

Table 1. Sittig and Singh[43] Model Dimensions and Descriptions

	Sittig and Singh[43] Model Dimension	Dimension description
Primarily technical dimensions	Hardware and software	Focused on the technical elements of a health technology, including hardware, software, and other related technological peripherals of the related system
	System measurement and monitoring	Related to the measurement and monitoring of a health technology, in terms of a number of variables, including system uptime, response time, click rates, and other measureable clinical or benchmark outcomes
Primarily social dimensions	People	This dimension represents all human users of the health technology, throughout development and implementation of the system. The dimension also captures how the system "help users think and make them feel"[43(pi70)]
	Workflow and communication	The process or steps that people take to complete action with a health technology system, including various communications between providers and also technological systems
	Clinical content	Represents all the information and data related to the clinical presentation or episode, including laboratory information, clinical records, and other various structured and unstructured clinical data
	Internal organizational policies and procedures	This dimension represents the various policy and procedural structures within an organization that shape action and behavior
	External rules, regulations, and pressures	The dimension encompasses the various forces externally that act upon various health technologies and its users in the delivery of care. These forces include various macropolicy data exchange agreements, data standards, and other health-human resource shortages
Sociotechnically blurred dimension	Human-computer interface	The human-computer interface dimension accounts for how users operationalize, interact, and "see, touch or hear"[43(pi70)] with the system and its related interface(s)

during their simulated clinical education. The physical layout of the CSS included a nine-bed hospital ward, with hospital beds, infusion pumps, simulated oxygen outlets, a medication room, nursing station, and storage area with supplies for patient care. The CSS also featured a host of medium- and high-fidelity mannequins that could be programmed to simulate a variety of patient conditions. A network of cameras and microphones was connected to each mannequin, allowing observers (eg, clinical instructors, teaching assistants) to act as the voice of the mannequins and interact verbally with students. Standardized patients (ie, actors trained by the local medical school to portray a variety of patient conditions) were also used during simulated practice by nursing students to provide realism in the simulation experience. Simulated medication administration experiences were initiated at the beginning of students' second year in the baccalaureate nursing program. The development of the SMART eMAR was directly inspired by the recognition of the gap in nursing curricula, regarding the increasing need to educate students about eMAR practices. Second, there was a desire by nursing faculty to obtain a platform that was customizable and owned by the university to afford students an opportunity to learn and use a computerized administration technology in a cost-effective fashion. Finally, the developers hoped to create a system that would replicate the workflow and processes of a real eMAR system as closely as possible, without burdening students or instructors with excessive functionality or technical complexity that would not be of value.

The SMART eMAR was developed over a 4-month period utilizing a custom-built user interface, thin-client personal computers, flat screen LCD monitors, barcode generation software, and retail-grade barcode scanners. The aforementioned components were mounted on six hospital-grade mobile clinical carts, similar to those used in the university-affiliated hospital system in order to develop a cost-effective, mobile, eMAR system workstation for educational purposes. The SMART eMAR system supported similar workflows and processes of a real clinical system (ie, prompts for incorrect medication scans, basic decision support, personalized demographic information for each patient) and also mimicked the physical usability of other eMAR workstation found within acute care environments (Figure 1).

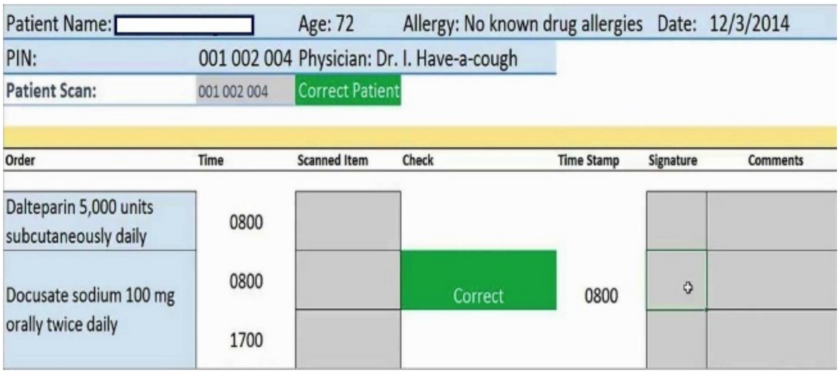

FIGURE 1. Image of the SMART eMAR user interface.

The design and programming of the SMART eMAR were principally conducted by two individuals at the school of nursing: a senior nursing student with a computer science background and familiarity with eMAR systems and the CSS faculty director. A commonly available spreadsheet database program was selected as the underpinning software from which to build the SMART user interface and eMAR functionalities. Given the need to provide decision support functionality within the eMAR's operation, a number of customizable macros and rule-based logic were programed into the software to make the user interface interactive. Decision support commonly found in eMAR technology was added to the system, including color-coded (ie, green or red) prompts for correct or incorrect barcode scans. The interface of the SMART eMAR was programmed to resemble other real eMAR interfaces in terms of structure, layout, and functionality. Self-populating fields in the SMART eMAR interface were also preprogrammed, including the current date/time headers and time stamps for medication administration recording and signature purposes. Barcodes were produced using the barcode software and affixed to a range of inert medications used by students during simulation. Patient identification wristband barcodes were also generated for various simulation scenarios that had been previously developed within the CSS. Retail-grade barcode scanners were affixed to the thin-client computers via a USB connection, and all mounted on the mobile workstations. As a final step, all barcode information was merged with the database software running the SMART eMAR interface, generating a system whereby scanning a barcode affixed to a patient's wrist band produced a visual prompt on the SMART eMAR's screen interface. Scanning a medication that was not prescribed to the specific patient (or a different dosage, route, or type) would generate a red flag on the medication administration record informing the student that some element of the closed-loop medication process had been violated. With the programmed SMART eMAR software and hardware finalized, a range of previously developed simulated patient scenarios and related information were added to the new system (ie, patient name, age, diagnosis, allergies, and a current prescribed listing of medications) (Figure 2).

SOCIOTECHNICAL CONSIDERATIONS IN DEVELOPING AND IMPLEMENTING THE eMAR SYSTEM

To help inform the development and implementation of the SMART eMAR, the Sittig and Singh's[43] Eight Dimensional Model was selected as the guiding framework to assist with the attention toward, and refinement of, specific sociotechnical considerations. Sittig and Singh's model attempts to illustrate the complex relationship among a range of variables (both human and nonhuman/technical) commonly found in clinical environments involving health technology. Composed of eight distinct, yet interrelated dimensions, the Sittig and Singh model conceptualizes these dimensions as important when exploring the use of health technology in practice. The model contains technical dimensions, including hardware/software and system measurement and monitoring; socially driven dimensions, including people, workflow and communication, clinical content, internal organizational policies and procedures, and external rules, regulations, and pressures; and a highly blurred human-technical dimension, human-computer interface. For the purposes of this article,

FIGURE 2. Image of the SMART eMAR mounted on a mobile workstation in the CSS.

the authors have used Sittig and Singh's model as a sociotechnical framework from which to present a number of implementation considerations, lessons learned, and emerging best practices related to the development and implementation of the SMART eMAR for nursing education.

Hardware/Software

As described by Sittig and Singh,[43] the hardware/software dimension is dedicated purely toward recognizing and appreciating the technical elements of a clinical technology. Stemming from previous research, it has been found that the reliability, responsiveness, and quality of clinical technology such as eMAR, CPOE, and EMRs are important predictors of usage.[42] Thus, it can be assumed that these previously validated variables are important to nursing students in simulated practice environments and should be sought in any eMAR implementation for educational purposes.

During the SMART eMAR development, the hardware/software dimension was an important consideration. Because the eMAR was to be used by both students and faculty, the system needed to be highly interactive and functional, yet easily scalable, reliable, and customizable by students and faculty with potentially limited technical understanding. In order to fulfill this mandate, off-the-shelf hardware components (eg, barcode scanner, thin-client PC, mobile cart) were selected to build the physical elements of the eMAR workstation. The spreadsheet database software used to develop the eMAR screens and interface was software that the university possessed as an institutional license to use and distribute.

System Measurement and Monitoring

This dimension examines the measurement and monitoring of a health technology, including a range of potential variables (but not limited to) system uptime, response time, click rates, and other measureable clinically based outcomes. Although suggested by Sittig and Singh[43] as an important sociotechnical concept to include in all health information technology development, it was determined that from a teaching-learning perspective the system measurement and monitoring capacities commonly found in real eMAR systems were not immediately valuable for new students or educators. Given the resource and time limitations faced during the initial design and implement phases of the SMART eMAR, the development team rationalized the measurement and monitoring dimension to be beyond the immediate teaching-learning requirements of both students and educators. Regardless, future development of the SMART eMAR might benefit from the ability to track metrics related to the navigation by end-users through mouse-click counts and other benchmarks such as student efficiency and frequency of decision-support use.

People

The dimension of people in the implementation and generation of best practices was one of the more difficult aspects to arrange. The end-users of the SMART eMAR are a heterogeneous range of nursing students across different levels of their baccalaureate education and further complicated by a varied range of past simulated, hospital, and community clinical experiences. Further to the people dimension, SMART eMAR was required to be used by a large number of clinical instructors and faculty who had varied previous experience using other hospital-based eMAR platforms. In order to generate a system that was as utilitarian as possible, the SMART eMAR system functionality and experience were tailored to meet the needs of second- and third-year undergraduate nursing students who were in some formative stages of their education in relation to medication administration. Similarly, decision support functionality (ie, clickable access to medication information in the eMAR and medication contraindications warnings within the interface) was developed, but not implemented in the original SMART eMAR prototype, in order to keep the medication administration interface as streamlined and usable for a new student.

Workflow and Communication

Along with the development and curriculum integration of the SMART eMAR, reconceptualizing workflow and communication related to eMAR medication administration in nursing-simulated practice was required. Workflow is the set of processes from which work is conceptualized, acted upon, and completed.[44] As part of the prototype quality assurance testing, development and research team members generated comprehensive process mappings of the new, eMAR-influenced workflows. Although seemingly subtle, the location and positioning of the workstation, student mobility around the patient and workstation, best practices surrounding hand hygiene, efficiency and safety considerations related to pouring and dispending medications, and issues related to maintaining warm and open interpersonal interactions with a patient were all elements discussed and analyzed. Overall, virtually all previously established processes related to medication administration were significantly evolved or altered with the addition of the SMART eMAR to the clinical workflow. For instance, traditionally established medication rights (ie, eight medication rights) sometimes became rigid and difficult to operationalize in medication administration processes using the SMART eMAR. Issues related to what role (if any) the eMAR system plays in reducing, removing, or subtly modifying the classic eight rights in medication administration workflow were explored, discussed, and vetted. Findings related specifically to the development of these eMAR best practices related to clinical workflow and communication, and the impact on medication administration process and student learning will be published elsewhere in a future manuscript.

Clinical Content

As outlined by Sittig and Singh,[43] a key component of any functional health technology is its ability to manage, translate, and transmit clinical information. The SMART eMAR allows an end-user (eg, student) the ability to modify and manipulate preprogrammed clinical content on a range of previously developed standardized patient situations. From a teaching-learning perspective, the ability to standardize the interface, documentation, and information regarding a patient situation is important to ensure all students receive similar experiences. Conversely, the SMART eMAR is flexible enough to allow students the ability to customize context-dependent features of the record (eg, adding a signature, adding qualitative comments related to medication administration), without corrupting the overall preplanned learning experience. This measured approach to content customization was deemed important both to ensure standardization in the learning experience and also embrace the fluid, nonlinear processes that sometimes occur within nursing care.

Internal Organizational Policies and Procedures

The internal organizational policies and procedures within a simulated educational environment could be considered as the nursing curriculum and learning activity assigned for students. As described previously in Workflow and Communication, it became immediately obvious that the inclusion of the SMART eMAR necessitated a significant reconceptualization of medication administration processes, including all related teaching-learning and student evaluation mechanisms. During the system prototype testing, the development team realized it had failed to consider how the SMART eMAR and its related processes affected current student evaluation practices. Medication administration quizzes and tests were still conceptualized and developed for processes relevant within a paper-based ontology. Stemming from the quality assurance and beta testing, medication quizzes for students were subsequently redeveloped to consider the differences of the medication administration process in an eMAR-enabled environment.

External Rules, Regulations, and Pressures

Within this examination, the external rules, regulations, and pressures dimension as described by Sittig and Singh[43] could be conceptualized as the various professional regulatory bodies and external organizational regulations that influence the school of nursing and its education of students. Within the context of the SMART eMAR, a number of external regulations and pressures hastened the development of the system. First, the local university-affiliated hospital network had implemented a full-scale eMAR/CPOE platform across all of its sites 6 months prior to the development of the SMART eMAR. Nursing faculty recognized that without a usable eMAR simulation platform students would be at a significant disadvantage from a clinical knowledge perspective when entering real practice areas as part of their clinical rotations. Second, the provincial nursing regulatory college had recently revised their medication administration practice standards away from the classic eight rights medication mindset. Currently, the College of Nurses of Ontario[45] espouses a more dynamic decision-tree logic model of medication administration that engages nurses to determine whether processes around medication administration are "clear, complete, and appropriate."[45(p4)] The *Practice Standard* also contains less rigidity toward decisions related to administration and dispensing, stressing that nurses must have the authority, safety elements, and competence to engage in medication practices as a nurse. Given this practice standard evolution, the development team and researchers used a flexible combination of the eight rights medication processes, combined with the "clear, complete, and appropriate"[45(p4)] perspective to generate new approaches to student learning and workflow processes with eMAR technology.

Human-Computer Interface

The human-technical interface is an extremely important dimension for consideration, both in terms of implementation of a simulated eMAR system and during the generation of teaching-learning activities. As defined by Sittig and Singh,[43] the human-computer interface "enables unrelated entities [eg, people and technology] to interact with the system and includes aspects of the system that users can see, touch, or hear."[43(pi70)] By this, they stress that through iterative development of a health technology system both the user and system must be allowed to simultaneously evolve or "change,"[43(pi70)] to achieve some degree of consensus in terms of usability and interface. For instance, this may include providing end-users with customizable mounts where the workstation keyboard is adjustable, or the ability to complete complex tasks on the eMAR without being burdened by unnecessary prompts, pop-up screens, or excessive mouse clicking.

Although the SMART eMAR is far from a perfect device, a sizable amount of time was spent during its original conceptualization and development to ensure the human-computer interface dimension was maximized to facilitate student learning. From an ergonomic perspective, the workstation on which the keyboard, mouse, computer monitor/thin client, and barcode scanner rest is completely customizable by an end-user (ie, positioning of keyboard and height of workstation). Similarly, the software interface of the SMART eMAR was developed to be as minimalistic as possible in order to streamline a learner's work processes and human-computer interaction. This was done purposefully in an effort to prevent cognitive overload of the student when learning a new technology and process, and to avoid excess system functionality that might not be meaningful.

LIMITATIONS

Although the SMART eMAR has demonstrated significant potential, it has yet to be fully tested empirically. Research is currently underway to determine a range of important considerations in relation to its usage as a teaching-learning device in eMAR education. Therefore, there are a few limitations that need to be highlighted in regard to this article and the SMART eMAR system. First, although the preliminary qualitative evaluation of the SMART eMAR has yielded positive findings, a more formal mixed-methods examination is required to conclusively evaluate the impact, role, and functionality of this sort of simulated eMAR technology in nursing education. Second, although the development team used the Sittig and Singh[43] Eight Dimensional Model to assist in the development and implementation of the SMART eMAR, only seven of the eight dimensions were actively sought during the development and implementation process. The dimension of system measurement and monitoring was purposely minimized and rationalized as beyond the needs or requirements of the immediate beta development of the SMART eMAR system. Regardless, adding this sort of measurement and monitoring functionality to future iterations of the SMART eMAR would be extremely important in order for educators to gain granular quantitative information in relation to student medication workarounds, overrides, mouse-click rates, and other interface navigation metrics.

CONCLUSION

As more schools of nursing adopt and implement simulated eMAR systems into curricula, it will be important for nursing educators to continue to develop understanding and pedagogical inclusion points for these sorts of clinical technology. It is suggested that use of sociotechnical perspectives is a valuable approach from which to help guide educators during the conceptualization, development, and evaluation phases of a simulated eMAR. Although a nontraditional theoretical lens in nursing education, sociotechnical perspectives can offer important directions and insights to educators wishing to develop or implement clinical technology in simulated practice. Similarly, unlike other teaching-learning strategies that predominately focus on a learner's cognition (eg, decision making, efficacy, knowledge), we suggest that the utilization of a wider sociotechnical perspective to inform pedagogical development of simulated eHealth systems and related learning activities is a worthwhile area for future exploration.

Furthermore, the development and implementation of simulated eMAR into nursing education represent an important opportunity from both policy and educational directions. With the increasing use of eMAR and other digital health systems worldwide, nursing students should have the opportunity to use these forms of clinical technology during their formative education. Given the exponential rise of various health and communication technologies, it behooves nursing educators to develop curricula that are relevant and timely—especially in regard to requisite nursing skills such as medication administration. As outlined in this article, the development and implementation of an educational eMAR system provided an opportunity for faculty and students to work together in a productive fashion to address an immediate learning requirement of modern nursing practice. With interest in simulation increasing, further research toward the efficacy, importance, and fidelity of using technology such as the SMART eMAR in nursing education should be sought, in order to ensure nursing educators are preparing the next generation of nurses to practice in technologically intense clinical environments.

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