TECHNOLOGY IN PHARMACY EDUCATION

Knowledge, Skills, and Resources for Pharmacy Informatics Education

Brent I. Fox, PharmD, PhD,[a] Allen J. Flynn, PharmD,[b] Christopher R. Fortier, PharmD,[c] and Kevin A. Clauson, PharmD[d,e]

[a]Auburn University Harrison School of Pharmacy
[b]Medical Center Information Technology, University of Michigan Hospitals and Health Centers
[c]Medical University of South Carolina Medical Center
[d]College of Pharmacy, Nova Southeastern University
[e]College of Osteopathic Medicine, Nova Southeastern University

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Pharmacy has an established history of technology use to support business processes. Pharmacy informatics education within doctor of pharmacy programs, however, is inconsistent, despite its inclusion as a requirement in the 2007 Accreditation Council for Pharmacy Education Standards and Guidelines. This manuscript describes pharmacy informatics knowledge and skills that all graduating pharmacy students should possess, conceptualized within the framework of the medication use process. Additionally, we suggest core source materials and specific learning activities to support pharmacy informatics education. We conclude with a brief discussion of emerging changes in the practice model. These changes are facilitated by pharmacy informatics and will inevitably become commonplace in our graduates' practice environment.

Keywords: informatics, technology, currriculum

INTRODUCTION

In the late 1870s, pharmacists helped pioneer the precursor of modern telemedicine as the first telephone exchange in history connected the Capital Avenue Drugstore with 21 local physicians.[1] Medicine continued to incorporate technology through the years, and in 1955, when fewer than 250 computers existed, early articles were published on the electronic digital computer and health.[2] Shortly thereafter, the term *informatique medicale* (medical informatics) was coined in France and subsequently adopted broadly.[3] As medical informatics became a recognized term, the debate began on how best to educate its corps of aspiring practitioners. The basis for formal education on the subject was conceived by a forward-looking group of experts almost 40 years ago. In 1974, they published one of the first guides for teaching medical informatics, *Education in Informatics of Health Personnel*.[4] While informatics may have a relatively recent presence in the mind of many pharmacists, it does possess a robust history over the last half century.

Informatics is commonly defined as the "use of computers to manage data and information" and represents the nexus of people, information, and technology.[5] Medical informatics, sometimes used interchangeably with health informatics, is a more specific application of the use of these tools and techniques in endeavors related to the infrastructure, development, and delivery of optimal healthcare. Umbrella terms for informatics contain numerous major domains such as bioinformatics (ie, cellular and molecular biology, and genomics), public health informatics (ie, application to surveillance and health promotion), imaging informatics, and clinical informatics.[5,6] Clinical informatics can be further subdivided by specialty into nursing informatics, dental informatics, and pharmacy informatics.

Pharmacy informatics focuses on the use and integration of data, information, knowledge, and technology involved with medication use processes to improve outcomes.[7,8] The uses of informatics have ranged from improving pharmaceutical care in oncology, to providing clinical decision support (CDS) for antimicrobial stewardship and pharmacokinetics, to containing costs in managed care.[8-12] Pharmacy informatics was actually part of practice long before it was a cogent term or discipline; in fact, even the study of computers and technology to improve pharmacy practice dates back over 20 years.[13] As technologies evolved that impacted the delivery of medication therapy, they permitted a reengineering of the medication use process.[7]

Just as informatics impacted the medication use process, it also has impacted pharmacy education. To provide direction regarding the informatics education of pharmacy

Corresponding Author: Brent Fox, 207 Dunstan Hall, Auburn University, AL 36849. Tel: 334-844-5152. Fax: 334-844-8307. E-mail: foxbren@auburn.edu

students, the Accreditation Council for Pharmacy Education (ACPE) Standards and Guidelines, Version 2.0, integrated an emphasis on informatics, including a mandate that pharmacy graduates "demonstrate expertise in informatics" (Guideline 12.1).[14] Example informatics competencies were adapted from the International Medical Informatics Association (IMIA) educational recommendations, which were revised in 2010.[15,16] Emphasis on informatics is found several times throughout the ACPE Standards and is certainly needed. However, the provision that requires all pharmacy graduates to demonstrate "expertise" may not be a readily achievable goal due to a shortage of pharmacy faculty members specialized in informatics and the rapid scope change for informatics in the Standards from minor to requiring expertise. Acquisition of basic informatics knowledge and skills will be absolutely necessary for pharmacy practitioners regardless of setting, just as it is for physicians.[17]

PREVIOUS EXPERIENCES WITH PHARMACY INFORMATICS EDUCATION

Although the profession has a history of relying on computers for business-related functions and the literature specifically addresses the practice and educational implications of new health care technology, considerable variation exists in the topics found among informatics articles in the pharmacy literature.[18,19] For example, a descriptive account of biomedical informatics primarily addressed student use of electronic drug information resources and communication tools.[20] Nearly 10 years later, a descriptive account of bioinformatics primarily addressed the topics of genomics and pharmacogenomics.[21] During the same time period, variability in the conceptualization of informatics is reflected in the titles/subjects of poster abstracts and serves as additional evidence of the evolving nature of pharmacy informatics.[22-26]

The profession appears to have made modest progress in developing and delivering pharmacy informatics education, although misconceptions exist.[8,13,27] The American Association of Colleges of Pharmacy Technology in Pharmacy Education and Learning Special Interest Group describes 5 domains to structure the incorporation of informatics into pharmacy education. Domain 3 includes using Web-based course delivery methods and new technologies to deliver coursework.[28] Consistent with this recommendation, Brock and Smith describe their experiences with an online, interdisciplinary informatics course.[29] We believe the variability found in the educational literature is due to a combination of the breadth of informatics, the evolving nature of informatics (especially within pharmacy education), and a general lack of awareness of the field.

A more consistent, harmonized conceptualization of pharmacy informatics is found in the acute care pharmacy practice literature, and can be divided into 2 broad themes: (1) automation and other technologies for safe and efficient medication management and (2) information technology to inform and improve information management and decision making. These themes also are reflected in 2 statements by the American Society of Health-System Pharmacists (ASHP) and in ASHP accreditation standards for pharmacy informatics residencies, which emphasize the role of automation/technology and information management.[7,30,31] Pharmacy educators may find considerable value in turning to their acute care colleagues to collaboratively identify opportunities, conceptualize models, and implement practical pharmacy informatics educational efforts.

With the ACPE Standards as the starting point, a group of informatics pharmacists began developing a set of informatics competencies in 2005. The consensus-based process focused on developing a core set of competencies for all doctor of pharmacy programs to equip future pharmacists with foundational pharmacy informatics knowledge and skills.[32] The competencies reflect the Institute of Medicine's (IOM) inclusion of informatics as a core component among all health professions' education.[33] Federal efforts to stimulate nationwide health information technology (HIT) adoption reinforce the IOM's approach. These efforts highlight the importance of informatics education for all health care providers, including pharmacists, and underscore the need for clinicians trained in informatics as a specialty.

This paper focuses on the foundational pharmacy informatics needs of student pharmacists whose future practice is not pharmacy informatics, but whose practice will *rely* on informatics. Avenues for students seeking a career in pharmacy informatics – and the associated expertise – include residencies, postgraduate training, and on-the-job training. Below, we describe pharmacy informatics-related activities, knowledge, and skills that pharmacy students should possess upon graduation, organized within the medication use process. Appendix 1 contains suggested readings, Web sites, and search terms to support pharmacy informatics instruction.

IMPROVING THE MEDICATION USE PROCESS THROUGH INFORMATICS

Pharmacists are directly responsible for the output of the medication use process (ie, for the medication-related outcomes of their patients). Pharmacy students need to be provided enough educational context not simply to understand the medication use process, but also to participate in its continuous improvement. This includes a scientific approach to understanding the safety and effectiveness of technologies for the medication use process. Further, because medication use systems operate as subcomponents within larger health information technology platforms, pharmacy students also must learn how health information technology is impacting a global healthcare delivery system.

Prescribing

Pharmacy student instruction about the first step in the medication use process, prescribing (ordering), should include the informatics topics related to the prescribing process found in Appendix 1. Future pharmacists should understand what information is necessary to best support medication-related decision-making and also to evaluate medication-related decisions. Pharmacy students also should be instructed to understand the available science of the physicians' approach to probabilistic medical decision-making. How physicians make decisions affects how they prescribe medications. Recommended educational approaches for understanding prescribing begin with conceptual discussions of how differential diagnoses lead to refinement of disease potentials and, ultimately, to decisions to prescribe prophylactic, empiric, and definitively indicated medication therapies. Medical decision-making and pharmacy informatics are directly related. We currently apply the knowledge of pharmacists in clinical information systems to guide, advise, and otherwise inform clinician decision-making during prescribing. Also, after prescribing, physician medication selection rationale is typically tacit or obscured. Pharmacy informatics can assist in documenting medication-use indications online as part of the ordering process. Documented indications will then assist pharmacists in the assessment of medication use and outcomes of therapy.

Education also should be provided regarding the known dangers of illegible handwriting and verbal transmission of prescriptions. These are unsafe but common practices. Regulatory mandates are intended to minimize misunderstandings from written or spoken prescribing practices. There also are electronic prescribing technologies intended to eliminate the need for handwritten and verbal orders altogether. The principal prescribing technologies that students will encounter and must understand are computerized provider order entry (CPOE) and electronic prescribing (e-prescribing). With both CPOE and e-prescribing, research with respect to clinician-computer interaction during prescribing is ongoing. CPOE and e-prescribing research often focuses on the use of clinical decision support alerting systems and the determination of best practices for onscreen medication-related information representation design. Order sets are but one example of an onscreen information representation design intended to help improve the overall prescribing practices of clinician users.

Students also should be familiar with the literature regarding the safety benefits and new types of medication errors associated with CPOE and e-prescribing systems (Appendix 1). Nowhere within the domain of medication use technologies is there a better example than CPOE of the complex "trade-offs" associated with medication use information technologies. Whereas CPOE greatly diminishes problems with prescription legibility and completeness, it may, in particular instances, actually facilitate ordering medications for the wrong patient, polypharmacy, and other consequential medication use misadventures. Students should be taught that technologies can be faulty in their design or misused. Information systems, like all human tools, remain subject to human error; therefore, the tight coupling of medication use technologies can lead to dangerous results. Furthermore, sociotechnical aspects of information system use, such as the power of suggestion of onscreen drug information, must be recognized and respected by all pharmacists.

Pharmacy students should be taught about the significant role pharmacists have in providing drug information and having medication therapy-related patient information onscreen to support safe, effective, evidence-based prescribing. In the past, most information support for safe and effective drug selection and dosing came from reference books carried by providers. Today, CPOE and e-prescribing systems are capable of providing the same information onscreen during the medication ordering process. Pharmacists are well-suited to interpret and manage drug information and often are enrolled in the process of adding select drug information to online ordering systems. Because pharmacists also know the best practices for monitoring medications, they instruct and counsel organizations in the application of demographic and clinical patient data within the medication use process. Clinical decision support for medications, with its emphasis on providing the right information to the medication therapy decision-maker at the right moment in their workflow, is a growing area of importance for all pharmacists.

Pharmacist Prescription Review

Pharmacists have a traditional role of reviewing prescriptions created by prescribers (Appendix 1). There are many types of pharmacy information management systems (PIMS) used in both ambulatory and acute care settings, whose functions students should understand. Typically, these systems bring together much, but not all, of the information needed for the pharmacist to review a prescription for safety and efficacy.

A limited amount of research has been published on how pharmacists analyze prescriptions; nevertheless, students should be familiar with the available information. Further, pharmacy students should be introduced to the available data on pharmacist interventions made during prescription review. Students should be able to list and describe the kinds of analyses that may be required to determine appropriateness, including analyses of allergy information, laboratory results, indications, dose, routes of administration, prescription instructions, drug-drug interactions, drug-food interactions, side effects, intolerance, clinical objectives, and expected and apparent outcomes. Clinical decision support tools and techniques, such as on-screen alerts and reminders, also should be used during pharmacist order verification and need to be addressed in the classroom.

The decision-making process involved in drug product selection to fulfill individual prescriptions also should be included in the curriculum. The automation of drug product selection by established algorithms is deserving of consideration, along with discussion of the many factors that pertain to drug product selection. Faults and problems with automating drug product selection should be highlighted as an area of concern in pharmacy informatics.

Because the prescription review process leads immediately to the generation of computer-printed labels and patient charges, these 2 aspects also should be mentioned by instructors teaching the technologies of the medication use process. In particular, pharmacy labels on dispensed products offer an excellent opportunity to introduce basic concepts of information representation design and readability. Automated billing is another area deserving of consideration, especially because the efficiency benefits of automated billing are often hampered by the challenges of achieving an accurate list of medication charges.

Compounding and Dispensing

Compounding and dispensing are associated with a host of newer technologies. A list of related pharmacy informatics topics is found in Appendix 1. Pharmacies have been automating their supply chains for several decades in an effort to achieve optimal, perpetual inventory management. Automation now is used to improve the safety of the supply chain by inserting barcode validation steps as products are received, stored, retrieved, and dispensed. Students should be provided with a general overview of the pharmaceutical supply chain for consumers (through retail channels) and for hospitals and clinics (through wholesale channels). With respect to the medication use process, compounding and dispensing is the step where patient prescription information is associated for the first time with actual, physical dosage forms in order to create finished, dispensed products.

Robotics in pharmacy practice can be addressed while teaching current compounding and dispensing practices. More than one type of automated, individualized syringe-filling robot has been brought to market. These technologies are deserving of study, especially as robotic drug selection and syringe filling clearly depict the varied and exceptional requirements that must be met to properly produce dosage forms ready for administration to patients. For example, after viewing a video demonstration of a syringe-filling robot, students could be asked to identify the required steps in the compounding process, the safety controls applied, and the compounding environment created and maintained by robotic technologies.

Automated identification of drug products, usually through the use of barcode scanning, is another important technology being applied to compounding and dispensing workflows. Students should become familiar enough with the basics of barcodes so that they can troubleshoot the most common barcode printing and scanning problems. Automated counting machines, packaging machines, inventory management technologies, and dispensing machines all rely on barcodes as medications move from the pharmacy to patients.

Students should be aware of the unique role that automated dispensing machines play in clinic and acute care settings. The ongoing debate about the optimal operational use of these technologies should be reviewed, along with the benefits and challenges of using computerized drug distribution cabinets for dispensing on nursing units and away from the pharmacy.

Medication Administration

The administration of medications, whether self-administered by patients and family members at home, administered by caregivers in clinics, or administered within the context of episodic acute care is associated with several informatics topics (Appendix 1). Pharmacy students should understand how the nursing and medical professions approach medication administration, including how the concept of the "5 rights" pertains to pharmacy practice. Nurses are taught that for each medication they administer to a patient they are to confirm that the right medication is being given to the right patient in the right dose by the right route at the right time. However, as medication administration workflow research continues, additional best practice medication administration imperatives are being identified. An ideal medication administration practice would include the elements of safety, quality, patient assessment, documentation, and patient education and engagement in their own care.

Computerized infusion devices with drug error reduction systems are now available to improve the safety of intravenous infusions of various types, including continuous infusions, patient-controlled analgesia, total parenteral nutrition, epidural infusions, and intermittent infusions from syringes. Typically, regulated medical devices known as computerized infusion pumps require pharmacists to develop or validate drug library files listing the drug items that can be managed by "smart" infusion pumps. These technologies often inspire a consolidation of available, dispensed drug product concentrations for the same drug from hospital pharmacies, which is intended to reduce complexity and improve safety by preventing confusion of dispensed product concentrations. An example exercise to illustrate the pharmacist's role in developing a smart infusion pump drug library would require students to consolidate a list of available medications based primarily on usage data and best practice criteria. Students also should be familiar with the data supporting the use of, the current inadequacies, and the predicted future developments for smart infusion pump systems.

Automated drug product identification, typically using barcode scanning to identify products using drug product databases, is now a fundamental medication use process technology. Much has been written about using barcodes to identify unit-of-use medications. Pharmacy students being introduced to pharmacy informatics should be instructed in both the benefits and the challenges of successfully using barcode scanning to identify drug products. Pharmacy students also must be taught to understand the basic safety, technology, and workflow elements of barcode medication administration conducted at the patients' bedside. Most new pharmacists will encounter some type of barcoding in their practice, regardless of the setting.

The electronic medication administration record (eMAR) is another key medication administration-related technology. Pharmacy students should be provided comparative examples of a paper-based and electronic medication administration record. Students should be taught to extract information from the electronic medication administration record and to identify doses not given, as they may require follow-up. An examination of medication regimen compliance management tools used by community pharmacies and by patients also is advisable.

Monitoring of Ongoing Medication Therapies

Monitoring of ongoing medication therapies used for both acute and chronic needs is critical to achieving the best possible medication use outcomes. Optimal monitoring of ongoing drug therapies is anticipated to lead to further improved prescribing by creating a cycle through which medication therapy outcomes are better documented and therefore more obvious to prescribers when determining medication therapy needs. Medication therapy monitoring is associated with several topics found in Appendix 1.

Before pharmacy students can be taught about technology-enabled monitoring of ongoing medication therapies, they must first learn about the large, integrated clinical information system platforms being used to manage most aspects of patient care. These include electronic health records (EHRs) and electronic medical records (EMRs). Furthermore, pharmacy students should be instructed in the US federal government's support for widespread deployment, connectedness, and interoperability of electronic records to create a nationwide health information network. Some of the most discussed and most expensive developments in the field of informatics involve integrating patient health data from multiple provider sources into exchangeable clinical summaries for patients and into de-identified population health databases to be used by public health professionals. Many information privacy and security concerns pertain to these initiatives and should be considered by future pharmacists.

Pharmacy students should be introduced to the concept of medication-related public health informatics (ie, population-based surveillance of prescribing and medication use trends). Pharmacoepidemilogy will be facilitated by the deployment and further development of electronic records. Students should be challenged to identify potential population-based uses for medication use process data outputs from all stages of the medication use process.

Using continuously operating conditional (ie, if-then) logic commonly associated with computers, it is possible to create CDS surveillance rules in an electronic record intended to identify potential adverse drug events. For example, a CDS system can be programmed to alert when a patient is receiving a potassium-sparing diuretic and their latest potassium level exceeds a predetermined threshold. Clinical decision support rules for medication therapy monitoring with this level of specificity are often created and managed by pharmacists because pharmacists are well versed in medication therapy management (MTM). As an exercise, students can be presented with a complex drug regimen and be asked to create potential CDS medication therapy monitoring rules to protect patients from potential problems with the assigned medication(s).

The documentation of medication therapy outcomes using online tools is an important feature of electronic records. This documentation may include, but is not limited to, success or failure of attempted medication treatments, individualized successful dosing information, patients'

Table 1. Sample Learning Activities to Incorporate Pharmacy Informatics into the Curriculum

Prescribing	
Didactic course	Review components and fields of prescriptions
	Discuss legibility issues of written, verbal, and electronic prescriptions (e-Prescribing)
	Discuss the rationale for structured data for e-Prescribing and computerized prescriber order entry (CPOE)
Skills laboratory/IPPE-APPE[a] rotation	Review clinical decision support options for prescribers
	Create and send e-Prescriptions and medication orders via CPOE
	Discuss technical and personnel challenges unique to e-Prescriptions/CPOE
Pharmacist Prescription Review	
Didactic course	Discuss the stepwise process to determine prescription appropriateness
	Discuss options to communicate with prescriber regarding received prescriptions
	Review relationship between product availability and product selection in received prescriptions
	Discuss the importance of prescription labeling as it relates to patient safety, including readability
Skills laboratory/IPPE-APPE rotation	Discuss options for and document interventions related to prescriptions (electronically and/or on paper)
	Experiment with clinical decision support options for pharmacists
	Search electronic resources for evidence based medicine, clinical tools, and drug information
Compounding and Dispensing	
Didactic course	Discuss the role, limitations, and benefits of dispensing automation for safe medication storage, preparation, and dispensing
	Watch a video describing IV robotics and automated IV workflow systems on how the technology prepares drug products while increasing safety
Skills laboratory	Print and scan barcodes; note challenges of scanning due to label size/shape of dosage form
	Observe process of loading automated dispensing machines (ADMs)
	Review operational reports and metrics; identify methods to improve drug preparation/dispensing workflow
IPPE-APPE rotation	Observe differences in nurse ADM workflow
	Use and discuss process of using barcode technology during inventory, drug preparation, and dispensing
HIT[b] vendor	Observe automated medication tracking systems from receiving through patient medication administration
	Review telepharmacy workflow to check a drug preparation remotely
Medication Administration	
Didactic course	Compare and contrast the benefits/limitations of paper and electronic medication administration records
Skills laboratory	Observe role of smart infusion pumps in patient safety and the development of drug libraries
IPPE-APPE rotation	Collaborate with nursing to review the 5 Rights of medication administration using automated systems
	Discuss/observe the role of auto-ID patient identification tools in ensuring the 5 Rights
HIT vendor	Review workflow allowing for IV interoperability communication between EHR and smart infusion pumps

(*Continued*)

Table 1. (*Continued*)

Monitoring of Ongoing Medication Therapies	
Didactic course	Discuss clinical documentation within the larger context of electronic health records
	Write clinical surveillance rules to identify potential adverse drug reactions and adverse drug events
	Discuss the rationale for structured clinical documentation as it relates to longitudinal medication monitoring
Skills laboratory	Observe the use of electronic clinical monitoring tools within community pharmacy software systems
	Discuss the various remote and mobile technologies to retrieve clinical information and medication database for us while on patient care rounds
IPPE-APPE rotation	Document patient intervention within organization pharmacy intervention system
	Discuss/observe medication monitoring technologies for use at the patient's residence
	Review real-time monitoring system that provides a work queue of patient needing review and intervention
	Enter a medication occurrence or adverse drug event report in organizations reporting system and determine how the reports are follow-up with
HIT vendor	Conduct a telepharmacy consultation that allows for interaction with a patient from a remote location
	Review ambulatory EHR patient profiles to incorporate information into an acute care EHR medication history
Overall	
Didactic course	Discuss positive and negative workflow implications of HIT
	Discuss role of HIT in pharmacy practice
	Describe human factors engineering to design and optimize safety and efficiency of technology
	Review security and privacy considerations for HIT
	Describe technology implementation project management principles for the assessment, build, implementation, maintenance, and optimization stages

[a] IPPE-APPE: Introductory pharmacy practice experience-Advanced pharmacy practice experience
[b] HIT: Health information technology; Vendors can provide tools, demonstrations, and real-world practical experience.

experiences with drug therapy, allergic reactions, adverse events, and rationale for continuing or discontinuing medications. Students should be challenged to consider optimal medication therapy practices with respect to documentation of medication therapy outcomes. Students also should be instructed on the reasons for the current gross incompleteness and inadequacy of pharmaceutical outcomes documentation. Medication reconciliation also should be discussed in light of the present difficulties associated with gathering necessary information to ensure a complete understanding of the patients' medication use and related behaviors.

Finally, pharmacy students should be supplied with real-world examples of how medication-related outcomes can inform the medication use process to influence MTM, including terminating an ongoing drug therapy, making dose adjustments, adding additional medications for a presently treated indication, and substituting or switching medications based on patient response. While not well-documented and obvious, patients' past experiences with specific medication therapies may influence the prescribers' medical decision analysis when considering what to offer or prescribe next. This feedback loop, from medication therapy outcome to future medication use, is implied by models of the medication use process depicted as feedback loops.

Future pharmacists in both acute and ambulatory settings will have many opportunities to leverage informatics to support their practice and improve care. In discussing the informatics education needs of students, we identified topics that can be considered *technology* focused, but we identified other topics, such as electrolyte monitoring, that were not technology focused. The goal is to develop pharmacists who understand and are prepared for a practice supported by informatics throughout the medication use process. Future pharmacists need to understand the role of informatics in medication safety and improving patient outcomes. We believe that a variety of instructional approaches can be used to bring informatics into the curriculum. In this paper we have included a table of key source materials for inclusion in curricula (Appendix 1) and details on suggested pharmacy informatics learning activities (Table 1).

EMERGING DIRECTIONS FOR PHARMACY INFORMATICS PRACTICE AND EDUCATION

Pharmacy informatics education should prepare students to use informatics effectively in their practice, and to be aware of its benefits and limitations. Examining the current landscape of healthcare, we identify specific areas to which students should be exposed because inevitably these will be part of the future pharmacy practice model. These emerging roles for pharmacists are greatly influenced by US federal government efforts and healthcare reform, as well as by quality initiatives within healthcare in general and pharmacy specifically (Table 2).

Workflow Mobility

Mobile devices (smartphones, tablets, etc) will enable the practice model of the future in which pharmacists have access to referential and patient-specific information whenever and wherever they need it. Pharmacists will become more visible and accessible within health systems and community pharmacy settings because of mobile health as they will no longer be tethered to fixed workstation computers. Telepharmacy also will allow increased access to pharmacy services.

Interoperability

The goal of interoperability is to share usable health information electronically. Desired is a closed loop medication process between the inpatient and outpatient

Table 2. Emerging Pharmacist Activities with Medication Use Technologies

Domain	Technologies	Activities
Clinical Medication Management	Electronic health record (EHR)	• Participate in the development of the EHR to include the appropriate medication analysis and clinical decision support tools
	Clinical decision support (CDS)	• Develop requirements to be built into various medication use technologies to impact prescribing, prescription review, dispensing, and administration • Participate in designing electronic work queue systems that can provide real-time lists of potential interventions based on the patient's medications, lab values, renal function, drug interaction, etc.
	Computerized prescriber order entry (CPOE)	• Collaborate with informatics divisions and other clinicians to develop and build CDS, electronic order sets, and other components of CPOE
	Smart infusion pumps	• Provide clinical data and medication safety principles to develop and optimize smart infusion pump drugs libraries based on prescribing patterns and literature
	Pharmacy information management systems (PIMS)	• Incorporate more clinical management principles into these systems to improve drug selection, preparation, and dispensing
Preparation and Dispensing Management	Automated workflow systems	• To prepare for increased direct patient care roles, pharmacists will design automation workflows and quality processes for compounding and dispensing activities to be overseen by technicians
	Pharmacy information management systems (PIMS)	• Develop process and procedures around consistent remote order review and approval of doses using CPOE and automated workflow systems while on patient care rounds
	Medication tracking systems	• Develop/implement auto-identification systems to track medications from receipt, through preparation, distribution, and administration
	Analytics and metrics	• Consult on the distribution process data needed to audit and steer analytic processes to improve operational efficiencies

settings, as well as the inclusion of patient-generated information. Information to be shared will come from the EMR, PIMS, the personal health record (PHR), and other systems housing patient-specific information.

Patient-centered Technologies

Patient-centered technologies reflect a growing emphasis on elevating the role of patients to that of collaborators in their own care. These technologies include personal health records, health-related social media resources, online medical information, home monitoring devices, and interfaces that can routinely monitor patient outcomes, such as blood pressure/blood glucose. These technologies will serve as rich resources to gain insight into patients' medication-related experiences.

Analytics

Health systems are implementing electronic work queue systems to ensure compliance with various parameters, such as the Joint Commission Core Measures. These systems provide alert reminders, or patient acuity scorecards based on custom triggers for variables such as laboratory values and antibiotic susceptibility data that require follow-up and potential intervention. Pharmacists must understand the role of these tools as enablers of safe and efficacious medication therapy.

Automation

Automation has been a hallmark of pharmacy practice for many years. Its role will continue to increase as the profession works to deploy pharmacists to direct patient care activities. Technologies such as automated workflow systems, robotics (oral and IV), medication tracking systems, and barcode/radio frequency identification (RFID) capabilities will significantly impact the role of both the pharmacist and the pharmacy technician. Pharmacists should be prepared for the changes in practice that will accompany increased use of automation.

CONCLUSION

Pharmacy has historically been an early adopter of information technology to support administrative and operational functions. Today, it is impossible to envision a future pharmacy practice model that is not heavily reliant on pharmacy informatics, which focuses on the use and integration of data, information, knowledge, and technology involved with medication use processes to improve outcomes.[7,8] Pharmacy students must be educated in pharmacy informatics to be able to leverage existing and future tools to support medication-related care. We have provided resources to assist pharmacy educators in delivering pharmacy informatics educational experiences. These tools are organized according to the medication use process and focus on knowledge and skills that PharmD students should develop to prepare them to use informatics in their future practice. Educators should be aware that the pharmacy informatics literature is dynamic. Educators are encouraged to survey the literature frequently to ensure the use of current information in their education efforts.

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Appendix 1. Informatics Resources to Support Teaching Concept

Topic	Recommended Articles	Suggested Websites & Search Terms
	Prescribing	
Physician medication selection and prescription-related decision-making	Tavakoli M, Davies HT, Thomson R. Decision analysis in evidence-based decision making. *J Eval Clin Pract*. 2000;6(2):111-120.	clinical, decision, making, Tufts, Society for Medical Decision Making
Challenges with handwriting, transcription, and verbal communication of prescriptions	Bates DW, Cullen DJ, Laird N, et al. Incidence of adverse drug events and potential adverse drug events. Implications for prevention. *JAMA*. 1995;274(1):29-34.	www.ismp.org
Impacts of computerized provider order entry and electronic prescribing	Ash JS, Sittig DF, Poon EG, Guappone K, Campbell E, Dykstra RH. The extent and importance of unintended consequences related to computerized provider order entry. *J Am Med Inform Assoc*. 2007;14(4):415-423.	www.cpoe.org
	Moniz TT, Segar AC, Keohane CA, Seger DL, Bates DW, Rothschild JM. Addition of electronic prescription transmission to computerized prescriber order entry: Effect on dispensing errors in community pharmacies. *Am J Health-Syst Pharm*. 2011;68(2):158-163.	www.cms.gov/eprescribing
Drug information availability and use at the point of prescribing	Teich JM, Merchia PR, Schmiz JL, Kuperman GJ, Spurr CD, Bates DW. Effects of computerized physician order entry on prescribing practices. *Arch Intern Med*. 2000;160(18):2741-2747.	www.amia.org/inside/initiatives/cds
Patient information availability and use at the point of prescribing	Galanter WL, Polikaitis A, DiDomenico RJ. A trial of automated safety alerts for inpatient digoxin use with computerized physician order entry. *J Am Med Inform Assoc*. 2004;11(4):270-277.	Agency for Healthcare Research and Quality, health IT, clinical, decision support
	Pharmacist Prescription Review	
Pharmacist analysis of prescription appropriateness	Hanlon JT, Schmader KE, Samsa GP, et al. A method for assessing drug therapy appropriateness. *J Clin Epidemiol*. 1992;45(10):1045-1051.	American Society of Health System Pharmacists (ASHP), medication therapy, patient care
Pharmacist interventions for clinical or other reasons	Kopp BJ, Mrsan M, Erstad BL, Duby JJ. Cost implications of and potential adverse events prevented by interventions of a critical care pharmacist. *Am J Health-Syst Pharm*. 2007;64(23):2483-2487.	Institute for Healthcare Improvement, medication systems, measures
Drug product selection for compounding and dispensing	American Society of Health-System Pharmacists Section of Pharmacy Informatics and Technology Executive Committee. Technology-enabled practice: A vision statement by the ASHP Section of Pharmacy Informatics and Technology. *Am J Health Syst Pharm*. 2009;66:1573-1577.	drug product selection
Dispensed product labeling	Shrank W, Avorn J, Rolon C, Shekelle P. Effect of content and format of prescription drug labels on readability, understanding, and medication use: a systematic review. *Ann Pharmacother*. 2007;41(5):783-801.	Institute for Safe Medication Practices (ISMP), tools, guidelines, label, format

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Appendix 1. (*Continued*)

Topic	Recommended Articles Prescribing	Suggested Websites & Search Terms
Generating charges or billing	Mitchell CL, Anderson ER Jr, Braun L. Billing for inpatient hospital care. *Am J Health Syst Pharm*. 2003;60(21 Suppl 6):S8-11.	American Health Information Management Association, resources, reimbursement
	Compounding and Dispensing	
Supply chain automation	Temple J, Ludwig B. Implementation and evaluation of carousel dispensing technology in a university medical center pharmacy. *Am J Health Syst Pharm*. 2010;67:821-829.	pharmacy, medication supply chain, automation
Robotics and process control technology for compounding workflows	Kastango ES. Using ACDs in the practice of pharmacy. *Int J Pharmaceutical Compounding*. 2005;9(1):15-21.	automated, compounding, devices
Automatic counting of oral solid dosage forms	Flynn EA, Barker KN, Carnahan BJ. National observational study of prescription dispensing accuracy and safety in 50 Pharmacies. *J Am Pharm Assoc*. 2003;43(2):191-200.	automation, society, pharmacy, cost, benefit, analysis
Validating selected products prior to dispensing	Poon EG, Cina JL, Churchill W, et al. Medication dispensing errors and potential adverse drug events before and after implementing bar code technology in the pharmacy. *Ann Intern Med*. 2006;145(6):426-434.	FDA, bar code, label, requirement, drugs
Automated dispensing	Klibanov OM, Eckel SF. Effects of automated dispensing on inventory control, billing, workload, and potential for medication errors. *Am J Health Syst Pharm*. 2003;60(6):569-572. Flynn EA, Barker KN. Effect of an automated dispensing system on errors in two pharmacies. *J Am Pharm Assoc*. 2006;46(5):613-615.	ASHP, ISMP, automated dispensing, machine, guidelines
	Medication Administration	
The five rights of medication administration	Elliott M, Liu Y. The nine rights of medication administration: an overview. *Br J Nurs*. 2010;19(5):300-305.	safe, medication, administration
Drug error reduction systems for parenteral infusions	Elias BL, Moss JA. Smart pump technology: What we have learned. *Comput Inform Nurs*. 2010 Nov 24.:epub ahead of print.	FDA, medical devices, infusion pumps
Automated drug product identification	Poon EG, Keohane CA, Yoon CS, et al. Effect of bar-code technology on the safety of medication administration. *N Engl J Med*. 2010;362(18):1698-1707.	Healthcare Information and Management Systems (HIMSS), auto ID, bar coding, task force
Documentation of medication administration and regimen compliance	Ramalho de Oliveira D, Brummel AR, Miller DB. Medication therapy management: 10 years of experience in a large integrated health care system. *Manag Care Pharm*. 2010;16(3):185-195.	electronic medication administration record (eMAR), electronic, medication, administration, record

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Appendix 1. (*Continued*)

Topic	Recommended Articles Prescribing	Suggested Websites & Search Terms
	Monitoring of Ongoing Medication Therapies	
The electronic health record and electronic medical record	DesRoches CM, Campbell EG, Vogeli C, et al. Electronic health records' limited successes suggest more targeted uses. *Health Aff*. 2010;29(4):639-646.	www.amia.org/content/got-ehr
Clinical decision support using rule-based alerting, highlighting and triaging of issues	Jha AK, Laguette J, Seger A, Bates DW. Can surveillance systems identify and avert adverse drug events? A prospective evaluation of a commercial application. *J Am Med Inform Assoc*. 2008;15(5):647-653.	www.cdc.gov/nhsn/index.html
Population pharmaco-surveillance	Penfold RB, Wang W, Pajer K, Strange B, Kelleher KJ. Spatio-temporal clusters of new psychotropic medications among Michigan children insured by Medicaid. *Pharmacoepidemiol Drug Saf*. 2009;18(7):531-539.	www.pharmacoepi.org
Documentation of positive and negative outcomes from medication therapy	Millonig MK. Mapping the route to medication therapy management documentation and billing standardization and interoperabilility within the health care system: meeting proceedings. *J Am Pharm Assoc (2003)*. 2009;49(3):372-382.	documentation, pharmaceutical care, outcomes
Informing the prescribing/ordering process	Davydov L, Ebert SC, Restino M, et al. Prospective evaluation of the treatment and outcome of community-acquired pneumonia according to the Pneumonia Severity Index in VHA hospitals. *Diagn Microbiol Infect Dis*. 2006;54(4):267-275.	ASHP, medication use, evaluation