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Integrating the Electronic Health Record into Education: Models, Issues and Considerations for Training Biomedical Engineers

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1. Introduction

The use of Electronic Health Record (EHR) systems is increasing worldwide. Electronic health records (EHRs) are electronic repositories of a patient's health information and their encounters with the health care system over a lifetime (Shortliffe & Cimino, 2006). Internationally, there has been a push to implement such systems worldwide. However, adoption rates of EHRs continue to remain low in North America, and biomedical engineers are encountering many challenges associated with integrating EHRs into health care work settings. This is especially the case when medical devices and other healthcare equipment (e.g. cardiac monitors, smart beds and intravenous pumps) are integrated into EHRs. To improve adoption rates and student ability to seamlessly introduce this technology, there is need to provide greater EHR experience and exposure to the problems associated with EHR use and to solve some of the real-world EHR related challenges by developing creative solutions. Our recent work in the area of health IT and health professional educational curricula (i.e. in medicine, nursing, allied health and health/biomedical informatics) demonstrates that there is a need for biomedical engineers to learn about several areas at the intersection of medical device usage by health professionals and EHRs: (1) healthcare systems analysis and design, (2) usability of health care information systems, (3) interoperability of EHRs and (4) implementation of differing configurations of medical devices and EHRs to support clinical work. The purpose of this paper will be to describe our experiences to date in using an EHR portal in the classroom setting to teach individuals about these key aspects of EHR design and implementation in hospital settings (where biomedical engineers are typically employed). In the next section of this paper we define and describe how we have introduced EHRs into education, using a novel Web portal. Following this, we describe how we have integrated exposure to differing EHRs in the classroom setting to a range of students (i.e. from medical students to health informatics students).
As noted above, the use of Electronic Health Record (EHR) systems in hospitals is increasing. Information technology, health and biomedical engineering professionals are encountering a variety of complex problems in integrating EHRs into healthcare work settings. For example, integrating EHRs, medical devices and health care equipment can be a difficult undertaking. To improve student ability to effectively design, develop, implement and work with EHRs

there is need to provide students with experiences that expose them to challenges typically encountered in hospital settings (using a wide range of examples of real-world EHRs, tools and problems). Our recent work in the area of health IT and health professional educational curricula (including medicine, nursing and health informatics) has revealed that typical educational programs (e.g. health informatics, medicine, computer science and engineering) often provide only limited exposure to EHRs (Borycki et al., 2009; Kushniruk et al., 2009).

2. The need for EHRs in biomedical engineering education

Graduates of biomedical engineering programs are being expected to deal with the design, implementation and customization of EHRs and medical devices in hospital settings. Therefore, it is important that future biomedical engineering graduates have training and experience with a full range of EHRs. Work on competencies related to EHRs indicates that graduates of biomedical engineering programs should understand interoperability issues, basic data standards, user interface design issues, and have an understanding of the impact of EHRs upon healthcare workflow and practice (Canada's Health Informatics Association, 2009). Additional areas of skill and knowledge needed include: the ability to assess usability issues, understand risk management, assess software safety, effectively test and procure HIS, understand security and privacy issues, and understand analytic methods for evaluating and improving EHR implementation/customization (Borycki et al., 2009; Borycki et al., 2011; Joe et al., 2011; Kushniruk et al., 2009). Providing an in-depth understanding of these topics requires a basic understanding of EHRs, including hands-on access and exposure to a variety of EHRs to assess their potential to improve healthcare and to learn about the current issues and challenges associated with their use. This also involves developing an understanding of the issues associated with the design, development, interoperability, implementation and customization associated with the integration of EHRs and medical devices. However, due to practical limitations, such as cost, the need for trained biomedical engineering professionals, and the complexity of work involved in setting up this technology locally (within educational settings), biomedical engineering student access to working examples of such systems has been limited (Borycki et al., 2009; Borycki et al., 2011). It must be noted that this is also the case for computer science, medical, nursing and health informatics professional students (as they are also expected to be able to work with full EHRs) upon graduation (Borycki et al., 2009; Joe et al., 2011).

3. The University of Victoria EHR portal

To address the need for ubiquitous, remote and easy access to a repository of EHRs and related technology, the authors have worked on developing a Web accessible portal known as the University of Victoria Electronic Health Record (EHR) Portal. The portal provides students from many differing health care disciplines with access to several electronic records or electronic repositories where a patient's health information or encounters with the healthcare system can be stored virtually (Borycki et al., 2009). The portal houses several types of EHRs including electronic medical records (EMRs), electronic patient records (EPRs) and personal health records (PHRs). EMRs are electronic health records used in the physician's office. EPRs are electronic health records that are used by health professionals such as physicians and nurses in the management of a patient's health care in a hospital. PHRs are electronic health records that patients store information (on the World Wide Web, on their home computer or on a mobile device) about their own personal health status or a family members' health status (e.g. child, parent or grand parent). PHRs are maintained by an individual but may be used by health professionals to obtain additional information about the patient's health status. The University of Victoria EHR Portal has several of these EHRs (e.g., Digital Anthrologix® - an EMR, OpenVista® - an EPR, OpenMRS – an EPR, Indivo – a PHR and a range of other systems) (Borycki et al., 2009; Borycki et al., 2011; Kushniruk et al., 2009). One of the motivations for the portal's development was to leverage the investment - creating a repository of systems by housing them on a Web-based platform that can be accessed locally, nationally and internationally for use in the education of biomedical engineers and other health professionals such as physicians and health informatics professionals (Borycki et al., 2011).

As a result, this unique, web-based portal allows students to access and interact with a set of representative EHRs over the WWW. To date, the portal, which links to several EMRs, EPRs and PHRs, has been used by several hundred students from different locations across Canada. The portal also provides practicing health and technology professionals with opportunities for continuing education. So that they are able to learn about how EHRs work and their impacts upon the health practice and workflow (Borycki et al., 2009; Borycki et al., 2011). Furthermore, we have been able to develop several approaches to integrating EHRs into student education so that there are opportunities to learn about differing solutions to healthcare problems that have prevented full adoption and integration of these systems (e.g. problems related to issues such as interoperability, usability, testing for safety and integration of systems into health professional individual and group workflow). The portal has been used successfully in the classroom, in the laboratory and with distance education students to give hands-on exposure to a variety of EHRs in several locations across Canada (Borycki et al., 2009).

To illustrate access to the portal, Figure 1 shows the screen that students see if they access the portal via the WWW (in Figure 1 the student has clicked on the icon for starting up an instance of the OpenVista® EHR system). The remote desktop that the student logs onto is located on servers in Victoria, Canada (that can be accessed worldwide) and allows each student private read and write access to a range of EHRs, including EMRs, PHRs and EPRs (represented as icons). In Figure 2, the student has entered OpenVista® and is examining a fictitious or dummy patient record. Fictitious or dummy patient records are used to avoid privacy and confidentiality issues associated with the use of real patient data. There are also a number of other benefits associated with using this approach. Fictitious patient data can be used to generate a wide variety and complexity of cases that can be used to illustrate the features and functions of EHRs as well as their limitations in supporting health professional work. Lastly, fictitious patient cases allow students to make errors typical of students learning an EHR. In a virtual EHR environment this allows for errors to occur without their being a direct impact on patients (e.g. if a medical order is submitted then it is not associated with a real patient) (Borycki et al., 2009; Borycki et al., 2011).

In Figure 3, the student is viewing a display of a fictitious patient's vital signs. By instructing students to explore all the tabs and all the main features and functions of systems such as OpenVista, the functionality and design of a full EHR can be conveyed. This includes the functionality essential to working EHRs such as the following: (a) ability of EHRs to provide an integrated and comprehensive view of patient data (e.g. as shown in Figure 1), (b) the ability of EHRs to provide decision support capabilities, such as patient alerts and reminders, (c) links to online educational resources such as drug databases, and (d) communication support for transferring and receiving information about patients, their conditions, their laboratory values etc.

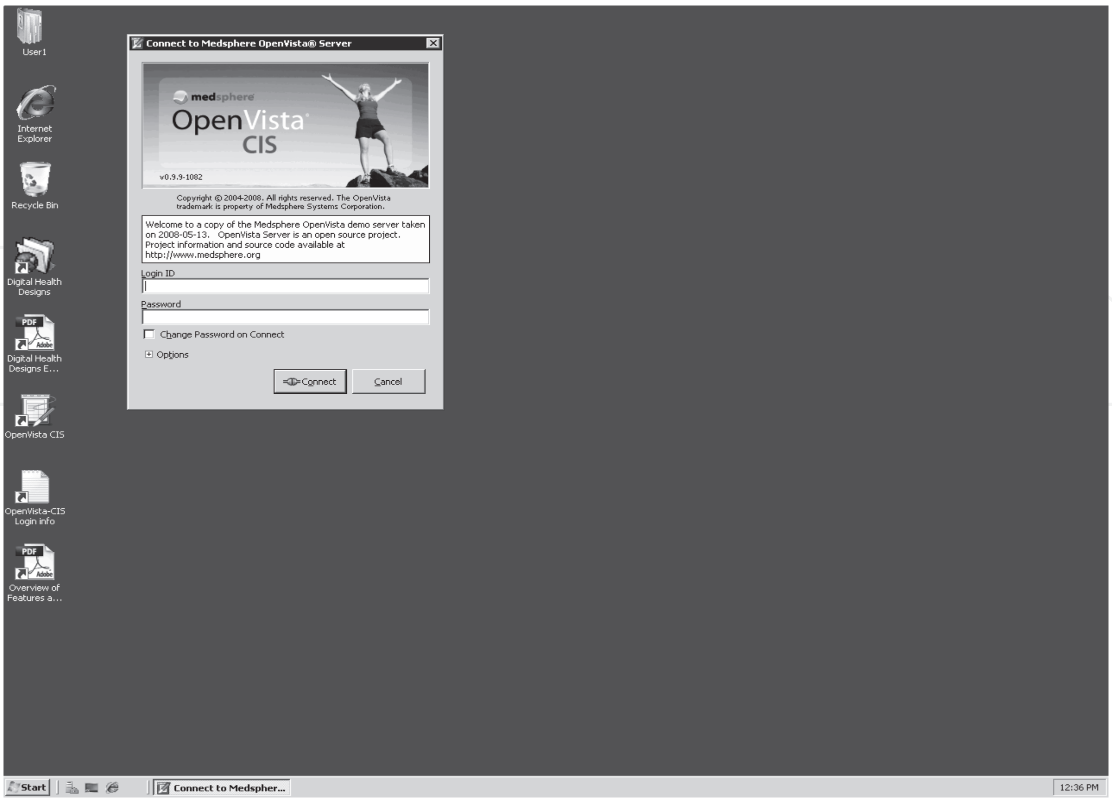

Fig. 1. Remote desktop of the UVic-EHR Portal, as seen by a student logging into the OpenVista® system remotely.

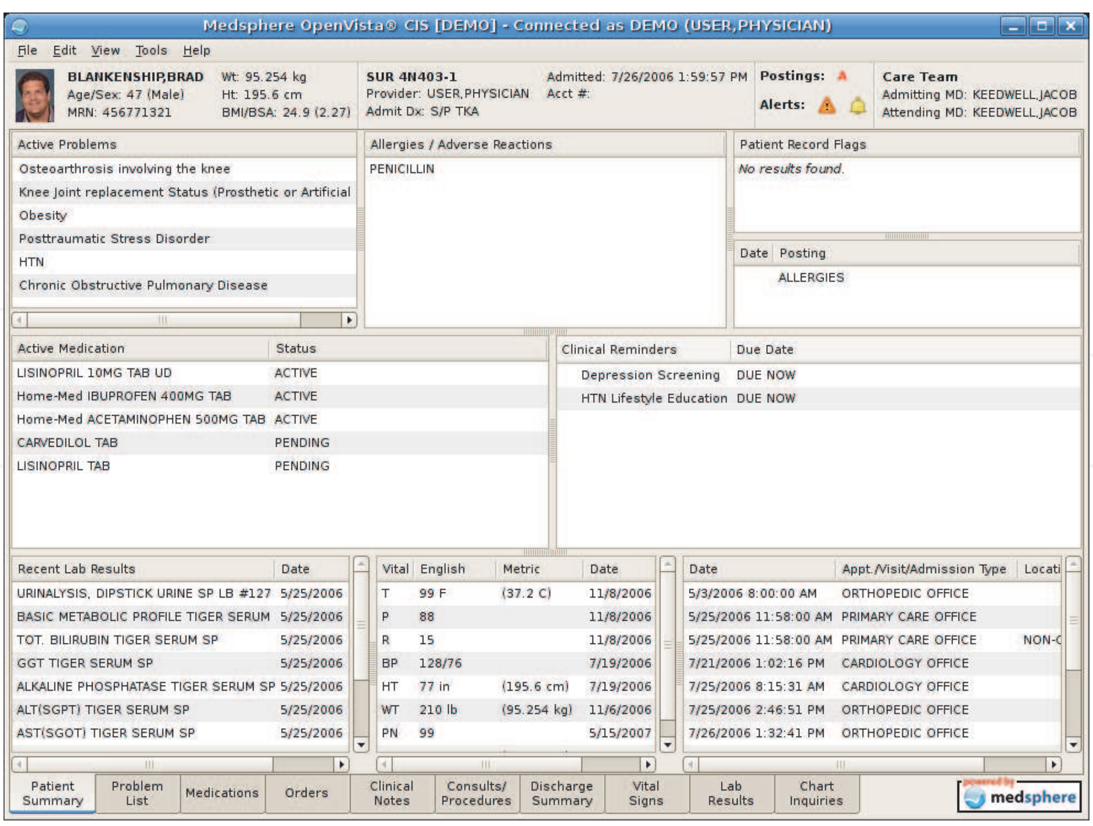

Fig. 2. Student view of a fictitious patient record displayed in OpenVista®.

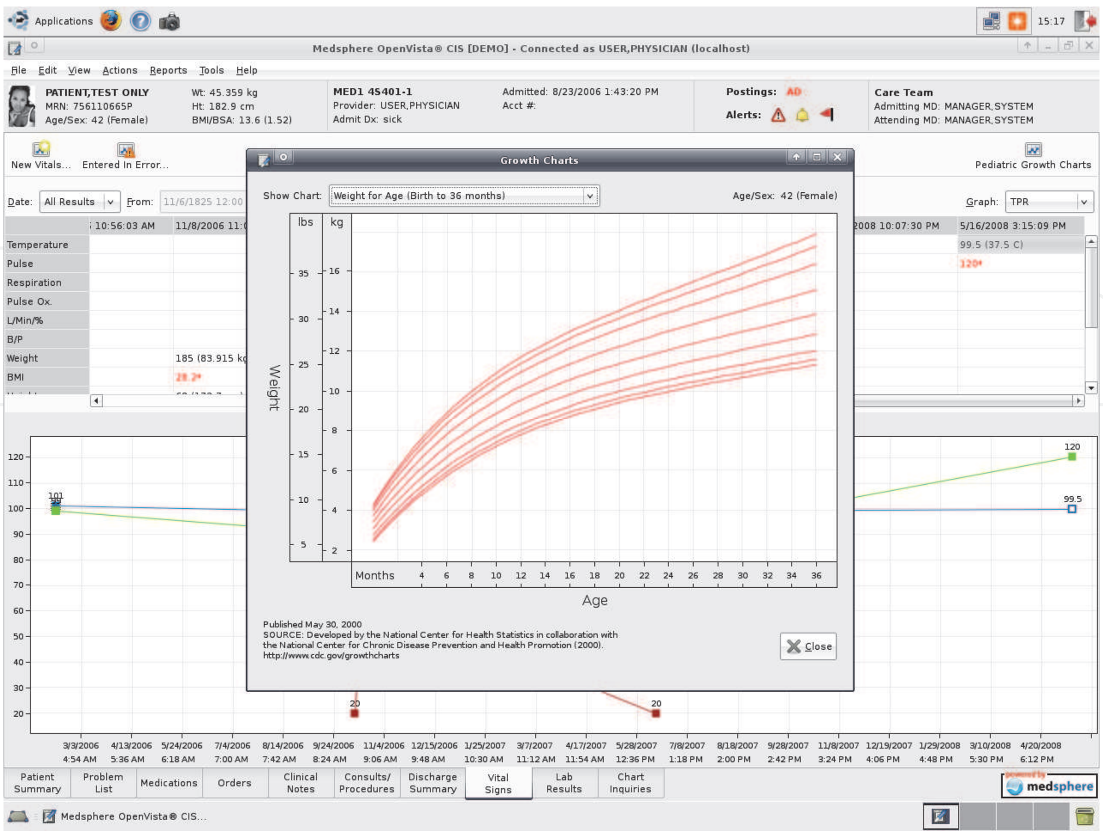

Fig. 3. Student view of a fictitious patient's vital signs displayed in OpenVista®.

In summary we have developed a portal that allows for ubiquitous access to working EHRs over the WWW. The portal has been used by students to learn about EHRs and some of the challenges and issues associated with their design, development, implementation and customization to health care settings such as physician offices and hospitals. The portal provides access to varying types of EHRs including EMRs, EPRs and PHRs so that students can have a full range of exposures to differing types of EHRs. This access is invaluable in courses where students need to explore the look and feel as well as functionality of working EHR systems, as will be described. In addition, EHR system components and systems developed by students (in courses) can be developed and hosted on the portal (as will be described) to allow for testing and deployment of project work in a realistic Web-based environment. In the next section of this paper we will discuss some of the uses of the EHR portal (including its integration in biomedical engineering education – especially where biomedical engineers must learn about EHRs).

4. Application of the EHR portal in biomedical engineering education

There are a number of current and emerging applications and models for integrating the EHR into biomedical engineering education. In our work this has included the incorporation of the EHR portal (as described above) to provide hands-on access to working EHRs and EHR system components (Borycki et al., 2009; Kushniruk et al., 2009) The applications described below are embedded within an integrated curricula focused on integrating informatics skills with understanding of user needs and healthcare requirements (as described by Kushniruk et al., 2006). The curriculum includes courses at both the undergraduate and graduate levels.

4.1 Healthcare systems analysis and design

As described above currently there are many issues facing the effective and widespread deployment of EHR technology in healthcare. There are many examples of failed EHR projects and implementations throughout the world. Reasons for such failure are varied but issues around the selection and application of inappropriate methods and approaches to healthcare system analysis and development have been implicated in many of these failures (Kushniruk, 2002). Biomedical engineering students who will become future designers and developers of these systems require improved training in more effective systems analysis and design, particularly in the context of healthcare. This training must go beyond the standard textbook knowledge contained in the generic software engineering literature as the challenges of designing and implementing healthcare systems have proven to be more difficult than in other traditional business areas. In addition, a focus on the whole System Development Life Cycle (SDLC), including consideration of methods and techniques that have proven to work most effectively in the domain of healthcare, is needed. In particular, healthcare information systems have often been criticized for not meeting the needs of their varied users (e.g. physicians, nurses, pharmacists, and allied health professionals) and their varied work contexts (e.g. emergency care, chronic care etc.). To address this and to allow students to see a range of possible functions and features of systems, we have used the University of Victoria EHR Portal to allow students to compare and contrast different types of EHRs. Thus, one way of applying the portal has been to have students access and assess EHRs as part of courses related to healthcare information system analysis and design. The instructions given to students typically have involved asking them to assess one or more EHRs in terms of identifying the following: (a) user interface design features (b) system features, (c) product advantages and disadvantages and (d) potential technical and user problems.

In addition, at the University of Victoria we have used the University of Victoria EHR Educational Portal to teach principles of systems analysis and design in an advanced fourth year undergraduate course (HINF 450 - "Systems Analysis and Design in Healthcare"). The intent of the course is teach object-oriented design approaches and students are required to develop working EHR modules (using UML and Java programming). The availability of open source EHRs on the portal offers the opportunity for students to assess existing system designs and to design and create working modules that can interface with existing open source software, reinforcing their programming and software engineering skills. In addition, the course focuses on training students in application of rapid prototyping and iterative refinement of systems based on iterative user testing. Allowing students to create modules early in the course, host their solutions and test them, can create a working test bed for them to improve their skills both in requirements gathering and system design.

4.2 Usability of health care information systems

Issues related to the poor usability of many healthcare information systems (in particular vendor based EHRs) is becoming increasingly recognized as a key factor in the failure of many efforts to implement EHRs and related technology (Kushniruk, et al., 1996; Kushniruk et al., 2005; Patel et al., 2000). Indeed complex socio-technical factors related to better understanding user needs, system usability and ensuring the usefulness of information provided to users have come to the fore in efforts to improve healthcare IT (Kushniruk and Patel, 2004). During several offerings of core courses in the undergraduate bachelor's degree program in health informatics at the University of Victoria, the portal has been used to provide students in health informatics (HI) with opportunities to explore EHRs from a range of formal analytical perspectives, from the technical to the cognitive and socio-technical. For example, in a third year undergraduate course entitled "Human, Social and Organizational Aspects of Healthcare Information Systems" several hundred students have been asked to critically analyze different EHRs currently available on the portal using evaluation methods from the field of usability engineering (e.g. using methods such as heuristic inspection, cognitive walkthrough as well as usability testing approaches). For example, given access to an EHR student work may involve having students conduct usability inspections of the system to identify: (a) violations of standard usability heuristics (b) usability problems (c) areas where the user interface and interaction should be improved (d)"usability catastrophes" that must be fixed to ensure proper system interaction and safety. Additionally, students are typically asked to design studies involving the video analysis of representative users interacting with the system under study and development. This has involved students creating full study protocols where a subject pool is identified, study materials designed, study procedures defined and also analysis methods indicated. The approach to this has involved teaching students about carrying out low-cost rapid usability testing (Kushniruk & Borycki, 2006), where subjects' computer screens are recorded, along with all user physical interactions and verbalizations. A focus of some of the courses where this has been introduced has been on training students to understand how usability problems may be highly related to safety issues and introduction of medical error (Kushniruk et al., 2005). This is termed technology-induced error. In courses students have had the opportunity to assess and evaluate the safety of EHR software and the implications of integrating EHRs with other medical devices such as IV pumps and smart beds on nurse and physician cognitive load, workflow and subsequent error rates (Borycki et al., 2008; Kushniruk et al., 2006). These learning experiences involving EHRs then formed the basis for student projects (see Carvalho et al., 2008).

In a number of iterations of this course, real systems were either accessed remotely by students (or systems hosted on the portal were accessed). Feedback, in the form of consulting reports developed by small groups of students, is typically presented to the system developers. Using this approach, students in the course have been involved in improving the usability of a number of Web-based EHR systems, allowing for experiential learning involving real systems. The portal thus has allowed students to compare and contrast different EHR user interface styles and designs and gain experience in evaluating differing EHRs in terms of both usability and safety, through both individual and group project work.

4.3 Interoperability of EHRs

There are many benefits associated with the use of Electronic Health Records (EHRs). According to IEEE, interoperability refers to "*the ability of two or more systems or components to exchange information and to use the information that has been exchanged*" (IEEE, 1991). Health data interoperability is an important EHR function as it allows for health data to be transferred electronically from one EHR system to another and from medical devices to the EHR. EHR interoperability has been found to improve the efficiency of healthcare delivery. Research findings have also suggested interoperability can reduce healthcare costs as well as the time taken to access, analyze, and document relevant patient health information by health professionals (Maki and Petterson, 2008).

Unfortunately, many software vendors do not provide EHRs with interoperability functions. Many countries around the world such as Denmark, Taiwan, Canada and the United States have developed or are in the process of developing interoperable EHR systems (iEHRs). For example, Canada Health Infoway working in partnership with federal, provincial and territorial governments is currently working towards implementing a pan-Candian iEHR. Once implemented, it is expected that the new iEHR, will allow healthcare providers (e.g. doctors and nurses) to access and update any Canadian's health record electronically, any time or place (Giokas, 2008). However, there are many challenges associated with iEHR implementation. For example, there are many differing types of EHR users in a typical healthcare system - clinicians, health information management (HIM) professionals, health care administrators, biomedical engineers, medical researchers and data modellers, *etc*. Each type of user uses the same EHR data to perform their work. However, there is considerable variation in the coding methods, terminologies/nomenclatures, software, hardware and medical devices that are used and the definitions that are present between EHR systems and devices. Other challenges include differences in the ways in which users may interpret the same data (e.g. words or medical terms). These challenges still need to be overcome to address issues associated with health data interoperability (Garde et al., 2007).

There are many differing methods that can be used to solve interoperability challenges. Kuo et al. (2011) has categorized a number of models for health system interoperability and they include the: (1) point-to-point oriented model, (2) standard oriented model, and (3) common-gateway model. In the point-to-point oriented model, organizations involved have chosen to use agreed–upon coding terminologies, messaging protocols and business processes. Therefore, health data can only be exchanged among organizations that have contractual agreements in the above mentioned three areas. The US Department of Veterans Affairs and the Department of Defense is a real-world example of an organization that has taken this approach. The US Department of Veterans Affairs (VA) and the Department of Defence (DoD) have built a patient data exchange gateway to exchange patient health information (Bouhaddou et al., 2008). This gateway allows for bi-directional, computable data exchange. It also achieves semantic interoperability. In the standard oriented model for health information exchange, organizations agree to follow a unique standard (terminology and message standard) for health information exchange. The Department of Health Taiwan (DOH-Taiwan) uses this model. The department of health promotes the use of the Taiwan Electronic Medical Record Template (TMT) format. To date the template is used by ten medical centres that collectively are responsible for 10 million outpatient visits a year. The TMT format forms the basis for document-based information standards and the information interoperability infrastructure for the Taiwanese healthcare system (Jian et al. 2007). The common-gateway model employs a messaging broker/bus approach. The model provides a common, standardized point of communication between systems to allow for information sharing. When health organizations exchange information, standard message structures (e.g. HL7 v2.x/v3) are defined to contain the information supplied in requests, responses and submissions by the parties who wish to exchange information. Therefore each health information system needs only to know how to connect to the messaging broker/bus and convert its data to standard message structures - a mutually agreed–upon data structure, coding terminologies and business process is not needed. Health organizations can therefore develop their information systems locally while at the same time reducing costs associated with complex development approaches. The Danish eHealth Portal, sundhed.dk (https://www.sundhed.dk/) uses this approach. Danish citizens can find information about treatments and waiting lists as well as communicate directly with health care providers via the portal. Citizens and health professionals have differing levels of access to the portal. Citizens and health professionals can also access a number of health services including EHRs (Sundhed, 2009).

To help students learn about and understand issues associated with interoperability involving the EHRs a well as the most common models or approaches (as outlined above), student projects have been developed for an undergraduate course entitled "Principles of Health Database Design" at the University of Victoria. As part of coursework students (assigned to groups) were asked to use PHP to design EHRs similar to OpenVista® (after viewing, exploring and assessing several EHRs on the portal). To train students in the basics of developing interoperable healthcare systems, the students were then instructed about how to export and import data across the different systems developed by each group of students. In a simulation system, data was stored in an Oracle or a MySQL database. Groups of students then used PHP and a Document Object Model (DOM) to export the data from Oracle to XML documents. Following this, the XML documents were used to import to other groups' EHR's using a MySQL database. As a consequence, students have developed a better understanding of how health data can be made interoperable among heterogeneous EHRs.

4.4 Implementation of differing configurations of medical devices and EHRs to support clinical work

One of the greatest challenges in effectively implementing EHRs into healthcare practice and settings such as clinics and hospitals has been the need to effectively (and safely) integrate this type of technology with the many other devices and information technologies that exist in healthcare settings. Along these lines, we have been able to use EHRs to teach students about the impact of integrating EHRs with medical devices upon health professional workflow and medical error rates in hospital settings (e.g. medical unit, emergency unit). In regional health authorities across Canada and hospitals worldwide medical devices are being integrated with the EHR (Kushniruk et al., 2006; Koppel et al., 2005 . The EHR is increasingly becoming the one source of information where all patient health information and their encounters with the health care system are being stored (i.e. uploaded to and downloaded from other medical devices). Health professionals (e.g. physicians and nurses) are using information in the EHR that comes from multiple differing devices (Kushniruk et al., 2006). For example, globally, intravenous pumps, smart beds, vital sign monitors, cardiac monitors, tablet computers and mobile phones are being used to collect and upload patient data to the EHR. Similarly, patient data is downloaded from the EHR to mobile tablet devices, mobile phones, mobile workstations and traditional desktop workstations by physicians, nurses and other health professionals for use in patient care related decision making. In every case patient data is being downloaded or uploaded to the EHR from an associated medical device. Initial, research in this area has revealed that medical devices (including mobile and traditional computer workstations), when not adequately integrated with an EHR, can have significant effects upon clinician workflow (Kushniruk, et al., 2006; Borycki et al., 2010) and error rates (Kushniruk et al., 2005; Koppel et al., 2005). This research has also shown that differing constellations of EHRs and medical devices can be tested using clinical simulations (to determine the potential effects of EHR – device integration upon clinician workflow and error rates) prior to the EHR-medical device constellation being implemented in a real-world hospital setting (Borycki et al., 2010). Introducing students to EHRs in the classroom (with hands on exposure opportunities) and providing students with classroom exercises where they can work with and observe the implications of EHR – device integration, helps students to learn about how to effectively procure, implement and customize EHRs- device constellations. Here, students learn how to implement and customize device implementations such that workflow is positively impacted while medical error rates arising from poor interactions with the EHR and its associated medical devices are at the same time reduced. Such work in the classroom also affords students with opportunities to design and evaluate the implications of specific EHR-device constellations on health professionals' workflow and error rates. We have also extended this work to include student discussions regarding procurement and the need for an integrated strategy towards EHR software and device selection and testing as part of the information technology and biomedical engineering department's long term management of EHR software and devices.

5. Discussion

EHR use is becoming increasingly more global as internationally there has been a move towards health information systems (HIS) implementation. As a result, biomedical engineering professionals are encountering a variety of complex problems in integrating EHRs in healthcare settings; for example, software, hardware and medical device interoperability issues. Graduates of educational programs are being expected to deal with the design, implementation and deployment of ever more complex HIS. Yet, biomedical engineering students may have few opportunities to work with more than one HIS before graduating from an undergraduate or a graduate program. This is also the case for many allied health professionals (e.g. physicians and nurses) who have little exposure to HIS before graduating from their educational programs. To address this need the authors worked on developing a number of educational initiatives to better inform students about key issues in EHR design, testing and implementation. Along these lines, we have also developed and employed a Web-based portal that houses a repository of EHRs and related technology for use in classroom instruction of health professionals who use EHRs. The authors have previously deployed portal EHRs for use in health professional educational programs (e.g. physician, nurse and health informatics training and education). This chapter represents a new advance in that it describes how portal EHRs can be integrated into and used for teaching biomedical engineering students. Portal EHRs have been used in a variety of ways to teach students about best practices in HIS design, development and implementation and to develop specialized knowledge that can be used to advance the design of HIS into the future. By providing students with practical hands-on experience (targeted at key areas where healthcare IT has been known to be problematic) it is hoped that upon graduation biomedical engineering students will be better prepared to meet the great challenges of implementing information technology in healthcare.

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