Perspectives on Global Public Health Informatics

Janise Richards, Hamish Fraser, and Gerald Douglas

Learning Objectives
1. Define global health informatics and discuss the differences from other instances of public health informatics.
2. List and describe some global policies that support public health in low-income, resource-constrained countries.
3. Describe public health informatics interventions that have been successfully developed and deployed in low-income, resource-constrained countries, and have also added value and have been sustained.
4. Articulate some challenges surrounding information technology use in health-care in a low-income, resource-constrained country.
5. Describe informatics solutions to common problems confronted in the deployment of systems in low-income, resource-constrained countries.

Overview

Public health professionals’ functions are rapidly expanding beyond their countries’ borders. Many academic centers recognize the importance of global health and are training students to meet this growing demand. Global health centers and institutes are focusing on the research and programmatic efforts needed to understand the burden of disease worldwide, as well as the financial, political, medical, policy, workforce, and infrastructure issues surrounding solutions to global health challenges. Due to this growing interest by the public health community, it is important to understand where the intersection between global health and informatics occurs. For many years, the promise of what technology can do to alleviate suffering and support disease surveillance and other public health activities took precedence over understanding the environment in which the technology has to function. People, and their participation in implementation of technological
solutions, are critical for success. In resource-poor environments, the deployments of technological solutions encounter many challenges beyond traditional adoption issues. Lack of stable electrical power, availability of Internet connections, and a workforce that can develop and maintain the necessary information technology remain barriers to successful implementation. Yet, through experiences in the implementation of information technology as supported by international donors and the *US President’s Emergency Plan for AIDS Relief* (PEPFAR), lessons are being learned to move towards the benefits that global health informatics can bring.

**Introduction**

As the world becomes more interconnected through travel, migration, and economic forces, many health issues are being increasingly recognized as a concern not for only one country, but for all nations. Infectious diseases such as measles, tuberculosis, and human immunodeficiency virus (HIV), as well as chronic diseases such as diabetes, cancer, and ischemic heart disease, are leading causes of death worldwide [1]. Sudden outbreaks, such as severe acute respiratory syndrome (SARS), H5N1 influenza, and Ebola virus have captured the world’s attention [2]. The neglected tropical diseases, so named for lack of adequate response, also are gaining attention and, in some cases, severity [3–5]. For example, global incidence of severe dengue, a mosquito-borne viral infection with no specific treatment, has grown rapidly in the past four decades, from only nine countries before 1970 to more than 100 countries in 2010, and with an estimated 390 million dengue infections per year worldwide [3]. None of these health issues are limited to particular continents or countries, socio-economic class, race, or gender. They are health issues that are important to all people.

Informatics has been involved in combatting infectious diseases [6], chronic diseases [7], and neglected tropical diseases [8, 9]. Surveillance systems, laboratory information systems (LIS), data warehouses, electronic health records (EHR), and other electronic health information systems (HIS) are used by public health professionals in detecting and responding to infectious disease outbreaks and supporting the continuity of care for chronic disease. Since global action is necessary to effectively reach the highest attainable standard of health and well-being for the world’s people, global health informatics is necessary to tackle these worldwide health issues.

**Global Health**

Global health is a term that has gained widespread use. However, to date, no single definition of global health has been widely adopted. As often occurs in a relatively new field, there appears to be ambiguity and elusiveness about what the term means.

A good place to start looking at the field of global health is to examine its genesis. As the focus developed into a consideration of health needs of people worldwide “above that of particular nations”, with increasing involvement of non-governmental organizations (NGOs), the term global health became popular. As part of an initiative from the Consortium of Universities for Global Health (CUGH) Executive Board, an examination was made to highlight the fundamental similarities and differences between global, international, and national public health [10, 11]. They determined that attributes of geography, cooperation, populations, access, and disciplines offer the best insights. In global health, the health issues transcend national boundaries; solutions require worldwide cooperation and involve both prevention and clinical care; health equity is a necessary pursuit among all nations; and collaborations are developed within and among multiple disciplines. The definition from Koplan et al. [12] is frequently cited and has been adopted by the 2011 Expert Panel on Canada’s Strategic Role in Global Health [13]:

Global health is an area for study, research, and practice that places a priority on improving health and achieving equity in health for all people worldwide. Global health emphasizes transnational health issues, determinants, and solutions; involves
many disciplines within and beyond the health sciences and promotes interdisciplinary collaboration; and is a synthesis of population-based prevention with individual-level clinical care.

**Global Health Informatics**

*Global health informatics* uses many different terms, concepts, and technologies. The exponential growth of the term in the scientific literature and Internet search engines has brought global health informatics to the fore. As the field has grown, additional terms such as *eHealth* and *digital health* are becoming more popular within global health related literature. The World Health Organization (WHO), in their 2019 publication on Global Strategy on Digital Health 2020–2024, defines digital health as “the field of knowledge and practice associated with any aspect of adopting digital technologies to improve health, from inception to operation.” However, global health informatics is more encompassing than technology. “*Global health informatics* is the discipline focused on empowering people to use appropriate technology to provide information-based solutions with a global perspective that support health care for all. The mission of global health informatics is to share informatics knowledge, skills, and research, and to foster local innovations to promote the highest standards of health for all with an emphasis on low-income, low resource countries and the medically underserved.”

**The Influence of Global Health Policy**

Over the past 30 years, the state of the world’s health has improved significantly. Life expectancy rates have increased and quality of life has improved in almost all countries. Public health measures, new medical technologies that have been readily adopted, and improved health literacy have all played a role in this increase. Collective global health actions also have been central to increasing the standard of health for all people. The foundation for these changes can be traced back to two critical policy statements—the 1978 *WHO Declaration of Alma-Ata*, which called for urgent action by governments and the world community to promote health of all the people of the world, and the 2000 *United Nations (UN) Millennium Declaration*, which built upon the ideas of the Alma-Ata Declaration more specifically by outlining eight goals, each with measurable objectives [15]. One of these eight goals, now known collectively as the *Sustainable Development Goals (SDGs)*, is *Goal 3: Good Health and Well-being*, which focuses on reproductive, maternal newborn and child health; infectious diseases; non-communicable diseases, mental health and environmental risks; and health systems and funding.

The establishment of these concrete goals provided the catalyst and focus for many other UN agencies and related programs. Countries also have used the framework of the SDGs to target their developmental aid funds, such as Sweden (SIDA), Norway (Norad), Germany (GIZ), United Kingdom (DFID), Canada (CIDA/IDRC), Australia (AusAID), and the United States (USAID/HHS-CDC). International organizations, such as the World Bank, Global Fund, and Asia Development Bank, have used the SDGs as a focus for funding in-country projects. During the last two decades, many NGOs have played a major role in supporting initiatives to reach the SDG health-related goals, including the Bill and Melinda Gates Foundation, Rockefeller Foundation, Ford Foundation, Aga Khan Foundation, Open Society Foundation, and the William J. Clinton Foundation [16]. For many decades, the United States (US) has been actively involved in working with other nations to improve global health. Most specifically, in 2003, President George W. Bush called for the creation of the *President’s Emergency Plan for AIDS Relief (PEPFAR)*, formally authorized by US Public Law 108-25, *United States Leadership Against HIV/AIDS, Tuberculosis, and Malaria Act of 2003* [17]. The original authorization was for five years and up to US$15 billion for HIV care, treatment, and prevention, and included support for capacity building and strategic information (i.e., surveillance, monitoring, and evaluation) in 15 focus countries, and for initiatives by
the Global Fund to Fight AIDS and UNAIDS. This initiative is considered the largest commitment by any nation to combat a single disease in history [18]. The 15 focus countries were among the countries hardest hit by HIV disease: Botswana, Cote d’Ivoire, Ethiopia, Guyana, Haiti, Kenya, Mozambique, Namibia, Nigeria, Rwanda, South Africa, Tanzania, Uganda, Viet Nam, and Zambia. PEPFAR was re-authorized in 2008 (US Public Law 110-293) and in 2013 (US Public Law 113-56). In 2018, US Public Law 115-305 expanded the initiative to 49 countries and regional programs [19].

Building on established prevention, care and treatment, capacity building, and strategic information programs, PEPFAR emphasizes country partnership, ownership, and strengthening of health systems. PEPFAR remains the largest funder of global health initiatives and has many successes in reducing the burden of HIV/AIDS in the focus countries. Since 2003, PEPFAR has directly supported HIV testing and counseling for more than 85.5 million people, care and treatment for over 14 million people, and through the prevention of mother-to-child transmission program has ensured 2.2 million babies of HIV positive mothers have been born HIV free [20].

**Health Information Systems in PEPFAR**

From the beginning, the use of electronic health information systems was a critical component of the PEPFAR implementation. High-quality data are essential to HIV prevention, care and treatment, policy development, resource planning, and accountability. Understanding the burden of disease requires functioning surveillance and aggregate indicator monitoring systems. Providing effective patient treatment requires consistent and available patient, laboratory and pharmacy data. All of the PEPFAR focus countries had major deficiencies in their national health information systems. During the first years of PEPFAR, the aim was to assist countries in developing health information system infrastructure that would support the national and PEPFAR HIV/AIDS programs. Health management information systems (HMIS) were developed to help report on core indicators required as a condition of funding. These indicators and other nationally-oriented indicators were also used for policy development, program planning, implementation, and identification of best practices. These systems frequently remain paper-based at the facility and district-levels of a country, with the information captured into an electronic system at or before arriving at the ministry of health. In the countries with electronic data systems in facilities or districts, the effort was placed on harmonizing data elements and core data sets. As health information infrastructure has matured in these countries, patient-level data collection systems are used for both patient care and for routine health information for surveillance, monitoring and evaluation (M&E), and resource planning.

Over the past fifteen years, counseling and testing has identified millions of people with HIV/AIDS, and anti-retroviral treatment has extended the life span of people living with HIV [20]. Due to this impact, electronic systems have become more necessary to manage the volume of patient data created by longitudinal health records. Electronic health records (EHR), laboratory information systems (LIS), and other patient-level systems are being implemented.

This growth in patient-level systems has created a greater need to standardize functional and technical requirements for health information systems, design systems that facilitate and enable interoperability between different systems (e.g., EHRs, LIS, pharmacy, and others), facilitate linkage and de-duplication of records, and strengthen data security, privacy, and confidentiality measures. This work will be done partly through innovative technical solutions. Most of the work will be accomplished through strengthening strategic planning and governance, developing in-country human capacity, and continuing the on-going evaluation of health information system implementations to identify effective informatics practices, efficiencies gained, and health impacts.
Building partnerships with countries to create sustainable health information systems is a foundational goal of PEPFAR. Working with Ministries of Health to build infrastructure and human capacity, PEPFAR has encouraged countries to assume more leadership responsibility. The focus has shifted from health information systems developed and supported by PEPFAR, to a situation where Ministries of Health recognize the necessity of leveraging and coordinating the investments in health information infrastructure and systems by donors and they develop country-level strategic HIS plans with measureable goals and objectives. Across Africa, Asia, and Latin America, advances have occurred in information and communication technologies, and Ministries of Health are seeking to take fuller advantage of these tools to improve service delivery.

How these policies have played out in countries has depended on many factors. Some countries have a more stable governmental infrastructure and are able to establish long-standing HIS policies; others have a more fluid governmental situation where leadership changes frequently and HIS policies may be retracted or radically changed. Environmental factors including lack of navigable roads, potable water, sanitary conditions, electrical power, and sheer distance between communities can impact countries’ motivation and ability to prioritize or implement an electronic HIS. The small gains in developing and retaining informatics skills and knowledge in-country may not be enough to sustain the systems. Sustainable and country-owned health information systems are the goal; the global informatics community is the supporting actor.

Below are two case studies that describe the evolution of health information systems to support care and treatment of people with HIV/AIDS in two low-income, resource-constrained countries. These cases provide insights into lessons learned, technologies used, and policies needed. They are illustrative of many health information system implementation endeavors within low-income, resource-constrained, and HIV/AIDS-burdened countries.

### Case Study of Health Information System Design and Implementation in a PEPFAR Focus Country: A Decade of Public Health Informatics in Malawi

#### Malawi: Background and Overview

Malawi is a landlocked country in sub-Saharan Africa with a population of approximately 18 million people. The Malawi Ministry of Health provides healthcare at no cost through a network of government health facilities comprising roughly 400 health centers, supported by 24 district hospitals and 4 central referral hospitals. Health adjusted life expectancy at birth is 51.2 years (2015) [21]. The World Health Organization (WHO) ranks Malawi 185 out of 191 in overall health system performance [22]. Approximately one in 16 children die before reaching 12 months of age, and one in 20 die before reaching five years of age (2018) and approximately 9% of the population is HIV positive (Ages 15–49, 2013). Malawi, like many low- and middle-income countries, is hampered in its ability to provide healthcare by a severe shortage of medical staff, medications, and diagnostic resources. Malawi has the lowest ratio of doctors per capita of any country (around one physician per 50,000 capita) (2015). Spending on healthcare is US$93 per capita per year (2014). The Central Monitoring and Evaluation Division (CMED), formerly the Health Management Information Unit (HMIU), housed within the Ministry of Health is responsible for the collection, analysis and reporting of key health indicators from all health facilities in Malawi. Prior to 2000 the collection of morbidity and mortality data relied on the completion of pre-printed forms by clinicians, nurses, and clerks. Outpatient diagnoses were recorded on a monthly tally sheet and inpatient data were abstracted from three-part discharge forms. A team of data entry clerks
with in the HMIU entered data from the paper forms into computers, using custom-developed data entry software written in Dbase IV. In 2001, following a national review, the HMIU/CMED introduced a series of paper-registers to replace tally sheets and discharge forms as the primary form of data collection. This shift to using registers for data collection required that health facilities manually aggregate their own data before reporting it to the HMIU/CMED. Additionally, and particularly at district and central hospitals, the registers were increasingly being completed by lay clerks with little or no training in health or medical terminology, rather than by clinicians and nurses. To produce district-level and national-level reports from the manually aggregated totals derived from paper registers, the HMIU/CMED adopted the District Health Information System (DHIS) software [23].

**Issues and Solutions**

The initial work in piloting informatics solutions with the Malawi Ministry of Health started in 2001. The investigations started at Kamuzu Central Hospital (KCH), a 700+ bed referral hospital located in Malawi’s capital city of Lilongwe. After visiting several departments in the hospital, the team made a number of observations. Ward clerks worked a standard 7.5 hour day, and sometimes on Saturday mornings. Given the volume of data, it was unrealistic to expect data to be complete without having clerks work weekends and potentially evening shifts. Additionally, clerks had no training in medical terminology, but were required to both transcribe medical data as well as map diagnoses into indicators (e.g., diabetes was mapped into an indicator called Other Non-communicable Diseases of Public Health Importance). This brought into question both the completeness and the accuracy of data reported. Clinicians were over-burdened with patient care and perceived documentation for “statistical” purposes as outside the scope of clinical work and therefore not part of their responsibilities. From these observations, a hypothesis was formed. A well-designed, electronic information system to support the delivery of healthcare in a resource-poor setting may provide clinicians and nurses with tools to augment their ability to efficiently and effectively deliver healthcare, while collecting data as a transparent byproduct of system use. The idea of a rudimentary electronic medical record (EMR) was proposed that would be used by clinicians in real-time at the point-of-care, and moved ahead with the development of a system to be piloted in the pediatric department at KCH.

As hardware and software solutions were developed for the pilot work, the team identified several potential barriers, two of which were critical barriers. First, health workers had little or no training in using computers. The team thought this could be mitigated by emphasizing simplicity and usability as part of the system design [24, 25]. Recognizing that to build computer literacy among the users would take time, a touchscreen-driven user interface was developed. Second, power outages at the hospital were frequent and would be a significant threat to building a reliable system. To address this the team developed a power back-up solution around locally-available deep-cycle batteries used for solar power installations. However, rather than charging them from solar panels they were simply connected to a charger powered by the national grid. This solution, combined with the selection on low-power touchscreen computers, provided 36–48 hours of power backup.

**System Description**

The pilot system was aimed at supporting the care of children attending the outpatient clinic as well as those admitted on the wards at KCH (216 beds). At that time, no records were kept for patients seen in the outpatient setting. Paper charts were created for patients admitted on to the ward, and for the most part could be retrieved during the normal workday on subsequent admission if the patient’s name and date of last admission were known. For the pilot, the team aimed to create a permanent electronic record of outpatient visits, capturing a limited set of
diagnostically-relevant signs and symptoms and a diagnosis. For inpatients, the system only captured the date of admission, discharge diagnosis, and the date of discharge, from which length of stay could be derived. While this seems trivial in the context of a western incarnation of an EMR, it allowed us to do a basic proof of concept. Furthermore, it did represent an improvement over the current paper system, allowing clinicians in both the outpatient clinic as well as on the wards to see a patient’s past medical history, albeit limited.

The greatest impediment to creating this time-series of patient visits was re-identifying the patient on subsequent visits to the hospital. Malawi has no form of national registration system, eliminating a national ID number as a possible unique patient identifier. Many patients were illiterate, making it impossible for them to verify the spelling of their name. Many older patients knew their year of birth, but not the month and day. Recognizing the importance of being able to uniquely identify patients, particularly to support continuity of care for chronic disease management, a simple patient registration system was chosen to implement. The system allowed a clerk to capture a limited set of demographic information from a patient, and generated a unique patient identifier. This information was stored in an electronic Master Patient Index as well as printed on an inexpensive adhesive label to be affixed to a patient’s health passport, a small patient-kept booklet issued to patients by the Ministry of Health. To facilitate ease-of-use and reduce the chance of transcription or data-entry error, the patient’s unique identifier was represented in barcode form as well as in human-readable text on the label. The patient registration module went live in March of 2001, and has gone through three revisions of the format of the ID number to bring it in line with best practices. The inpatient module was primarily an admission and discharge module and, like the patient registration system, was operated by clerks. The outpatient module was developed with the intention of having clinicians use it. However, once deployed, the team determined that the system was both too onerous when managing patients who would be treated on an outpatient basis, and not sufficiently detailed to support the admission process for sicker patients who would be admitted for care. Several months after deploying the outpatient module, clinician use was dwindling and the decision was made to discontinue use of the module until the team could determine how to better add value for the clinicians. Following discussions with pediatricians at KCH as well as the College of Medicine in Blantyre, the focus changed to strengthening the admission process. An admission module was created that modeled a paper-based admission guideline developed at the College of Medicine [26]. The module systematically stepped the clinician through the assessment of the patient and creation of a treatment plan, including medications to be prescribed and diagnostic tests to be ordered. Time-saving features of the module included automatic medication dosage calculation based on the child’s weight and age, and generation of specimen labels for all samples to be drawn for laboratory testing. On completion of the process the system printed hard copies, essentially replacing what were previously hand-written admission notes; the printouts included a pre-populated medication administration record and a nursing plan template. This was the first example of a true point-of-care application working in a low-resource setting, and demonstrated that this approach could be extended to other clinical domains.

In 2003 and 2004, two small demonstration projects were conducted to determine the potential use of information systems for supporting ancillary services in the hospital. Working with pharmacy technicians in the KCH pharmacy dispensary, the team developed a simple medication dispensation tracking system. At that time, tracking of medication usage was done at the level of bulk containers. For example, the pharmacy would document that the dispensary had received 5000 tabs of Ibuprofen, but not to whom or in what dosage those tabs had been dispensed. While only a small portion of the medications had barcodes printed on the packaging, a simple barcoding system was created by labeling the shelf on which the medications were stored at the
dispensation window. Medication ID numbers were arbitrarily assigned to all drugs in the pharmacy and printed barcoded labels for each section of the shelf. Using these barcodes to identify medications being dispensed, and patient identifiers in barcode form on the patients’ health passports, pharmacy technicians were able to record patient-level dispensation of medication in real-time using a touchscreen computer located at each of the four dispensation windows in the pharmacy [27].

Working with the radiology department at KCH and with the assistance of a consultant radiologist we developed and deployed a simple touchscreen-based system to improve the labeling of radiology films. Prior to this intervention, x-ray films were labeled in the top left-hand corner by transferring the patient’s name from a hand-written note onto the x-ray film using a photo-imprinting process at the time of developing the film. Legibility of the label was poor, making it hard to identify to which patient the film belonged and making filing of films almost impossible. The solution used a touchscreen computer, barcode scanner, and thermal label printer located in the radiology department to retrieve the patient’s demographic record from the master patient index, select the type of study ordered and referring department using on-screen prompts, and print a legible adhesive label to first be used for photo-imprinting onto the film and then be affixed to the film envelope for clear identification.

In 2005, with support from the United States Agency for International Development (USAID), the team developed and piloted a touchscreen-based electronic pharmacy inventory control system (ePICS) to manage medication inventory at the stockroom level. The system combined features found in advanced inventory management software, with the high usability offered by the touchscreen user interface.

Supporting HIV Care and Treatment

With increasing interest and investment in HIV prevention and treatment, and the requirement for increased M&E for donor-supported programs, the team focused on applying these newly-developed tools to addressing problems in this space. In 2003, working with a Malawian NGO providing voluntary counseling and testing (VCT) services and with support from the US Centers for Disease Control and Prevention (CDC), the team developed a touchscreen system designed to guide counselors through the counseling process, while collecting data to be used for M&E. This system was deployed at three VCT sites in Malawi where it was used by dozens of counselors with no prior computer training. This apparent success increased the team’s confidence that electronic systems, if appropriately designed, could be used in real-time in low-resource settings [28]. In 2004, working with the Lighthouse Clinic, an HIV Center of Excellence in Malawi, the focus on HIV moved into the development of a prototype EMR for managing patients receiving antiretroviral therapy (ART). This was a first encounter with designing a system to accommodate multiple points of care (patient check-in, vital signs station, nurses’ exam room, clinicians’ exam room and pharmacy) and multiple workflows. This was a large undertaking and pushed the limits of the team’s capacity and capabilities. While still under development, there were many revisions to the system specification, partially due to changes in treatment regimens and guidelines, and progress was painfully slow.

In mid-2005, decisions were made to change the development platform to take advantage of free and open source software as much as possible. This was motivated by the vision that these systems, if successful, would be adopted by the Malawi Ministry of Health, and the cost of scaling-up could be reduced if license costs for operating system and database management systems could be eliminated. An additional appeal of open source was the emphasis on community-based support rather than vendor-based support, which was perceived to be a better model for supporting systems in low-resource settings.

By 2006 Malawi’s national response to providing antiretroviral therapy was in full swing with some of the more well-established clinics
managing several thousand patients. Overwhelmed with the challenges of generating quarterly and cumulative cohort reports for programmatic M&E, the Department of HIV and AIDS within the Ministry of Health issued a request for proposals for the development of an electronic system to automate the generation of reports at high-burden sites. Rather than relying on transcription from paper records into an electronic system, a decision was made to adopt a point-of-care EMR approach that would support patient care while collecting the data required to produce the M&E reports. Governed by a task-force of stakeholders, a functional specification for the system was created to guide development. Working in collaboration with the Ministry of Health and through a cooperative agreement with the CDC, a prototype point-of-care EMR system to manage patients receiving ART was created [29]. System development was informed by lessons learned building the point-of-care pediatric admissions module, and by domain knowledge gained developing the HIV EMR prototype for the Lighthouse Clinic. This new system differed from the one developed for the Lighthouse Clinic. It was developed around newly-introduced clinical practice guidelines and the newly introduced cohort reporting M&E framework. Additionally, it was developed using the Ruby on Rails open-source software stack, adopted in 2005 over the Microsoft Visual Basic development environment previously used, and incorporated aspects of the recently-introduced OpenMRS system, particularly the data model [30, 31]. The EMR was piloted at two district hospitals in 2007. Refining the system, particularly the creation of the detailed cohort reports, took much longer than anticipated. Again, changes in national guidelines and the introduction of new drug regimens complicated the process. However, following a lengthy pilot period, the system was adopted by the Ministry of Health in 2010 for national scale-up to high burden sites pending the availability of funds. By the end of 2012 the national ART EMR was deployed at 21 high-burden ART clinics (including the Lighthouse Clinic), collectively managing care and treatment for roughly 98,000 patients [26].

### Beyond HIV

Having established a model to support HIV care and treatment in low-resource settings using an EMR, the team explored the feasibility of supporting the management of chronic non-communicable disease in the same way. In 2009, in collaboration with the International Union Against Tuberculosis and Lung Disease and the Malawi College of Medicine, an EMR was developed and piloted to support care and treatment for patients with diabetes mellitus. The system was piloted at Queen Elizabeth Central Hospital in Blantyre, and later expanded to the remaining three central hospitals in Malawi [32]. Work commenced in 2013 to extend this model to address a broader package of non-communicable diseases. With increased emphasis on improving maternal and child health, work began in 2011 to develop clinical modules to support antenatal care, maternity and child (under five years old) services.

### A Model for Sustainability

Work thus far had focused on emphasizing the clinical benefits and contribution to improving M&E realized through using these systems, with no attention paid to the costs. In 2010, this was addressed by modeling the potential return on investment that may result from deploying these systems. Focusing on the specifics of KCH, the team projected potential savings could be generated by the use of EMR modules. Using these projected savings and projected costs for installing and maintaining a hospital-wide EMR system at KCH, a five-year net present value model was constructed to determine the potential return on investment from installing the EMR. Based on this model the team was able to demonstrate a complete recapture of the initial investment costs of a hospital-wide system in less than three years [33]. This finding generated some optimism that the use of information technology in low-resource settings may actually be a cost-saving intervention, and this important conclusion may be the basis for the long-term sustainability of these systems.
Lessons Learned

Results were mixed. Many of the systems developed and piloted could not be sustained for a variety of reasons; others have been integrated into the clinic workflow.

False Starts and Experience Gained

The outpatient module developed in 2001 was so constrained in its functionality that it resembled an electronic register more than an electronic medical record system. Once the team recognized the poorness of fit, the use of this module was discontinued. The pediatric admission module was significantly more successful, running for more than 18 months before being discontinued. Despite the apparent goodness of fit and the positive feedback from users, it was difficult to keep the system running. Unlike other systems the team had developed, the pediatric admission module relied on the use of laser printers. At the time there was no technical solution to powering laser printers from a backup source of power (now solved). Consequently, during periods of power failure clinicians would have to complete the admission note by hand. Other problems arose when printers ran out of paper and there was no paper available to refill the tray. These problems frustrated clinicians. The system was finally discontinued when both laser printers were damaged by a power surge and there was no funding to replace them. KCH pharmacy staff reported the ePICS system deployed in 2005 was greatly beneficial to the smooth running of the pharmacy. However, without a directive from hospital management the pharmacy staff were unable to discontinue using the paper-based stock system, and doing both was far too time-consuming. Several months after the ePICS system went live, in the absence of a strong champion and with the burden of maintaining parallel systems, staff use of ePICS became inconsistent. This resulted in inaccurate stock levels in the system and a general agreement was reached to terminate the pilot. Both the pediatric admission module and the ePICS module were essentially demonstration projects that had no clear strategy to sustain them.

Exemplars for Sustainability

Despite these challenges, several systems have been sustained. The patient registration system is now in its 12th year of use, having issued more than 1.6 million unique IDs to patients. The specimen labeling component of the pediatric admission module was implemented as a stand-alone module and deployed at the Lighthouse Clinic in 2003, where it continues to generate labels for CD4, full blood count and TB sputum testing at both the main site, as well as its sister clinic, the Martin Preuss Center. The radiology module has been in continuous use at KCH since 2005. Both systems are stand-alone, simple in their functionality, and have a strong value proposition for the user. Yet despite their simplicity, these systems generate a large volume of data, which can be reported in multiple ways. Not unlike the discontinued systems described above, both the radiology system and specimen labeling system were demonstration projects with no clear model for sustainability. The team suggests that the continued use of these systems is a result of the low overhead to maintain and support them, combined with the strong value proposition for the user.

Keys to Success

Establishing a patient identifier scheme and master patient index at the beginning simplified the development of other modules as it provided a level of interoperability through which different modules could share patient information. Designing systems for simplicity and usability was a core design principle, and appears to have been a prudent decision. Health workers with little or no previous exposure to training in the use of computers quickly became proficient in the use of the touchscreen systems. To increase the sustainability of the systems being built, a strategic decision was made early to develop a local team to build the systems, rather than rely on international contractors and consultants. The availability of experienced local software developers was limited, requiring that many of the developers be trained on-the-job. This slowed down productivity, often resulting in milestones being missed. Emphasis on adapting hardware to
work with a centralized 48 Volts Direct Current (DC) power backup system required extra work, but ultimately paid off in increased system uptime in the presence of grid power failures. Despite these challenges, this 10+ year legacy of systems in Malawi validates the goal of local development and ownership.

The Past Is Prologue

Looking back over the work in Malawi, the health information systems development has tangentially touched on two pillars of healthcare - medications and laboratory testing. In hindsight, had the demonstration projects expanded in those areas, they may have had a broader impact on strengthening health systems and healthcare delivery in Malawi, rather than the somewhat narrower scope of managing HIV and non-communicable diseases that has been achieved to date.

In high-resource settings, the sustained use of EMR systems by staff results less from users finding value in these systems (the “carrot”) and more from the mandated use of such systems (the “stick”). In low-resource settings, where supervision is minimal and sometimes nonexistent, the latter cannot effectively work; sustained system use depends squarely on a strong value proposition for system users. Of all the lessons learned this decade of work has reinforced the importance of addressing the needs of the system users as the highest priority. This work in Malawi started with the hypothesis that small, highly usable systems designed to address challenges in process or work-flow identified by health workers can add value, fully recognizing that the use of these systems would create large amounts of valuable data, but setting the primary purpose as process improvement. From time to time the team deviated from this strategy, creating large monolithic solutions, often seduced by the appeal of collecting data for more distal benefits rather than addressing a more proximal problem, and without a clear understanding of the mechanisms such as decision support that these systems were trying to leverage at the point-of-care. As health information systems development and implementation moves ahead, it is crucial to leverage the lessons learned and refocus on the mechanisms through which EMR use at the point-of-care can both improve patient outcomes as well as reduce healthcare delivery costs. This will require a strategic approach at the national level, with involvement and cooperation of the Ministry of Health, technical partners, and funding agencies. The development of a strategic plan for the evolution of eHealth solutions in Malawi will serve as a road-map for the future, as well as a model through which we can share ideas, facilitate discussions, and validate design decisions and priorities.

Case Study of Health Information System Design and Implementation in a PEPFAR Focus Country: Rwanda

Rwanda is a small, landlocked country in central Africa with almost 12 million people. In 2005 Rwanda had a gross domestic product (GDP) per person of less than US$230 per year, one of the lowest in the world [34]. Infectious diseases remain among the largest health challenges, along with maternal and child health, trauma and mental health. These challenges were in part legacies of the genocide of over 800,000 people in 2004, and a very poor response in development aid from the international community in the next two years [35]. HIV prevalence was 3.3% in 2005, causing a major burden of disease. Substantial progress has been made by Rwanda over the last seven years, with GDP per person rising to US$582 in 2011 and $826 in 2018, and while HIV prevalence remains about 3%, 108,113 HIV patients were receiving ARV treatment in June 2012, the second highest rate in Africa [35]. Between 2005 and 2016, HIV fell from the number one cause of death to number four, whilst ischaemic heart disease rose from number eleven to five, and stroke from seven to six [36]. Challenges for the Rwandan health system were very similar to Malawi, including lack of roads and communications to remote clinics, a severe shortage of trained healthcare workers and limited investment in clinic infrastructure. There was
limited knowledge of the disease burden in communities, including prevalence of HIV, and a need to track lifelong care for those patients. The existing processes for managing clinical data were also similar to Malawi, with a focus on multiple paper registers and limited paper charts, which were often difficult to locate.

History of Partners in Health Informatics Projects in Rwanda, 2005 Onward

Partners In Health (PIH) was first invited to work in Rwanda by the Ministry of Health (MOH) in 2004, to help develop a strategy to support the expansion of HIV care to remote rural areas. PIH’s successful provision of HIV care in the remote and extremely impoverished Central Plateau area of Haiti had impressed the MOH, and they wanted to achieve similar success in the many underserved rural areas of Rwanda. The first PIH supported clinic was established in 2005, in Rwinkwavu hospital in the east of the country, an area with exceptionally poor infrastructure. Two years previously in Haiti, PIH had developed and deployed a web-based EMR system to support HIV care [37]. To support the Rwinkwavu hospital, this EMR system was set up on a server accessible over the Internet. Then the team adapted the EMR to the needs of the Rwandan health system, including capturing data on paper intake and follow up forms, as well as laboratory data including CD4 counts used to monitor the clinical status of HIV patients. As the team adapted the EMR to this country’s specifications, it was found that the extent of adaption and customization needed was extensive and time-consuming, including changes to the language, the demographic data and address structure, the form and report design, and especially the workflow. The team also recognized that further extensive modification would be required to support other disease types. At this time the team had started to collaborate with the Regenstrief Institute in Indiana and their AMPATH project in Kenya, as well as the South African Medical Research Council (MRC), to develop a new, flexible, open source EMR platform—OpenMRS [30]. This offered a more sustainable way of building EMR systems in resource poor environments. The decision was made to pioneer the system in Rwanda and Kenya. The first version of OpenMRS went live in Eldoret, Kenya in February 2006, with the first version using a Linux environment going live at Rwinkwavu hospital in August that year, and a cloud-based approach at Richmond hospital in KwaZulu, South Africa shortly after.

Technical, Organizational and Functional Description of the System

OpenMRS is an open source software project written in Java. It uses the MySQL database and can run on Linux, Windows, or MacOS [38]. It is designed around a “concept dictionary” of structured data items that defines virtually all the data that can be stored in OpenMRS (other than patient demographics). An unlimited number of concepts can be added to the system without modifying the underlying software, and concept dictionaries can be standardized or shared. The CIEL dictionary of over 50,000 standardized concepts, many mapped to coding systems including ICD10, SNOMED-CT and LOINC, along with the Open Concept Lab project, assists in sharing data and functional components [39]. Unusual for an EMR system, OpenMRS has a modular architecture which allows new functionality to be programmed without modifying the core system. More than 200 modules are available in the OpenMRS module repository, ranging from core functions such as form creation and reporting tools to more customized code for specific implementations. However, it is not necessary to write new modules to implement the system. Core groups of paid programmers have supported OpenMRS from the beginning, with Rwanda playing an important role in the development of the core code as well as customization and field testing. An increasing role in development, bug fixing and testing of OpenMRS is now being played...
by the international OpenMRS community [30, 31]. With the exception of AMPATH, most implementations of OpenMRS in the first five years were small, usually one or more clinics running the system on a single desktop PC. Some sites with better Internet access use an offsite web server (cloud based approach), simplifying support of the individual clinics and the sharing of data such as laboratory results and patient transfers. Most sites in low-income countries require a local copy of OpenMRS to provide good-enough performance, which necessitates stable power and information technology (IT) support, as well as a strategy for offsite data backup.

Current Status and Uses of OpenMRS at IMB

As of October 2019, OpenMRS was used in 41 MOH clinics supported by Inshuti Mu Buzima (IMB, which means Partners In Health in the Kinyarwanda language) in Eastern and Northern districts of Rwanda, covering a population of almost one million people. All sites collect HIV patient data for clinical use, analysis and reporting. This includes capturing data on intake and follow up forms and clinical flowsheets, with the help of data entry staff. Data are also collected on voluntary counseling and testing (VCT) and prevention of mother-to-child transmission (PMTCT) programs and pediatric HIV care [40]. Data are used for a range of purposes including:

- Supporting clinical care through printed patient consult sheets and direct lookup of patient records by clinicians
- Creating reports to MOH and funders
- Clinical research on HIV care
- Assistance with forecasting medication requirements

In addition to HIV care, OpenMRS is used to support the care of heart failure and diabetes patients in many sites.

Current Status and Uses of the System at the MOH

After observing the OpenMRS implementation in IMB sites, in 2009 the MOH decided to initiate a rollout of the system to several hundred clinics in mostly rural areas of the country. With support from the Global Fund to Fight AIDS, Tuberculosis and Malaria (GFATM) and International Development Research Centre of Canada (IDRC), the MOH hired seven Rwandan programmers who had graduated from a PIH/IMB run training program. The initial clinical focus was for HIV and primary care. They then started to customize the systems to support new functions for pharmacy and supply chain management, laboratory data management, billing and reporting. OpenMRS was set up in four initial sites in 2010 and then the rollout was scaled up in 2011. Today more than 350 clinics have been running OpenMRS for five years or more, and new modules are being added for billing and to collect data on NCDs.

Informatics-Related Issues Faced and Challenges Overcome during Implementation

OpenMRS hardware requirements are simple; the basic version can be downloaded from the OpenMRS web site and run on a basic PC. There are several key challenges in getting the system running smoothly, which are very similar to those described for Malawi. Unstable power can be very disruptive, especially if clinicians rely on the system being available during clinics. Smaller clinics in Rwanda supported by PIH use laptop computers as servers, providing several hours of running time and ensuring that the system shuts down safely. Lack of Internet connectivity makes supporting OpenMRS more difficult and prevents use of one central server to share data. Initially IMB provided satellite internet access to clinics and hospitals, which can greatly simplify the rollout and support of information systems, but this connection was
expensive and variable in quality. More recently, the cellular phone 3G network has been used to link clinics to a central server in Rwinkwavu hospital over a virtual private network. However, this connection is usually too slow to allow direct web-based access to the OpenMRS server, so a module was created that allows data to be synchronized between instances of OpenMRS and a central server over an intermittent connection. This has greatly improved the performance of OpenMRS in remote clinics, allows clinical reporting across all sites in a district, facilitates pushing laboratory results out to clinics, allows lookup of records for patients transferring between clinics in the district (reducing duplicate records), and provides an automatic offsite data backup. The main disadvantage is that synchronization requires more technical support than a standard installation; a new version is currently being developed by OpenMRS for general use.

Improving Reporting Tools

Reporting and data use are core functions of OpenMRS, whether for clinical care, program management, or research. The flexibility and power of the OpenMRS concept dictionary comes at the price of making certain types of data export and analysis more difficult than simple relational database designs. A number of different reporting tools have been developed over the past five years to address these challenges. The OpenMRS reporting framework is the most flexible example and was partly developed in Rwanda with support from the Rockefeller Foundation. It is used extensively at IMB and increasingly at the MOH. Improving the flexibility of this framework and simplifying its use by non-programmers remains a priority. OpenMRS data is increasingly used for research studies, such as analysis of HIV care outcomes at IMB and the MOH, The IEDEA project (sharing data on clinical outcomes between countries), and a large clinical epidemiology study in Peru [41].

Capacity Building and the EHSDI Training Program

Finding Rwandan programmers with good Java programming skills proved to be very difficult. In 2008, with support from the IDRC, PIH set up a training program for programmers to obtain hands-on skills in enterprise Java programming and OpenMRS development [42]. A total of 34 programmers graduated over the three years to 2011. Many graduates continue to work with the MOH, IMB, and in other counties developing and implementing OpenMRS.

The Future for the System

The initial use of OpenMRS in resource poor environments nearly always involved clinicians collecting data on paper forms that were later transcribed by data entry staff. Outputs were usually in the form of printed patient summaries, consultation sheets and reports. As in Malawi, clinicians at IMB-supported sites were keen to access clinical data directly to ensure that they had the most up to date clinical findings, laboratory results and drug regimens. This required the addition of a clinical summary for HIV care, and training for the clinicians on searching for patient records. It also required upgrading the infrastructure and IT hardware to ensure that systems were available consistently on clinic days. These improvements were made possible by a grant from the US Centers for Disease Control and Prevention (CDC). These “point of care” versions of OpenMRS are being piloted or rolled out in 2019 in countries such as Kenya, Mozambique, Nigeria, and Uganda with widespread scale up expected in the next two years.

Supporting a Broader Range of Diseases

Most of the initial implementations of OpenMRS were designed to support HIV care, with many also covering TB co-infection. Adding the capa-
bility to manage new clinical areas can be as simple as adding one or more forms and reports and a patient summary. However, for more complex care processes, particularly if healthcare staff use the system directly, more extensive customization and programming may be required. The first example of this was OpenMRS-TB, designed to support the care of Multi-Drug Resistant TB (MDR-TB). It included custom tools for managing and viewing laboratory and medication data, a variety of WHO specified reports, and a custom timeline for visualizing the whole treatment process [43]. Similar customization was carried out by IMB in 2012 to support the care of oncology patients in Rwanda, and this system has been supporting oncology care there, including prescription of chemotherapy, since then. Programming was required to support patient registration and management of bar coded ID cards, as well as capturing clinical diagnoses and problems. An additional challenge is to program these clinical components as generalizable modules that can be reused worldwide, which requires substantially more investment in design, programming and testing than simply customizing the system for one site.

The Rwanda Health Information Exchange Project and Open Health Information Exchange

In 2010, the Rwanda eHealth Enterprise Architecture Project was started as a collaboration between the MOH, Jembi Health Systems in South Africa, the Regenstrief Institute in Indiana, IDRC, the Rockefeller Foundation, and the PEPFAR program. The goals of this project were to create an overarching plan for all eHealth systems in the country, with clear specifications of their functions and use of medical data standards and tools to ensure interoperability. Beginning in 2012, a pilot project was carried out in the Rwamagana district in the south east of the country to support maternal health care. Data were collected by clinic and hospital based staff using OpenMRS, as well as community healthcare workers using mobile phones and text messaging with RapidSMS software. An instance of OpenMRS was installed on a server in the Rwanda national data center to function as a shared health record, combining data from local OpenMRS installations as well as from RapidSMS. Three national registries provided shared lists of patients, providers and facilities, along with a terminology server. An additional project used a prototype data standard called SDMX-HD to send reports from OpenMRS to a web based national reporting system called TRACnet.

This pilot project illustrated the need to plan for and overcome the many technical, sociopolitical, and capacity development challenges that accompany this type of initiative [44]. Health information systems, particularly in low-income settings, generally operate independently, resulting in disaggregated information in different locations and formats. This leads to lack of data harmonization; barriers to share knowledge and collaborate in an individual’s care; and inability for healthcare staff to fully understand the breadth of an individual’s health history. Health system managers and public health staff lack the ability to make inferences from these data for M&E purposes. Clinical personnel can be forced to make important decisions without access to all the key health information [44]. Recognizing the importance of effective tools to share clinical data, several funding organizations and NGOs came together to develop common, open sources tools and applications to allow interoperability between EHRs like OpenMRS, other hospital and clinic based applications including laboratory information systems, pharmacy systems, radiology systems and national health data reporting systems like DHIS2 (see below) [43]. These lessons helped lay the foundations for the Open Health Information Exchange project (OpenHIE) that is increasingly being adopted in many low- and middle-income countries.
In addition many mobile health (mHealth) systems interoperate through open standards with EHRs and DHIS2, with or without HIE components.

Successful health data exchange that includes electronic capture of individual patient data is crucial to managing population health and tracking disease outbreaks. Older approaches that collect data from paper records to enter into public health systems such as DHIS2 frequently lead to incomplete, inaccurate, and delayed data [45].

Hospital Information Systems Based on OpenMRS

In addition to supporting clinics with OpenMRS, the Rwanda MOH was interested in supporting the data needs of district hospitals. Starting with a government run hospital in Kigali they implemented tools for management of patients in a range of clinical services. These included modules for:

- patient registration system (described above)
- medication prescribing, dispensing and inventory
- laboratory orders and results
- capturing diagnoses and problem lists
- forms for a range of clinical services

At that time, the broader OpenMRS community started to work on direct use of the EHR by clinical staff in hospitals, with a particular focus on a new teaching hospital at Mirebalais in Haiti built by PIH. The Mirebalais version included a new user interface; support for ordering and viewing imaging studies; a triage system for emergency department patients; and support for primary care registration and diagnosis tracking, maternal child health and surgery. Other countries have adopted this “reference application,” or an executable example of learned best practices. An OpenMRS partner organization, Thoughtworks Inc., developed a hospital-based version of OpenMRS for the JSS hospital system in India. This incorporated an updated user interface, a laboratory information system (OpenELIS), an Enterprise Resource Management system (Odoo), and a radiology PACS system (dcm4che)—all open source software. This combined system is called Bahmni [46]. It is used in several projects, including national rollouts in Bangladesh, and in Mozambique, as the basis for a new EHR for MDR-TB, and for some hospitals supported by Medicines San Frontiers, such as a surgical reconstruction hospital in Amman, Jordan.

Broader International Rollouts Based on Rwanda Experience

Rwanda and Kenya have been the main sites for much of the early development and implementation of OpenMRS. Rwanda’s contributions include the first use of OpenMRS on Linux and the first deployments of many core modules, including HTML form entry, the reporting framework and data synchronization. Other key initiatives have been to enable direct clinician viewing of patient summaries (a prelude to point of care systems), and the implementation of patient registration with bar coded IDs (building on the experience from Malawi). The MOH team pioneered work on a broader national rollout of OpenMRS to over 350 health centers and hospitals, with the initial use in hospitals. There is now a large and growing international community developing and implementing OpenMRS. More than 65 countries are currently using OpenMRS clinically, and many are carrying out development of new modules or contributing to improving the core system. The Kenyan MOH rolled out OpenMRS to 350 rural clinics, building on the experience in Rwanda and with help from programmers at PIH. The reference application forms the basis for an EHR system being used for a national roll out in Uganda to 1000 clinics, which was completed in 2019.

Evaluation Studies of OpenMRS

As the use of OpenMRS has grown in Rwanda, there has been increasing interest in evaluating
the systems and assessing what benefits this investment has brought to the health system. A key requirement in the management of HIV is access to CD4 counts, which indicate the status of the patient’s immune system. At IMB in 2009, it was found that many CD4 counts in patients’ charts were out-of-date. Amoroso and colleagues studied the impact of adding a module to OpenMRS to allow direct entry of CD4 counts in the laboratory [47]. The findings showed the number of CD4 counts that were out-of-date decreased from 25.7% to 16.7% ($p < 0.002$).

Were, et al. [48] in Kenya studied the impact of giving clinicians access to printed clinical summaries from OpenMRS, containing advice on seven clinical actions needed for pediatric patients, including PCR testing for HIV antigen, routine blood investigations, starting ARV treatment and referring malnourished children for nutritional evaluation and support. In a randomized controlled trial in a pediatric clinic at Moi University in Kenya, they showed that clinical staff (mainly nurses) increased their compliance with tasks from 18% to 68%.

As OpenMRS is rolled out to hundreds of sites with often poor infrastructure, it is particularly important to be able to track the performance of the system including down time, daily use of the system, and completeness of key variables. A server monitoring tool (SMT) has been developed to track these variables and transmit them to a DHIS2 instance. In Rwanda a large-scale evaluation of OpenMRS is being carried out, testing the effects of adding clinical decision support tools to improve HIV care. This includes an evaluation process including a user survey, a data quality assessment, key informant interviews, and analysis of data from the SMT. In addition, a costing study is being conducted on the development, deployment, and support of the enhancements to the EHR. A randomized control trial examining the impact of the enhanced decision support tools on clinical care is underway.

Initial results from this study include a survey of 90 users in 54 sites (half clinicians, half technical staff). This showed evidence that users are generally satisfied with the EHR usability and functions, with most using it for clinical activities and reporting. They were generally satisfied with the training they received, but in free-text comments, 81% requested more training. The EHR system was generally perceived as stable, with 81% saying grid power was available “Always/Almost Always” or “Most of the Occasions”, but only 75% had those responses on the question “How often can you count on EHR to be up and available?” with 7% of responses “seldom” or “never/almost never”.

Availability of backup generators was “never/almost never” 59% of the time, and availability of mobile Internet was relatively low. In intervention sites with the enhanced EHR package, users said that they made more use of certain clinical functionality, particularly decision support tools ($P = 0.0127$). Compared to technical staff, clinicians were significantly less likely to carry out certain tasks with the EHR, such as “creating new patient records”, “updating existing patient records”, “viewing laboratory results”, “following test results over time”, or “generating adhoc reports”. Although users were generally confident in using the system, 78% expressed concern about making errors.

**Future Plans**

Going forward, top priorities are to simplify the setup of OpenMRS in new projects, improve the user interface and workflow, and provide reusable tools for managing a full range of diseases. Improvement of interoperability, including support for data exchange standards like FHIR [49] and the open modular format for EHRs—SMART [50], are currently underway. The core goal will continue to be the use of data from OpenMRS for clinical care, program management, forecasting of supplies and clinical research. Work is currently underway to create tools for screening and management of COVID-19 with early deployment in Kenya and Nepal.

Rwanda has played a critical role in the development and evaluation of OpenMRS. The software developed for the projects there and the lessons learned are informing many projects around the world, enabling decisions on whether or not to use the OpenMRS software.
Other Key Health Information Systems in LMICs

While EHRs play a central role in clinical data collection and management in LMIC, several other applications fill key roles in collection, storage, analysis and management of health data and have important roles in public health. These systems focus on crucial clinical and prevention services tasks and requirements as described below.

The District Health Information System (DHIS2)

DHIS2 grew out of a project to support data collection in health districts in South Africa in 1994. This open-source software platform was updated into a web-based system in 2007 allowing data entered at remote sites to be transmitted to a central system typically located in a capital city. DHIS2 is primarily designed to accept aggregate data equivalent to a report, for example, detailing the status of HIV patients receiving care from a specific clinic each month. It contains a variety of analysis and data visualization tools including GIS mapping tools [23, 51]. Data are often entered directly into digital forms in DHIS2 where Internet connectivity is available, with the indicators calculated either by hand from paper records or as a report from an EHR or similar data collection and reporting system. A range of approaches to automatically upload this data from OpenMRS to DHIS2 have been developed, starting with a project in Sierra Leon in 2010. Currently a WHO supported standard, ADF, is used. There is also functionality in DHIS2 for collecting individual patient level data. An internal module within DHIS2 called “Tracker” has the ability to collect, store, analyze and aggregate individual patient data within its own sub-application separate from the aggregate, indicator data normally associated with DHIS2. This approach overlaps with EHR systems, although it is generally used for public health and disease surveillance purposes such as tracking patients during the Ebola outbreak in West Africa and the COVID-19 pandemic, or for use in HIV Case Surveillance system for tracking HIV positive patients from time of positive test result to death. DHIS2 and its sub-module, Tracker, can accept data input direct from mHealth systems.

CommCare

CommCare is a mHealth application designed to support community health care workers in patient management tasks [52]. Functionality includes alerts and reminders for activities of patient care and the ability to synchronize the data to other medical information systems such as OpenMRS and DHIS2. CommCare is used in over 350 countries for a range of medical tasks including clinical care of pregnant women and children, vaccination programs, improving diagnosis of childhood diseases, supporting supply chains for medication, and for tracking COVID-19, non-medical tasks such as improving agriculture [52]. Data can be collected offline and synchronized to a central server when connectivity is available. It is a commercial application with a monthly or annual fee but with open source versions.

Open Data Kit

Open Data Kit (ODK) is a mHealth application widely used for collecting and managing healthcare data [53]. Like CommCare, it can interoperate with OpenMRS and DHIS2 and can function online or offline. It differs in being fully open source and supported by a community of programmers. It is highly adaptable for a range of uses, including public health applications for Ebola, HIV care and community data collection.

The Range of mHealth Applications

Figure 25.1 shows 12 key areas of functionality for mHealth and other health informatics applica-
The key areas cover patient care, direct patient use, management, finance and supply chain activities. Over the last decade use of mHealth has grown rapidly. With offline functionality, even very remote populations are now accessible. In addition, the sophistication of applications has grown with low cost smart phones and improved applications and workflow. There is increasing evidence of positive impacts of some applications, such as reminders for ANC appointments [55], advice to health care workers for the treatment of malaria [56], reminders to patients to take antiretroviral medications [57, 58], and tools to manage medication supply chains [59]. A new generation of applications are offering sophisticated diagnostic tools [60], and one example uses simple ultrasonic devices linked to mHealth applications used to screen fetal heart rate traces in rural Guatemala [61].

Tools for screening and management of mental health disorders are showing increasing effectiveness and are likely to see increasing use over the next decade [62].

**Summary**

The OpenMRS EHR and several other HIS, mostly open source, are transforming the care of chronic diseases including HIV, MDR-TB, non-communicable diseases and oncology in low-resource countries. Moving from pilots and small-scale projects a decade ago, they are now scaling to regional and national levels. Local leadership and control are important factors in many projects, allowing better user input and national ownership. These systems include OpenMRS, DHIS2, and systems for lab and pharmacy/supply chain management. Mobile health projects have also grown rapidly over the last decade and are now transforming many aspects of care, including supply chains, effective medication prescribing, reminders for patients, diagnosis, and mental health screening and management. Initiatives to support improved data quality, better user interfaces and interoperability are making progress, and promise more usable and comprehensive tools for clinicians, community healthcare
workers, and patients. An initial evidence base is being created but more studies are required to fine tune systems and assess the appropriate tools for widespread use.

**Future Directions**

The growth of global health informatics is continuing. Policies and funding are shaping the course of global health informatics as the field seeks to better understand the impact that solutions have on health outcomes of the medically underserved. For global health informatics, use of an approach that is both “top-down” (starting from the larger system and breaking it down to the smaller segments) and “bottom-up” (piecing together of the smaller segments to build the larger system) is advocated. Working in global health informatics requires an implicit recognition that the differences in countries’ characteristics, health challenges, and priorities have a direct bearing on how information systems should be developed and used. When developing health information systems in low-income, resource-constrained environments, simple, focused solutions can work well in specific sites but are usually of limited general value. More comprehensive and adaptable informatics solutions are necessary to scale to multiples sites, multiple diseases, and large numbers of patients. Keeping a focus on the clinical and programmatic needs, rather than the technology, is essential to achieve better acceptance, adoption and sustainability. Remembering that practical things do count—such as stable power, printer repair, and even paper—leads to success when deploying a system in the field. Building local expertise in system development and maintenance is necessary for on-going success and system sustainability.

Determining the value added that the users will gain from the system, and then creating a system that provides the benefit is critical. Interoperability between systems is necessary to be able to provide comprehensive patient care and conduct accurate disease surveillance, and is increasingly supported by established solutions like OpenMRS and DHIS2. Monitoring and evaluation of the performance, cost, and impact of systems is essential to allow resource and policy decisions based on data. The world of health information and technology is a rapidly changing place. Several systems that were still being piloted or scaled up five years ago are now established national solutions in many countries. Exciting opportunities exist in keeping pace with that change and discovering new informatics solutions to provide health for all.

**Review Questions**

1. There are many different ways to view the discipline of global health informatics. What are some of the defining attributes that set it apart from other informatics disciplines?
2. Describe three challenges to operationalizing electronic information systems designed to support patient care in low-resource settings and what may be done to overcome these challenges.
3. In developing the electronic medical record system to support HIV care and treatment, a point-of-care solution was selected over a paper-based data collection system with retrospective data entry. What was the rationale for this decision?
4. How can the benefits of creating a common database of patients be achieved when clinic sites have unreliable network connections?
5. When might mHealth tools be appropriate to apply?

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