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E-Health in Low to Middle Income Countries

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Introduction

Electronic health (e-health or eHealth) is often defined as healthcare practices supported by electronic processes and communication [1], and includes mHealth, which is turn is often defined as the practice of medicine and public health supported by mobile devices [2]. However, definitions vary, and include many other areas of computer science and engineer (such as informatics, cyber security, cloud computing and human computer interaction) as well as medicine, public health, anthropology and even public policy. A study in 2005 found 51 unique definitions for e-health alone [3].

Limited funding for medical technology, low levels of education and poor infrastructure for delivering and maintaining technology severely limit medical decision support and medical diagnostics in Low to Middle Income Countries (LMICs) [4]–[6]. However, the rapidly increasing coverage of smart mobile devices, not only in developed regions of the world, but also in the world's rural communities and LMICs have spurred the development of mHealth solutions [7]. Despite the enormous potential for leap frog dynamics in healthcare, mHealth technologies have only seen very limited success, as reported in scientific literature [8]. Key challenges for mHealth solutions in lower resource environments include not only cost, but also the socio-cultural context and the formal or informal healthcare systems in place. It has been highlighted that, for a successful implementation of mHealth initiatives, their integration into the existing infrastructure, supporting and complementing resources available is crucial [9]. This includes working with frontline community healthcare workers to ensure ownership and committed participation [10]. By far the greatest potential for big wins lies in LMICs, where oligopolistic practices, proprietary protocols, vested interests and outdated regulation is often less than in richer countries [5], [11]. Of course, there is a flipside to this issue, in that limited regulatory oversight often exists, which can lead to highly variable quality, ethical standards, and safety for medical devices, and the systems to which they are attached. Finally, the issue of scalability and financial sustainability are rarely addressed, or included in the design in the first place.

This special issue presents a collection of articles which aims to address these issues, present best practices and useful frameworks, in order to generate discussion and to move forward the field of e-health and mHealth, particularly in LMICs.

Overview of Articles in this Special Issue

The nine articles are now described in the following subsections:

1. Automated signal quality assessment of mobile phone-recorded heart sound signals

In Springer et al. [12] the authors present perhaps the lowest cost modification of a mobile phone into a medical diagnostic instrument. By attaching the hands free kit that comes with a mobile phone to a USD $0.25 metal egg cup, the create a digital stethoscope and demonstrate it can be used to collect diagnostically useful heart sound recordings for screening children for rheumatic heart disease.

The key to the success of the design was to include a signal quality metric for ensuring that a recording can be trusted and the medical worker collecting the data, who may only have a limited education, is not recording noise that an algorithm may read incorrectly, or may be useless at review time. The key point is that the most important time to ensure the quality of the data is at the time of recording so that it can be corrected in situ by the person who knows the context, and can most benefit from understanding how and why the recording was in error.

2. An mHealth Monitoring System for Traditional Birth Attendant-led Antenatal Risk Assessment in Rural Guatemala

In Stroux et al. [13] the authors take this concept a step further and introduce a self-learning mHealth framework to empower traditional birth attendants and address the issue of intra-uterine growth restriction (IUGR) with the article. Perinatal and maternal mortality is of particular concern with millions dying every year from potentially treatable conditions. The field site focus is on Guatemala, which has one of the worst maternal mortality ratios, the highest incidence of IUGR, and one of the lowest gross national incomes per capita within Latin America. To address the lack of decision support in rural Guatemala, the authors developed a smartphone- based system to include peripheral sensors, such as a $17 handheld Doppler for the identification of foetal compromise.

Designed for use by illiterate birth attendants, the system uses pictograms, audio help and guidance, on-phone and cloud processing, SMS alerts and voice calling for emergencies. The initial prototype was evaluated on 22 women in highland Guatemala and the results were fed back in to refine the system, now undergoing RCT evaluation.

The described system illustrates that a complex informatics infrastructure can successfully be developed and welded to everyday tools that require little to no training by most people for practical use. The key to the successful design included careful research into local capabilities, and cultural sensitivities (partnering with anthropologists), as well as working closely with an established streamlined NGO that has an extensive referral network. The researchers provided the key missing component - the accurate identification and transmission of medical information, as well as a novel screening technique for intra uterine growth restriction, and automated guidance for systematic health evaluation in the population.

Moreover, the researchers found that the implementation of signal analysis capabilities, such as the discrimination of maternal from foetal cardiac signal by comparing the pulse oximeter to the ultrasound measure, provided real time quality improvement and reduce false readings. In addition, user feedback throughout the intervention, such as the

acknowledgement of successful recordings, and confirmation of flags generated by the software, can further prevent unnecessary loss of data, which is rarely quantified in any meaningful manner in any eHealth setting, LMIC or otherwise.

3. Development of a Mobile Phone-Based Intervention to Improve Adherence to Secondary Prevention of Coronary Heart Disease in China

In Chen et al. [14] the authors address the key issue of treatment adherence. Despite many years and thousands of studies, very little progress has taken place in this problem and SMS reminder based studies still dominate, despite the lack of evidence for any hard end points beyond appointment uptake.

Chen et al. attempt to address this issue using a multifaceted approach in a coronary heart disease (CHD) population. Their study is the first of its kind to target both providers and patients using a comprehensive mHealth intervention to improve the secondary prevention of CHD. The mHealth intervention tools included three key elements: (1) an Android based bilingual user- friendly physician app, (2) a bank of 60 evidence-based patient-directed physician-validated text messages and (3) a system integrating the mobile app and SMS/ voice call system to enable the automatic sending of messages. The associated study has been designed to fill a key gap in the evidence on the efficacy of mHealth interventions in improving secondary prevention to CHD by increasing prescription of and adherence to evidence-based medications as well as facilitation of lifestyle changes among patients with CHD.

4. Designing a Ruggedization Lab to Characterize Materials for Harsh Environments

One of most important factors that determine success of products is their ruggedness and suitability for the target environment. All too often a system fails because of poor connectors, and (often proprietary) replacement parts are hard to source or prohibitively expensive in low resource and remote regions.

As Frazzette et al. [15] point out, despite this fact, ruggedness is a critically under-tested facet of most medical devices. Ensuring functionality and durability in these harsh conditions is especially relevant for products in LMICs where localised climates are often more extreme. Therefore, a materials characterisation core facility is needed to test various physical properties related to operating conditions relevant to the product. The authors identify the most relevant testing parameters for LMICs as: (1) dust ingress, (2) water ingress, (3) humidity exposure, (4) high temperature and heat exposure, (5) sunlight and ultraviolet light exposure, (6) vibration, (7) normal stress or pressure exposure, (8) torsional stress or sheering exposure, (9) shock from dropping, (10) mechanical fatigue and (11) scratching.

The authors point out that the product characterisation and ruggedisation processes requires specific expertise and resources that are seldom available outside of large corporations and elite national research labs. There is often no standardised process since product needs strongly depend on the context and user base, making it particularly onerous for underfunded start-ups and academic groups. Standardised protocols that identify essential

lab testing regimens for specific contexts and user groups can complement field-testing and accelerate the product development process while reducing costs.

A framework which addresses these issues is then proposed, which synthesises current methods and strategies for product testing employed by large corporations as well as defence-related entities. A technological and organisational framework for a service-for-fee product characterisation and ruggedisation lab that reduces costs and shortens the timespan from product invention to commercial launch in harsh settings is then described.

In the absence of strong leadership and open standards / regulation, there is clearly a need for such a framework. However, long term trust in a product is also important in an environment where the user has perhaps not entered the western disposable culture and is still highly circumspect when it comes to key purchases. Applying best practices such as those described here, should help lead the way into creating the level of trust both national and international actors may have in an LMIC product. Japan's and more recently Taiwan's electronics industry is perhaps the best example of this, and may provide an example of how counties can significantly boost their economy.

5. The Hackathon Model to Spur Innovation around Global mHealth

Hackathons have often been criticized as hiring pools for companies which generate few, if any, real solutions. There are isolated examples of successes, but in general, they are considered a poor second to well thought out competitions run over several months.

In Angelidis et al. [16] the authors describe an innovative and focused variant of the hackathon, hosted at the Institute for Medical Engineering and Science at the Massachusetts Institute of Technology. Over the past several years, the authors and colleagues have developed a model of organising mobile health boot camp and hackathon events at MIT and simultaneously in other countries, including LMICs, with the goal of encouraging increased collaboration between information and communication technology and medical professionals, and leveraging the growing prevalence of cell phones to provide health solutions in resource limited settings. Most recently, these events have been based in Colombia, Uganda, Greece and Mexico. The lessons learned from these events are described in order to provide a framework for rapid prototyping sessions for health solutions in the developing world.

The authors point out that measuring the output and impact of hackathons is hard, and product commercialisation has not been their focus for several reasons. They quote a recent study from Harvard Business School which found that 95% of start-ups between 2000 and 2010 failed to see the projected return on investment. Moreover, start-ups in the healthcare arena tend to address low-hanging fruits; any potential benefit is trumped by much bigger issues in the rest of the healthcare value chain. Better clinical outcomes, the objective of every healthcare start-up if it were to succeed, almost always requires a multi-pronged, inter-disciplinary, collaborative approach, which often runs counter to the entrepreneurial spirit. They point out that hackers need to understand better the systems-level issues in healthcare delivery if they are to create sustainable and scalable solutions, and avoid naive solutions that "reinvent the flat tire". They go on to point out that perhaps more important than mobile

health applications, systems-level innovations are needed. While incredible advances have been made in health “gadgets”, like low- cost point-of-care diagnostics, or wireless monitors, what remains to be developed are innovations that will integrate these components into health systems in a manner that can be brought to scale. As Angelisis and co-authors point out, perhaps most importantly, beyond the potential impact hackathons may have through the solutions they sometimes generate, they provide learning experiences that promote content mastery, development of technical and thinking skills, and creation of supportive professional and social networks. They have been championed as a powerful new pedagogy, able to provide students opportunities to learn and solve problems in authentic contexts, using twenty-first century skills and technologies, and to break down walls between classrooms, peers, role models and mentors. Despite this, there is little evidence for this because systematic approaches to hackathons rarely exist. The authors therefore propose to “Hack the Hackathon” by partnering with education organisations such as the MIT Teaching Systems Lab, which has experience in evaluating education programmes for quality improvement in order to define and refine their approach to capacity building. Sustained effort and continued rethinking of the hackathon may well produce the results so very much needed in healthcare.

6. Value Propositions of mHealth Projects

The majority of mHealth initiatives never proceed beyond the pilot stage. In Gorski et al. [17] the authors address this issue by analysing the downstream value proposition and attempting to design from the customers’ perspective to address their specific problems and/or create appreciable value. The authors suggest that a customer-centric view, where direct tangible benefits of interventions are identified and communicated effectively, can drive customer engagement and advance projects toward self-sustaining business models. Their article reviews the business models of 234 mHealth projects to identify nine distinct value propositions that solve specific problems for customers. Each of these value propositions is discussed with real-world examples, analyses of their design approaches and business strategies, and common enablers as well as hurdles to surviving past the pilot stage. The authors then perform a deeper analysis of 42 mHealth ventures that have achieved self-sustainability through project revenue. In doing so they provide practical and important insights into the design of mHealth enabled systems that may address long term healthcare challenges.

7. Leveraging design thinking to build sustainable mobile health systems

In Eckman et al. [18] the authors apply design thinking principles to assess the feasibility of novel mHealth projects during early conceptualisation. With roots in participatory processes and self-determined pathways, design thinking provides a compelling framework to understand and apply the needs of diverse stakeholders to mHealth project development through a highly iterative process.

Eckman and colleagues begin by summarising common failure modes including financing, sustainable and validated revenue models, failure to validate technology, omission of adequate training, poor employee management, lack of trained professionals (particularly in medicine), lack of a proper incentive structure leading to high rates of employee turnover,

lack of social and cultural context of their target region and failure to adequately engage the community, resulting in a lack of trust with the target customer base. The authors then go on to describe how many of the failure modes identified could be avoided through the application of design thinking principles. The authors point out that for mHealth ventures to be successful in the long term, patients or end-users must be considered customers with specific needs, preferences and rational or irrational leanings. Human-centred design incorporates insights from the end-user and other critical stakeholders into every aspect of the design process and captures these kinds of details in venture operations.

A conceptual framework for applying design thinking principles to mHealth ventures is presented with clear steps on how to map this out. The authors list key components of this design philosophy, including the use of community representatives, healthcare professionals, healthcare administrators, venture champions, design space, and a validation of the value proposition, together with the production of a refined business model, and a list of tasks that need to be accomplished to move the venture forward.

8. Building quality mHealth for low resource settings

Ettinger et al. [19] describe a project focused on developing a high-quality diagnostic tool for community healthcare workers (CHCW) in LMICs. They applied human-centred design (HCD) methods in the development process to improve the usability and the likelihood of adoption of the technology. Since standards, regulations and their enforcement are generally lax or missing in many LMICs, the authors also used a bioethics consultant who addressed four aspects of health care ethics: (1) privacy, quality, reliability and safety of the technology (2) research with human subjects (3) clinical ethics issues arising from the technology (4) social justice implications with inclusive innovation considerations At the time of the study, there were no health care ethics frameworks or assessments for mHealth apps targeting LMIC and so the authors developed a framework to consider the ethical implications of an mHealth app. The framework delineates five key points: Privacy, Quality, Reliability, Safety and Transparency. Although sustainability and affordability were not addressed explicitly in this framework, they are also key ethical considerations.

The authors concluded by finding that the bioethics consultation prompted early consideration of safety concerns, social implications of our mHealth app and our technology’s impact on the CHCW-patient relationship. Moreover, they found that combining a HCD approach with bioethics consultation improved the design quality and reduced safety concerns for their mHealth app.

9. Why do Entrepreneurial mHealth Ventures in the Developing World Fail to Scale?

The final article in this special issue by Sudin et al [20] addresses the key issue of why entrepreneurial mHealth ventures in LMICs fail to scale. The authors point out that despite the strong financial, logistical and clinical support from NGOs, government ministries and private industry, the majority of telemedicine projects do not survive beyond the initial pilot phase and achieve their full potential. Sudin and colleagues review 35 entrepreneurial telemedicine and mHealth ventures, and 17 reports that analyse their operations and challenges. They then delineate multiple failure modes in order to inform the design of

sustainable and scalable telemedicine systems focused on effectively addressing the growing healthcare disparities in developing countries.

The authors conclude that mHealth ventures need to ensure they are effectively leveraging their resources in the country of operation to overcome cultural barriers that could hinder development. Even with highly sophisticated technology, telemedicine systems will never be able to scale beyond their pilot without thorough knowledge of socio-cultural dynamics and (local) business practices. In particular, they stress that practical and innovative incentive models and accountability mechanisms for all stakeholders is a vital target for the conflicting of fighting pilotitis in the developing world.

Discussions and Conclusions

This special issue has surveyed a wide range of issues from the basics of collecting data we can trust from scalable medicalised low cost instruments [12], through issues around standards, compliance [14] and cultural design considerations for low literacy populations [13], to ethical [19] and systemic economic sustainability issues [20].

I deliberately solicited articles from colleagues which covered a vast range of issues because I believe it is important to consider all these aspects when designing technological support systems for health care. Of course, engineers cannot cover all these aspects in practice, but they should co-design with the relevant experts in ethics, anthropology, business, human-computer interaction/human centred design, informatics, politics, public health, and supply chain management. Perhaps the hardest of all of these issues is the need to build an economically stable product or service. (Much of this can be said in any market or county, but it is especially true in LMICs.) In [11] I point out that there have been many worthy attempts to create healthcare products and services in LMICs, but without a supporting infrastructure of relevant supply chains and consideration of competing industries, it is almost impossible to position a company for success in LMICs. As Clayton Christensen points out in the Innovators Prescription [21], not only is a revolutionary business model needed, but also a set of mutually reinforcing business models are required for a revolution in technology (such as mHealth) to take hold. Rarely are all three issues addressed simultaneously. For example, Engineering World Health has a wonderful innovation model, but I have always thought that, putting myself in the position of a person asked to assemble and manufacture medical equipment, I would probably opt for an easier job to feed my family, especially if it had some stability to it. There is a high opportunity cost of attempting to compete in a highly litigious market, often dominated by often oligopolistic practices, with large barriers to entry in the most lucrative markets, and widespread corruption elsewhere. Why wouldn’t a rising engineer just opt for a more lucrative and safer option? More than a decade ago I helped set up a software consulting company in Bolivia (at no profit to myself), as a way to empower local skilled programmers to lead the way in self-managed, self-owned tech start-ups in this region. The company saw many early successes due to the relative cost of living, but eventually every programmer was enticed to join larger companies, such as Microsoft, which are able to offer health insurance and other key benefits. This external multinational pressure made it impossible to compete on a local level for skilled employees. Perhaps it is only governments themselves that can address this issue,

aligning incentives and providing group benefits to employees in incubator environments. Recent developments in Kenya (high speed fibre from the Middle East) Nigeria (medical incubator support) and Rwanda (national standards for healthcare records) are promising and should provide optimism, but industry needs to follow en masse into these regions.

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