An Ontology of mHealth

Full Paper

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Abstract

Amidst this rapid explosion of interest in mHealth there is absent a clear definition of the concept and its domain. We review the extant definitions of the term and present an ontology of mHealth to articulate its combinatorial complexity. The ontology parsimoniously encapsulates the logic of mHealth. It moves away from technology-based conceptualizations to a systemic one. It can be used to articulate the components and fragments which constitute mHealth using structured natural English sentences and phrases. It serves as a multi-disciplinary lens to study the topic drawing upon concepts from information systems, knowledge management, healthcare policy, and healthcare information technology. The ontology can be used to systematically map the state-of-the-research and the state-of-the-practice in mHealth, discover the gaps in research and between research and practice, and formulate a strategy to bridge the gaps.

Keywords

mHealth, mobile healthcare, ontological analysis.

Introduction

The domain of mobile health, or mHealth as it is commonly denoted, has garnered much attention in recent years as its application has come to permeate the healthcare industry. Part Moore’s law, part “smartphone” generation, the reasons for such widespread integration and use distinguish the mHealth of today from that of its past, demonstrated in practices such as MASH (Mobile Army Surgical Hospital). The concept of mobility has evolved from the physical transportation of healthcare staff and equipment to simply transporting information using modern technologies; a novel paradigm that begins in telemedicine and telehealth, giving rise to the concept of eHealth with mHealth as its subset (Nacinovich 2011). The smartphones and associated technologies represent the next stage of the evolution in ‘transporting information to transform healthcare’ (Ramaprasad et al. 2009).

There has been an explosion of research on mHealth in the last few years. The number of papers with mHealth or m-Health as a keyword in an article (published and in-press), editorial, or review in Scopus (Figure 1) since 2010 indicates the scale of this explosion. A search of other databases and documents with synonymous terms like ‘mobile health’, ‘telehealth’, and ‘telemedicine’ will likely show even sharper growth.

Amidst this rapid explosion of interest in mHealth there is absent a clear definition of the concept and its domain. Researchers and practitioners have focused selectively on different parts of the whole, neglecting the “big picture” – a theme analogous to the story of the five blind men and the elephant (Börner et al. 2003; Ramaprasad and Papagari 2009). This selectivity results in fragmentation of the research and development agenda; the sum of the parts simply falls short of making the whole. There is a need to articulate and make the combinatorial complexity of mHealth visible to facilitate both the effective design and evaluation of mHealth systems (Ramaprasad and Syn 2013a). “The current confusion in the nomenclature and classification hinder telemedicine research and implementation. Regarding research, it frustrates our efforts to reach a reasonable understanding of what we already know and what we need to know. Equally important, it impedes progress toward development and implementation of a research agenda geared toward reaching answers to questions regarding the true benefits and costs of telemedicine. Regarding implementation, the lack of clarity interferes with informed and prudent decision making by policymakers,
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With these concerns in mind, we use an ontology to visually represent the complexity of mHealth systemically and systematically. We will first review some key definitions of mHealth and then logically deconstruct the concept using an ontology. We will then describe how the ontology can be used to define the domain of mHealth, and how it can be extended, reduced, refined, and coarsened to adapt to the evolving technology and environment for healthcare. Last, we will delineate how the ontology can be used to map the state-of-the-research and the state-of-the-practice in mHealth, discover the gaps in research and between research and practice, and formulate a strategy to bridge those gaps and generate synergy – all with the goal of making the whole greater than the sum of its parts.

Definitions of mHealth

The term mHealth and its variant m-Health date back nearly twenty years, a period that has seen their definition shift within both the landscape of health technologies and the discipline to which they were applied. The definitions suggest the dimensions and elements of the mHealth domain but do not comprehensively denote the domain. We will present and discuss these definitions, and in the next section draw upon them to construct an ontology of mHealth.

Istepanian et al. (2004, p. 405) define mHealth [they spell it m-Health] as “mobile computing, medical sensor, and communications technologies for healthcare.” As the title of their article suggests, they envision it leading to “...seamless mobility and global wireless health-care connectivity.” In a more recent article they suggest the “…evolution of m-health towards targeted personalized medical systems with adaptable functionalities and compatibility with the future 4G networks.” (Istepanaian and Zhang 2012, p. 1, italics in the original) Their definition focuses on the hardware and networks driving the transition, and the potential impact on healthcare in general due to enhanced connectivity. It is a technology-based definition.

Figure 1. Explosive Growth of Documents on mHealth (Source: Scopus)
Akter et al. (2013, p. 182) define “mHealth... as the use of mobile communications such as PDAs and mobile phones for health services and information. Researchers have recently extended the definition of mHealth by focusing on any wireless technologies (e.g., Bluetooth, GSM, GPRS/3G, Wi-Fi, WiMAX) to transmit various health-related data content and services through mobile devices, including mobile phones, smartphones, PDAs, laptops and Tablet PCs.” Further, they suggest that the ubiquity of mobile phones “is a central element in the promise of the mobile platform for healthcare.” (Akter et al. 2013, p. 182) Like the previous, this definition is singularly technology-based.

The World Health Organization affirms the absence of a standardized definition of mHealth (World Health Organization 2011). It goes on to use the definition of mHealth as “medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices... [It] involves the use and capitalization on a mobile phone’s core utility of voice and short messaging service (SMS) as well as more complex functionalities and applications including general packet radio service (GPRS), third and fourth generation mobile telecommunications (3G and 4G systems), global positioning system (GPS), and Bluetooth technology.” (World Health Organization 2011, p. 6) Speciale and Freytsis (2013) use the same definition in their call to action for midwives. This definition too is primarily anchored on technology with reference to both medical and public health practice instead of healthcare in general; the two healthcare areas have different stakeholders and information management needs.

Nacinovich (2011, p. 1) defines mHealth as a subsection of eHealth. It is “the use of mobile communications for health information and services... to improve health outcomes.” This definition does not focus on the technology but on health information, services, and the outcomes the technology may enable. It complements the earlier definitions.

In contrast to the above definitions, Bashshur et al. (2011) hierarchically deconstructs mHealth (they refer to it as m-Health) as a component of the ICT (Information and Communication Technology) health domain. Within this domain they portray the progression from Telemedicine to Telehealth to eHealth (or e-Health) to mHealth (Bashshur et al. 2011, p. 486). They propose four components of the mHealth domain: clinical support, health worker support, remote data collection, and helpline (Bashshur et al. 2011, p. 489). They further suggest functionality, applications, and technology as the three basic dimensions of any telehealth (including mHealth) system. Each dimension has many components as shown in Figure 2.

![Figure 2: Dimensions of Telemedicine (Bashshur et al. 2011, p. 491)](image)

It is understandable that many of the definitions are driven by the ‘m’ for mobile technology. The technology is the catalyst. Yet the technology must be embedded in a mobile system for healthcare to be effective. These definitions do not embody a systemic view of the information system in which the technology is embedded, nor do they explicitly include the stakeholders and outcomes of the healthcare system for which it is intended. They do not capture the combinatorial complexity of the domain. The Bashshur et al. (2011) paper comes closest to doing so, but it too suffers from the type of selectivity bias that risks skewing the design of...
the system and undermining its effectiveness. Using definitions such as those illustrated, the designers and users may fail to see the ‘elephant’ – they may develop excellent technological solutions but whose effect on healthcare is unpredictable. In the next section we logically deconstruct mHealth and define its domain using an ontology.

An Ontology of mHealth

An ontology represents the conceptualization of a domain (Gruber 2008); it organizes the terminologies and taxonomies of the domain. It is an “explicit specification of a conceptualization,” (Gruber 1995, p. 908) and can be used to systematize the description of a complex system (Cimino 2006). “Our acceptance of an ontology is... similar in principle to our acceptance of a scientific theory, say a system of physics; we adopt, at least insofar as we are reasonable, the simplest conceptual scheme into which the disordered fragments of raw experience can be fitted and arranged.” (Quine 1961, p. 16) Using an ontology we hope to make the metaphorical ‘elephant’ visible.

An ontology of mHealth is shown in Figure 3. Four illustrative components of mHealth derived from the ontology are listed below the ontology, each with an example. A glossary of all the terms is given in Appendix 1. We will discuss the construction of the ontology, its dimensions, taxonomies, elements, and the components encapsulated within.

Construction of the Ontology

Our method of constructing the mHealth ontology is explained by Ramaprasad and Syn (2013a) and Ramaprasad and Syn (2013b). It was iterative amongst the authors of the paper (a physician in training and two information systems professors) and by the authors with the extent literature. The challenge was to construct an ontology which is logical, parsimonious, and complete. It had to be logical in the deconstruction of the domain, parsimonious yet complete in the representation of the domain. It had to be a closed description of the mHealth domain.

The challenge was also to adapt the information system terminology to mHealth. This was done by iterating with the literature and creating a glossary of terms (Appendix 1). In this context, we should note that the ontology presented is one of many possible ontologies of the mHealth domain. A complex domain like mHealth can be studied from many points of view, each with its own ontology. It is a ‘wicked’ (Churchman 1967) problem with many potential formulations. Each ontology can be seen as a lens by which one may study the domain – ours is one of many possible lenses.

Dimensions of the Ontology

The ontology deconstructs the domain of mHealth into three dimensions: mHealth System, Stakeholders in the healthcare system, and the Outcomes of the healthcare system. (Note: words which refer to the dimensions and sub-dimensions of the ontology are capitalized. We will also capitalize references to elements of a dimension – its categories and subcategories.) The dimensions are represented by columns or a concatenation of columns in Figure 3. The definitions of mHealth discussed earlier include these dimensions implicitly; we have explicated them in the ontology. The mHealth System is the system built around the mobile technology to manage healthcare information. The Stakeholders are those with a stake in the delivery/receipt of healthcare whose role includes the associated management of information using mobile technology. The Outcomes are the desired results of healthcare sought through the meaningful use of mobile technology for the management of healthcare information, extending the concept of meaningful use of healthcare information systems (Centers for Medicare & Medicaid Services ; Ramaprasad et al. 2014).

The ontology further deconstructs the mHealth System into three sub-dimensions: Structure, Function, and Semiotics. The Structure defines the physical and organizational objects constituting the system; the Function defines the actions of the system; and the Semiotics the information objects managed by the system. The structural/functional deconstruction is widely used in analysis of physical, biological, and logical systems. The explicit identification of the Semiotics dimension recognizes the centrality of management of the morphology, syntax, semantics, and pragmatics of information (Ramaprasad and Rai 1996) in mHealth.
An Ontology of mHealth

<table>
<thead>
<tr>
<th>Structure</th>
<th>Function</th>
<th>Semiotics</th>
<th>Stakeholder</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware</td>
<td>Acquisition</td>
<td>Data</td>
<td>Healthcare Providers</td>
<td>Efficiency</td>
</tr>
<tr>
<td>Sensors</td>
<td>Storage</td>
<td>Static</td>
<td>Physicians</td>
<td>Cost</td>
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<td>Devices</td>
<td>Encrypted</td>
<td>Streaming</td>
<td>Nurses</td>
<td>Time</td>
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<tr>
<td>Software</td>
<td>Non-Encrypted</td>
<td>Health Records</td>
<td>Pharmacists</td>
<td>Resource</td>
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<tr>
<td>Platform</td>
<td>Analysis</td>
<td>Current</td>
<td>Care Teams</td>
<td>Quality</td>
</tr>
<tr>
<td>Applications</td>
<td>Quantitative</td>
<td>Historical</td>
<td>Organizations</td>
<td>Standard</td>
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<tr>
<td>Networks</td>
<td>Qualitative</td>
<td>Knowledge</td>
<td>Government/Health</td>
<td>Accuracy</td>
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<tr>
<td>Local Wireless</td>
<td>Interpretation</td>
<td>Current</td>
<td>Agencies</td>
<td>Efficacy</td>
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<tr>
<td>Telecommunication</td>
<td>Diagnostic</td>
<td>Traditional</td>
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<td>General Population</td>
<td>Parity</td>
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<td>Manual</td>
<td>Interventional</td>
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<td>Individuals</td>
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<td>Automated</td>
<td>Application</td>
<td></td>
<td>Families/Groups</td>
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<td>Policies</td>
<td>Adoptive</td>
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<td>Communities</td>
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<td>Privacy</td>
<td>Prescriptive</td>
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<td>Local</td>
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<td>Systemic</td>
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</table>

Illustrative components:

Software for mobile interpretation of data by general population to meaningfully manage quality of healthcare.

Example: Applications for tracking/flagging health data (e.g., fitness, blood pressure, glucose, etc.).

Software for mobile application of knowledge by healthcare providers to meaningfully manage quality of healthcare.

Example: Clinical decision-support tools promoting adherence to evidence-based guidelines (e.g., e-checklist).

Networks for mobile application of knowledge by healthcare providers to meaningfully manage efficiency of healthcare.

Example: Real-time communications tools between providers (e.g., text-based, voice-based, cloud-based, etc.).

Hardware for mobile acquisition of data by healthcare providers to meaningfully manage efficiency of healthcare.

Example: Wireless Data Acquisition Module (WDAM) for continuous monitoring of patient data derived from wearable sensors.

Example: Bluetooth-embedded mobile devices for remote data transmission (vitals, GPS coordinated, etc.)

Software for mobile interpretation of health record by general population to meaningfully manage safety of healthcare.

Example: Personal Health Records (PHRs), Applications providing medical support/health information tools for general population (e.g., WebMD, MedicineNet, Healthline).

Policies for mobile application of knowledge by organizations to meaningfully manage quality of healthcare.

Example: Government regulatory control (e.g., FDA safety and innovation act), mHealth Regulatory Coalition

Processes manual for mobile deletion local of data static by healthcare providers to meaningfully manage safety in healthcare.

Example: Default expiration dates for patient data downloaded/entered/stored on mobile devices.

Figure 3: Ontology of mHealth

Each dimension is articulated by a two-level taxonomy of elements. These taxonomies can be extended by adding more elements, reduced by deleting elements, refined by adding more levels, and coarsened by aggregating existing levels. The elements and the number of levels in the taxonomy define the scale and granularity of the dimension.
mHealth System – Structure

The first-level taxonomy of elements is based on the common body of knowledge in information systems (for example, Rainer and Cegielski 2011). The structure of an information system is commonly described in terms of Hardware, Software, Networks, data, Processes, people and Policies. To limit the redundancy of elements, we have excluded data and people from this level given their inclusion as fundamental components of the Stakeholder and Semiotics dimensions respectively.

The second-level elements are particular to mHealth. Thus, Sensors and Devices are the focus of mHealth Hardware; Platforms and Applications are the focus of Software; Local Wireless and Telecommunication networks are the focus of Networks; Manual and Automated processes are the focus of Processes; and, Privacy and Regulation are the focus of Policies. The five categories and the ten subcategories define the elements of Structure for performing the Functions of mHealth described next.

mHealth System – Function

We started with the commonly used taxonomy of information system Functions: acquisition, storage, retrieval, processing, and distribution. These functions are relevant to mHealth but do not fit well with the focus of mHealth in research and practice. Hence, we modified the first-level taxonomy of Functions to include: Acquisition, Storage, Analysis, Interpretation, Application, and Deletion/Erasure. The modified taxonomy overlaps with but also extends the common taxonomy.

The second-level elements are particular to mHealth, as with the second-level elements of Structure. Thus, Storage can be Encrypted or Non-Encrypted; Analysis can be Quantitative or Qualitative; Interpretation can be Diagnostic, Predictive, or Interventional; Application can be Adoptive, Prescriptive, Scholastic, or Distributive; and Deletion/Erasure can be Local or Systemic.

mHealth System – Semiotics

Here we use the variant of the traditional taxonomy of data, information, and knowledge. We substitute information with Health Records and keep Data and Knowledge. These correspond to the morphological, syntactic, and semantic levels (Ramaprasad and Rai 1996) of semiotics. It must be noted that there is no element corresponding to the pragmatic level.

The second-level elements are again customized to mHealth. Thus, Data can be Static or Streaming; Health Records can be Current or Historical; and Knowledge can be Current or Traditional.

mHealth System

The mHealth System is defined by the combination of elements from its Structure, Function, and Semiotics. It includes, for example: (a) hardware for mobile acquisition of data – possibly a smartphone; (b) software applications for mobile interpretation of health records current – possibly a decision support app; and (c) policies privacy for mobile deletion/erasure of data static – possibly policies for storing patient data on personal devices. (Note: Second-level elements are shown as subscripts.) The ontology encapsulates 90 potential first-level components of the mHealth System and 780 potential second-level components. These components constitute a complete, closed description of a mHealth System.

Stakeholder

There are three broad stakeholders in the mHealth System. They are: (a) the Healthcare Providers, (b) the healthcare Organizations, and (c) the General Population who receive healthcare. The Healthcare Providers include the Physicians, Nurses, Pharmacists, and Care Teams. The Organizations include Hospitals/Clinics, Government/Health Agencies, and Insurers. The General Population includes Individuals, Families/Groups, and Communities.

A mHealth system may cater to the selective needs of a subset of stakeholders. Continuing with the three illustrative components of a mHealth system, one may think of: (a) hardware for mobile acquisition of data for healthcare providers' physicians; (b) software applications for mobile interpretation of health records current for general population individuals; and (c) policies privacy for mobile deletion/erasure of data static for organizations.
Each of the 90 potential first-level components and the 780 potential second-level components of mHealth may be concatenated with the Stakeholder groups or subgroups to enumerate the potential requirements of mHealth for the stakeholders. It will be a very large number. In designing a mHealth system one will have to be selective.

**Outcome**

Efficiency, Quality, Safety, and Parity of healthcare are the dominant concerns of healthcare information systems, at least in the USA (Centers for Medicare & Medicaid Services; Ramaprasad et al. 2014). They define the meaningful use of healthcare information systems. It would be appropriate to seek the same outcomes for mHealth systems. Efficiency may be measured in terms of the Cost, Time, and other Resources utilized by stakeholders in the delivery of healthcare – these three components constitute the second-level elements. Quality may be measured in terms of the adherence to Standards, Accuracy of diagnosis and treatment, and the overall Efficacy of care. Extending the illustration of the three components of a mHealth system one may consider the following three components of mHealth: (a) hardware for mobile acquisition of data for healthcare providers physicians to meaningfully manage safety in healthcare; (b) software applications for mobile interpretation of health records current for general population individuals to meaningfully manage efficiency cost of healthcare; and (c) policies privacy for mobile deletion/erasure of data static for organizations hospitals/clinics to meaningfully manage quality standard of healthcare.

**Components of mHealth**

The dimensions (and sub-dimensions) of the ontology are arranged left to right with adjacent words/phrases with a purpose. The concatenation of an element from each dimension with the adjacent words/phrases creates a natural English sentence illustrating a potential component of mHealth. The concatenation has been demonstrated with the three examples carried through the discussion of the dimensions of the ontology as well as the four illustrative components with examples listed below the ontology (Figure 3).

At the most detailed level, the ontology encapsulates 67,200 potential components of mHealth. For an aggregate view, one may consider only the first-level of the taxonomies. The components and fragments (of these components) define the domain of mHealth. It would be laborious and voluminous to enumerate all the components. The ontology provides a convenient and concise ‘big picture’ of mHealth. It helps visualize the combinatorial complexity and make the ‘elephant’ visible.

It may be possible to instantiate a component in many different ways. Consider the first example above: hardware for mobile acquisition of data for healthcare providers physicians to meaningfully manage safety in healthcare. Instantiations may vary in terms of the hardware used, data acquired, and safety criterion addressed. The same logic can be extended to the other examples.

A particular mHealth system may instantiate only a small number of components encapsulated in the ontology. Further, some components may be instantiated frequently and some infrequently. We will call those frequently instantiated as ‘bright’ spots, those infrequently instantiated as ‘light’ spots, and those uninstantiated as ‘blind/blank’ spots. A component may be ‘bright’ because of its relative value to the field and/or ease of study/implementation; it may be ‘light’ due to its lack of value and/or difficulty for study/implementation; it may be ‘blind’ if it has been overlooked; or, it may be ‘blank’ due to infeasibility of study. By mapping the state-of-the-research and the state-of-the-practice onto the ontology one can discover the ‘bright’, ‘light’, and ‘blind/blank’ spots in each, thereby demonstrating deficiencies existing both between and among research and practice. Further, since the possible explanations for the luminosity of a component is equivocal, one must dig deeper to find the underlying cause. An important ‘bright’ spot would be functional but an easy one would be dysfunctional. Similarly, an unimportant ‘light’ spot may be acceptable but a difficult, highly valued ‘light’ spot may be unacceptable. Last, a ‘blind’ spot has to be investigated deeper lest it be important, and a ‘blank’ spot clearly demarcated so as not to waste one’s effort. In the next section we will discuss how the ontology can be used as a lens to study the topography of mHealth research and practice (Ramaprasad and Syn 2014).
Discussion – Ontology of mHealth as a Lens

The ontology of mHealth presented in this paper makes visible the combinatorial complexity of an emerging topic in healthcare. From amongst the many definitions of mHealth and its articulation, it follows the attempt by Bashshur et al. (2011) to develop a taxonomy of telemedicine and to locate mHealth within it. In fact, the three-dimensional model they propose (Figure 2) can be studied as a partial ontology. Our attempt seeks to include, refine, and extend the previous definitions and conceptualizations.

The ontology is logically constructed but grounded in the theory and practice of the domain. The dimensions are logically specified and not empirically generated. They are deduced from the definition of the domain. In contrast to our method, an ontology may be induced from the corpus of a domain. There are a number of automated ontology extraction tools based on linguistic extraction techniques such as Part of Speech (POS) tagging and Natural Language processing (NLP) (Alani et al. 2003). Based on the nouns and verbs in the corpus, these techniques can help develop comprehensive and detailed (with reference to the corpus) OWL-based ontologies (OWL 2 Web Ontology Language 2012), thesauruses of hierarchically arranged terms, and other ISO-based ontology exchange standards (Ahmad and Gillam 2005). The automated tools are designed for standardizing terminologies (Burton-Jones et al. 2005; Evermann and Fang 2010; Staab et al. 2004), as for example in medicine, but not to deduce semantically meaningful logical components of a domain as we seek to do. The automated tools cannot yet formulate an ontology which is (a) parsimonious as the one we propose, and (b) organized such that the domain components can be concatenated to form natural language sentences.

The logical construction of the ontology minimizes the errors of omission and commission. For example, inclusion of the Outcome dimension compels the research designer to explicitly pose the question of how a mHealth system might affect Efficiency, Quality, Safety or Parity of care. Without consideration for outcomes (error of omission), mHealth systems are unlikely to advance the field. Indeed, the ontology can help specify the precise outcomes it can achieve, instead of broadly specifying that it can improve healthcare (error of commission).

Last, the ontology is a multi-disciplinary lens. The Structure and Function dimensions are drawn from the information systems literature and refined for healthcare; the Semiotics dimension draws from the knowledge management literature and adapted to healthcare; the Stakeholder dimension is from the healthcare policy literature; and the Outcome dimension from the healthcare information technology literature. The ontology compels the user to analyze the mHealth problem and synthesize solutions by drawing upon these disciplines.

Conclusion

The proposed ontology of mHealth can advance the state-of-the-research and the state-of-the-practice in the domain. It can be used to systematically identify the ‘bright’, ‘light’, and ‘blind/blank’ spots in the two states and between the two states. The state-of-the-research can be analyzed by mapping the corpus of mHealth research onto the ontology. The mapping can be done by identifying categories within each dimension articles in the corpus fit into. An article may be mapped to one or more categories in one or more dimensions, or none at all. Such mapping will highlight the bright, light, and blind/blank spots in mHealth research. The ontological map will help researchers visualize the landscape of the mHealth domain enabling them to set appropriate research direction. Similarly, the state-of-the-practice can be analyzed by mapping mHealth systems and best practices onto the ontology. The resultant mapping will identify the focus and gaps in mHealth practice. The comparison of the ontological maps of research and practice will bring to fore the alignment between the two states, or lack thereof. The gaps between the two states should inform researcher, practitioners, and policy-makers alike the need for action to advance research and development. In other words, the ontological map can be used as a road map for mHealth research and practice. It can illuminate the ‘big picture’ of the domain.

The landscape of a domain can change over time with emerging technologies and development. The ontology-based road map can be amended to reflect the changing landscape. New categories and dimensions can be added, obsolete ones discarded, and existing ones modified. Changes can also be introduced by the shifting focus in the domain. The finer levels of dimensions and elements can be added to the ontology to reflect the greater focus on certain dimensions or categories. As an example, Hardware
Sensors can be expanded to capture the growing list of mobile sensory devices such as GPS, accelerometer, heart rate monitor, etc. On the other hand, sub-categories and -dimensions can be collapsed to echo their diminishing importance in the domain. The shifting focus and direction of research and development can be monitored by analyzing the snapshots of the ontological maps over time. The ontology can help visualize the past and present of the domain, and envisage its future. It is a future-proof road map of the mHealth domain.

Appendix 1

Glossary:
mHealth System: Mobile health system used to meaningfully manage healthcare.
Structure: The structural elements of a mHealth system -- the nouns describing the system.
  Hardware: The physical elements of the mHealth system.
    Sensors: Hardware used to measure and input a variety of data for healthcare.
    Devices: Hardware used to perform a variety of other information management functions in healthcare.
  Software: Computer programs used to manage healthcare information.
    Platform: The foundation for software such as an operating system.
    Application: Software used to perform a variety of other information management functions in healthcare.
Networks: Wired and wireless connections for transfer of information.
  Local Wireless: Wireless networks with limited range, confined to a facility.
  Telecommunication: Wired and wireless connections with virtually unlimited range.
Processes: Processes used by the stakeholders to manage information.
  Automated: Processes handled almost entirely by computers.
Policies: Stakeholder rules guiding the management of information.
  Privacy: Policies regarding privacy of information.
  Regulation: Policies regulating the management of information.
Function: The functions of the mHealth system -- the verbs describing the behavior of the system.
Acquisition: The function of obtaining information.
Storage: The function of storing information.
  Encrypted: Storing the information with encryption to limit its readability.
  Non-Encrypted: Storing the information as is, without encryption, and hence directly readable.
Analysis: Processing the information to discover relationships within.
  Quantitative: Processing of numerical information.
  Qualitative: Processing of non-numerical information.
Interpretation: Discovering the meaning of relationships within the information.
  Diagnostic: The meaning of relationships for diagnosis.
  Predictive: The meaning of relationships for prediction.
  Intervenational: The meaning of relationships for guiding intervention.
Application: The use of the interpreted information.
  Adoptive: Translating the interpretation into action.
  Prescriptive: Prescribing action based on the interpretation.
  Scholastic: Using the interpretation for study or further analysis.
  Distributive: Propagating the interpretation to others.
Deletion/Erasure: Removal of the information.
  Local: Removal of the information locally on a device.
  Systemic: Removal of the information everywhere.
Semiotics: The transformation of symbols constituting the information.
Data: The raw symbols -- numerical, textual, graphical, etc.
  Static: Time invariant data, acquired and stored.
  Streaming: Time variant data, acquired in real time.
Health Records: Organization of data to render healthcare.
  Current: Record of the current health data.
  Historical: Record of historical health data.
An Ontology of mHealth

<table>
<thead>
<tr>
<th>Knowledge: Understanding of the logic of health and healthcare.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current: Current, on-the-point knowledge about health and/or healthcare.</td>
</tr>
<tr>
<td>Traditional: Commonly accepted or evidence-based knowledge about health and/or healthcare.</td>
</tr>
<tr>
<td>Stakeholder: Entity with a stake in healthcare.</td>
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<tr>
<td>Healthcare Providers: Providers of healthcare.</td>
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<tr>
<td>Physicians: Doctors in clinics and hospitals.</td>
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<td>Nurses: Nursing staff in clinics and hospitals.</td>
</tr>
<tr>
<td>Pharmacists: Preparers/dispensers of pharmaceutical products in clinics, hospitals, and pharmacies.</td>
</tr>
<tr>
<td>Care Teams: Teams of providers.</td>
</tr>
<tr>
<td>Organizations: Organizational entities involved in the provision of healthcare.</td>
</tr>
<tr>
<td>Government/Health Agencies: Entities regulating and providing auxiliary healthcare services.</td>
</tr>
<tr>
<td>Insurers: Organizations providing insurance to healthcare recipients.</td>
</tr>
<tr>
<td>General Population: The general recipients of healthcare.</td>
</tr>
<tr>
<td>Individuals: Individual recipients of healthcare.</td>
</tr>
<tr>
<td>Families/Groups: Recipient families or collections of individuals sharing some activity, interest or quality.</td>
</tr>
<tr>
<td>Communities: Communities receiving healthcare.</td>
</tr>
<tr>
<td>Outcome: The outcomes of healthcare</td>
</tr>
<tr>
<td>Efficiency: The efficiency of healthcare delivery.</td>
</tr>
<tr>
<td>Cost: The cost efficiency of healthcare delivery.</td>
</tr>
<tr>
<td>Time: The time efficiency of healthcare delivery.</td>
</tr>
<tr>
<td>Resource: The efficiency in terms of other resources like space, people, material, etc.</td>
</tr>
<tr>
<td>Quality: The quality of healthcare.</td>
</tr>
<tr>
<td>Standard: Quality of adherence to standards.</td>
</tr>
<tr>
<td>Accuracy: The accuracy of diagnosis, treatment, etc. in healthcare.</td>
</tr>
<tr>
<td>Efficacy: The success of care.</td>
</tr>
<tr>
<td>Safety: The safety of recipients and providers of healthcare.</td>
</tr>
<tr>
<td>Parity: The parity of healthcare delivered by the providers to the recipients.</td>
</tr>
</tbody>
</table>

REFERENCES


OWL 2 Web Ontology Language. 2012.


