A Knowledge Graph to Understand Nursing Big Data: Case Example for Guidance*

Pamela Hussey PhD, MSc, MEd, RN

Subhashis Das PhD, MS

Sharon Farrell Cert PM

Lorraine Ledger MSc, BNS, RNID

Anne Spencer MSc, BA(Hons), RN

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Abstract

Purpose

To provide a summary of research on ontology development in the Centre of eIntegrated Care at Dublin City University, Ireland.

Design

Design science methods using Open Innovation 2.0.

Methods

This was a co-participatory study focusing on adoption of health informatics standards and translation of nursing knowledge to advance nursing theory through a nursing knowledge graph (NKG). In this article we outline groundwork research conducted through a focused analysis to advance structural interoperability and to inform integrated care in Ireland. We provide illustrated details on a simple example of initial research available through open access.

Findings

For this phase of development, the initial completed research is presented and discussed.

Conclusions

We conclude by promoting the use of knowledge graphs for visualization of diverse knowledge translation, which can be used as a primer to gain valuable insights into nursing interventions to inform big data science in the future.

Clinical Relevance

In line with stated global policy, the uptake and use of health informatics standards in design science within the profession of nursing is a priority. Nursing leaders should initially focus on health informatics standards relating to structural interoperability to inform development of NKGs. This will provide a robust foundation to gain valuable insights into articulating the nursing contribution in relation to the design of digital health and progress the nursing contribution to targeted data sources for the advancement of United Nations Sustainable Development Goal Three.

Introduction

Nursing engagement in big data science has been well referenced, particularly in the nursing management literature over the past 20 years. Less evident, however, is the contribution of nursing informatics leadership in primary care, and specifically methods that focus on the design science of domain-specific requirements for care delivery to support health in intellectual disability services. As a consequence of the Covid-19 pandemic, expectations and use of technology are shifting, and healthcare professionals are increasingly considered vulnerable populations (World Health Organization [WHO], **2020c**). The advancement of telehealth (e.g., to support service delivery and at-risk healthcare professionals) is now accelerating, and with this turn of events nursing informatics plays a pivotal role in addressing

core anticipated requirements for designing and expanding quality-orientated data sources (International Council of Nurses, **2020**; Spring, 2020).

Health service policy over the past 10 years has advocated strongly for engagement in universal health care and closer alignment across the United Nations Sustainable Development Goals (SDGs) WHO, **2016a**. Data collated from electronic resources that align with WHO-related policy and SDGs can provide new insights for patient-centric support, informed by timely and accurate data sources (Blobel, Lhotska, Pharow, & Sousa, **2020**; WHO, **2016b**). It is critically important that nursing as a profession understands the impact of digital resources on contemporary professional practice and thinks carefully on how it will change care delivery routines. Recent global reports by the (WHO **2020a**; ICN, **2020**; WHO, **2020c**) highlights the need for education and capacity building in technology in the profession. At the European level, advanced nurse practitioners with digital literacy skills will be required, which can contribute to a stronger digital Europe, in turn contributing to better health and better public services (DIGITALEUROPE, **2020**).

Nursing knowledge provides the scope for knitting together disparate forms of knowledge in such a way that they can be applied to address practical problems, and in so doing, nurses can attend to a wider diversity of service users' needs (ICN **2020**; ISO, **2014**). Nurses are therefore not simply a policy solution to fill in for the missing physician (Trotter, **2020**), but a key driver in planning change and delivery of future digital services. The importance of domain knowledge in the challenge of designing next generation services and systems is instrumental for future health service delivery. Generating knowledge through ontology development (Gruber, **2009**) can provide much needed content-specific details and support an open innovation methodology to formally represent specialist domain knowledge.

In this article we provide a small example on groundwork preparation to explain to readers how health informatics standards and Open Innovation 2.0 can provide much needed guidance and methodologies, respectively, to advance nursing data science. The topic is a complex one, and one that we consider best explained through case study with associated details of our experiences and related activities.

The material is presented in four sections. Firstly, we briefly introduce the context of the case with background to the center, presenting some of the current research and how it links to health informatics standards for design of domain-specific information models to inform future data science. Secondly, we outline the Open Innovation 2.0 methodology and our approach with design science methods.

Thirdly, we present initial findings on the case study through the lens of a Plan-Do-Check-Act (PDCA) research development cycle approach. We present examples of the research in sequence from both a technical and clinical perspective. For example, Figure 2 illustrates the core concepts for a service improvement clinical process map and Figure 4 illustrates an emerging nursing knowledge graph (NKG). We conclude with some discussion, insights on our progress, and final comments for future research plans.

Context of the Case

Background

The Centre for eIntegrated Care (CeIC) is an International Classification for Nursing Practice (ICNP) Research and Development Centre established at Dublin City University (ICN, **2020**). It is an interdisciplinary research center that has a core mission to advance eIntegrated care to improve the health and well-being of citizens (CeIC, **2020**). At the heart of the center and guiding research approaches are health informatics standards. In 2020 the center was funded through a Marie Curie Fellowship and the ADAPT Research Centre to support an EliteS proposal (ELITE Standards, **2020**) for leadership in advancing standardization in the European Union (ADAPT Research Team, **2020**). The program offers training and scholarship through the Marie Curie Fellowship (ELITE Standards, **2020**). Through the Nursing and Midwifery Planning Unit at Dublin North, a dedicated intellectual disability scholarship group is engaged in developing a service improvement initiative. Working in partnership with the CeIC, the scholarship group and CeIC team embarked on an innovative program to review existing information and communications technology systems and consider how health informatics standards can prepare the scholarship group to engage with digital transformation in line with

national and international policy and plans (ISO, **2019**). In the following sections we provide a summary of the core resources used to support and guide nurses on engaging in practice development activity to advance interoperability. One key resource from this research process links to an NKG. We focus on a key aspect of interoperability, structural interoperability to progress research on the NKG, which we explain further in the methodology section.

Methodology

Using an established scholarship team, the project aligns with the Open Innovation 2.0 philosophy. Open Innovation 2.0 is a new paradigm recommended by the European Union to advance innovation and shape Europe's digital future, where government, industry, academia, and civil participants work together to co-create the future and drive structural changes far beyond the scope of what any one organization or person could do alone (Curley, **2018**). Open Innovation adopts a user-oriented innovation model to take full advantage of ideas for cross-fertilization, leading to experimentation and prototyping in a real-world setting (Curley, **2018**). Contributing to system design to access shared records across and between services was a shared vision for the group that aligns with the Open Innovation 2.0 approach. To meet this goal and accelerate the vision of achieving shared care for next-generation models of health care, the challenge of tackling interoperability was explored as a core theme. Information that cannot be shared, often referred to as heterogeneous data in our services, is reported as a core barrier to achieving integrated care services (Meyer, Müller, & Kubitschke, **2014**). Heterogeneity occurs when two data sources are not expressed in the same language in a system. In this article we do not discuss the challenges of heterogeneity to advance integrated care; further reading on this topic can be accessed from Benson and Grieve (**2016**) and Blobel and colleagues (Blobel, **2018**; Blobel et al. **2019**). The focus in this article is to provide explanation through a case study on how nursing can contribute to the translation of care through development of an NKG.

Models of Use and Models of Meaning

For large-scale projects that include telehealth solutions to support big data analytics, it is generally acknowledged that there is a need to provide a platform with access to stored data for analysis in a format that allows it to be re-used and accessible across a wide range of different services (e.g., provider-to-provider or direct-to-consumer solutions). As a consequence of this process, there is a need to translate information from a model of use (MOU), often presented in paper format as a document template for admission or referral, to a model of meaning (MOM), for use in a computer or a smart device. MOUs are therefore regularly considered a key source of information for defining system requirements. The process often involves a translation or mapping process in order to present the material in a computer-readable format, which requires a different structure and format. This revised structure, called a MOM (Benson & Grieve, **2016**), is created to explicitly represent the data in such a manner as to support any future data exchange specification requirements (Oemig & Blobel, **2020**) and to support sustainable solutions for future wider access and adoption. Although the description provided above is simple, this process is complex and multifaceted and involves a number of different levels of translation layers to ensure that all of the systems devices and applications can connect and co-ordinate the retrieval of the information correctly. This involves defined terms, codes (WHO, **2020b**; SNOMED, 2020) and values for any information to be used and agreed upon by service providers. It also involves the associated systems to have agreed upon permissible information (data) to accept the information to be exchanged. To achieve interoperability to advance integrated care, research by Blobel (**2018**) and Blobel et al. (**2020**) was adapted. Seven distinct levels of development are recommended to advance interoperability, as outlined in Figure **S1**. We focus in this article on the interoperability levels that are critical to advance structural, semantic, and skills-based engagement at the individual level. We consider building capability and sharing knowledge on context-specific requirements to be the areas in which the profession of nursing needs to build capacity in order to progress competency in system design for digital health (Blobel, **2019**; Blobel & Giacomini, **2019**; Blobel & Oemig, **2016**).

Initial Case Study Findings

To provide insights to the nursing community on our approach to build capability and understand professional representation through an emerging NKG, the following steps were adopted. The PDCA action steps to identify core structural component development (9000 Store, **2020**) were used and are summarized. Figure 1 provides a high-level summary illustration of the core activity completed in the PDCA cycle.

Figure 1

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High-level view of methodology adopted. NGK = nursing knowledge graph; MOU = model of use; MOM = model of meaning.

Plan

Informing the planning stage, an initial scoping review of the evidence on interoperability and related standards from the International Organization for Standardization/Technical

Committees (ISO/TC; International Organization for Standardization, **2020a**, **2020b**) and European Committee for Standardization (**2020**) communities was conducted. Drawing on initial work conducted in 2019 was a detailed analysis completed as part of a public service initiative to inform eHealth in Ireland (eHealth Ireland, **2015**; National Standards Authority of Ireland, **2020**). A summary of specific evidence sourced on tooling and standards in use in this project is included in Table S1, with a brief description of how the project used the resource.

In line with Open Innovation 2.0 at the service-orientated level, the clinical team created a shared vision called My Life Plan in addition to a set of project plan objectives.
Figure 2 provides an example of completed planning work that demonstrates details of the clinical process maps designed to advance discussions on best approaches to instigate long-term service improvement initiatives in line with national policy.

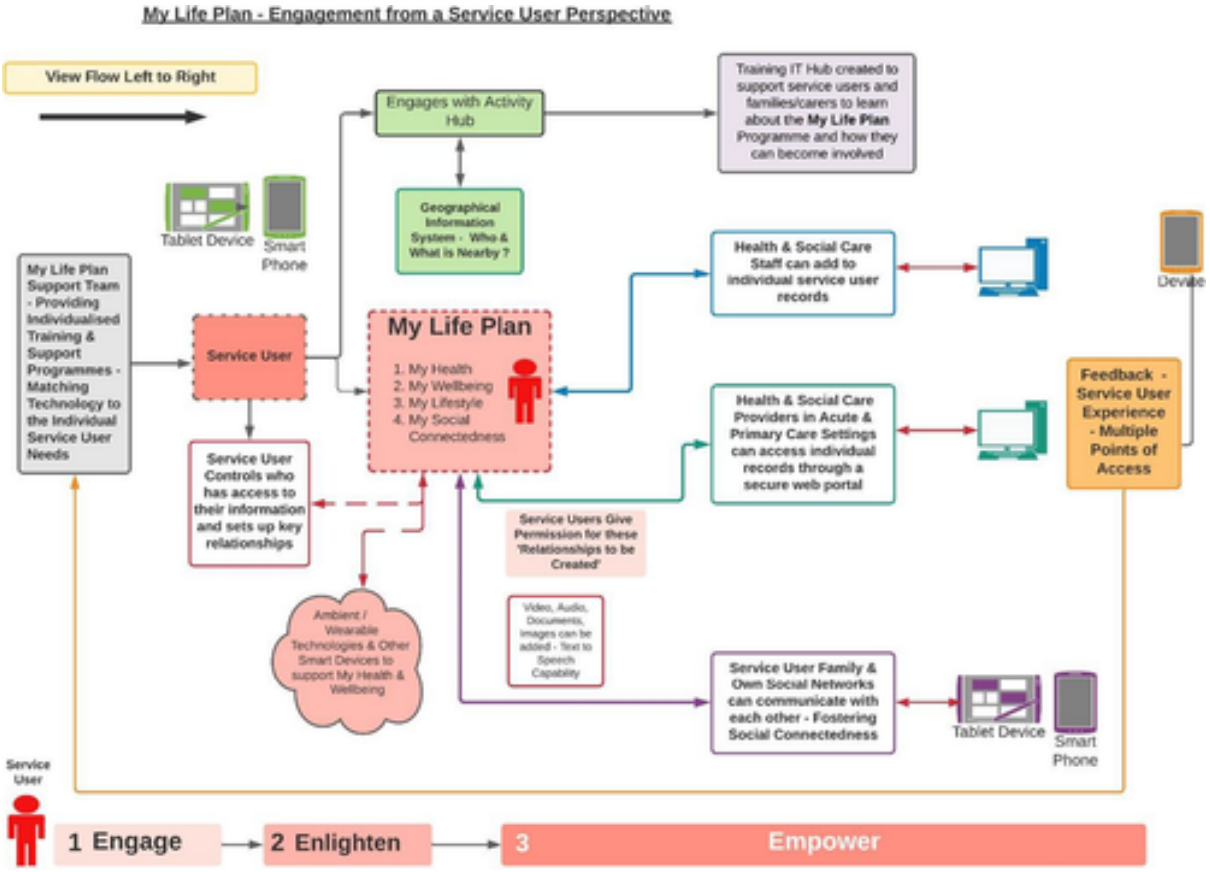

Figure 2

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My Life Plan clinical process map to inform service planning.

The clinical objective was to conduct a documentary analysis of the existing service MOUs and complete a series of focus groups on service improvement initiatives where digital resources may be useful in an intellectual disability community service.

Figure 2 provides a summary view of the overall process and daily activity of a service user in a particular residential care unit to inform service planning. Figure 3 provides a summary of the technical team's working plan and overall goal to deliver a demonstrator to the service for structural interoperability. As with the clinical team, the following objectives were defined.

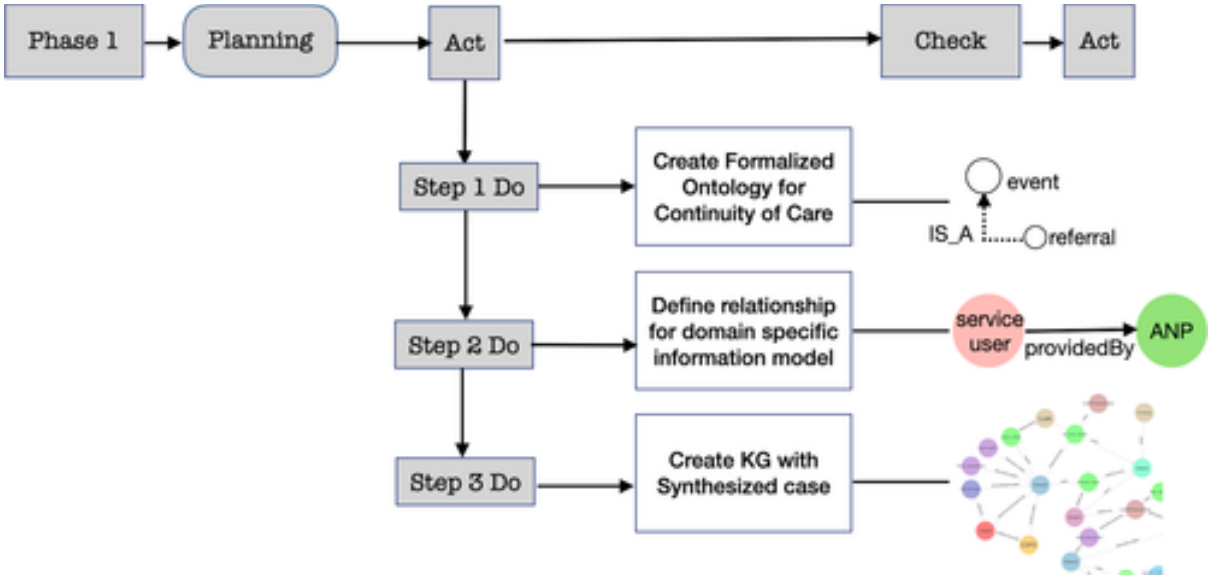

Figure 3

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Act formal information model for continuity of care record. KG = knowledge graph; ANP = advanced nurse practitioner.

The technical objective was to conduct a detailed scoping review of relevant standards for interoperability and disseminate information on progress and early demonstrators through the open science community. To achieve the technical objective, three action steps were completed as follows: (a) create a formalized ontology for continuity of care ISO, (**2015**); (b) create a domain-specific information model; and (c) develop a synthesized case study to illustrate a simple knowledge graph. Key deliverables from the plan action steps include Table 1 and Figure 3.

Table 1. Supporting Information Standards and Tooling

Standards and techniques	Category	Framework development utility.
ISO/DTR 22272	Enterprise	Used to define business mission aims and objectives, conceptual model, and capacity building.
Contsys ISO 13940:2015 https://contsys.org	Computer	Overarching ontology framework designed in OWL as a formalized web ontology (published on May 2020). https://contsys.org/pages/Guest%20blog/FormalOntology
HL7 FHIR v.4 https://hl7.org/FHIR/	Computer	Used to specify observation, medication statement, medication administration, medication diagnostic report, patient.
EHRcom ISO 13606:2019	Engineering	Reviewed in terms of harmonization of HI standards to describe distribution of objects and applications across platforms
IHE CCR https://www.astm.org/Standards/E2369.htm	Information	Provides a patient health summary standard that facilitates timely and focused transmission of information across and between health professionals involved in the delivery of patient care.

Standards and techniques	Category	Framework development utility.
SNOMED International ICNP	Information	Formalized reference terminologies used for semantic mapping of concepts in healthcare systems.
Protégé **https://protege.stanford.edu**	Engineering	A free, open-source ontology editor and framework for building intelligent systems.
Karma **https://usc-isi-i2.github.io/karma/**	Engineering	Data integration tools and aligning with interoperability level 1 technical automation. Semi-automation of semantic mapping is important so that the semantic detail used is approved and validated by nurses.
GraphDB **http://graphdb.ontotext.com**	Engineering	Used as a specification with common functions providing a technology-neutral architectural framework and database support.

Do

On completion of the focused discussion and the defined process maps agreement, the research commenced with the development of a case study to act as a demonstrator. The case study could be used as an example of how the NKG could represent core nursing-related healthcare activity; in the midst of the Covid-19 pandemic, face-to-face meetings with clinical service staff were minimized. In the selected case study we illustrate how the health information can be linked for review using the NKG structure to demonstrate relationships for a person by role, event, and location (Figure 4).

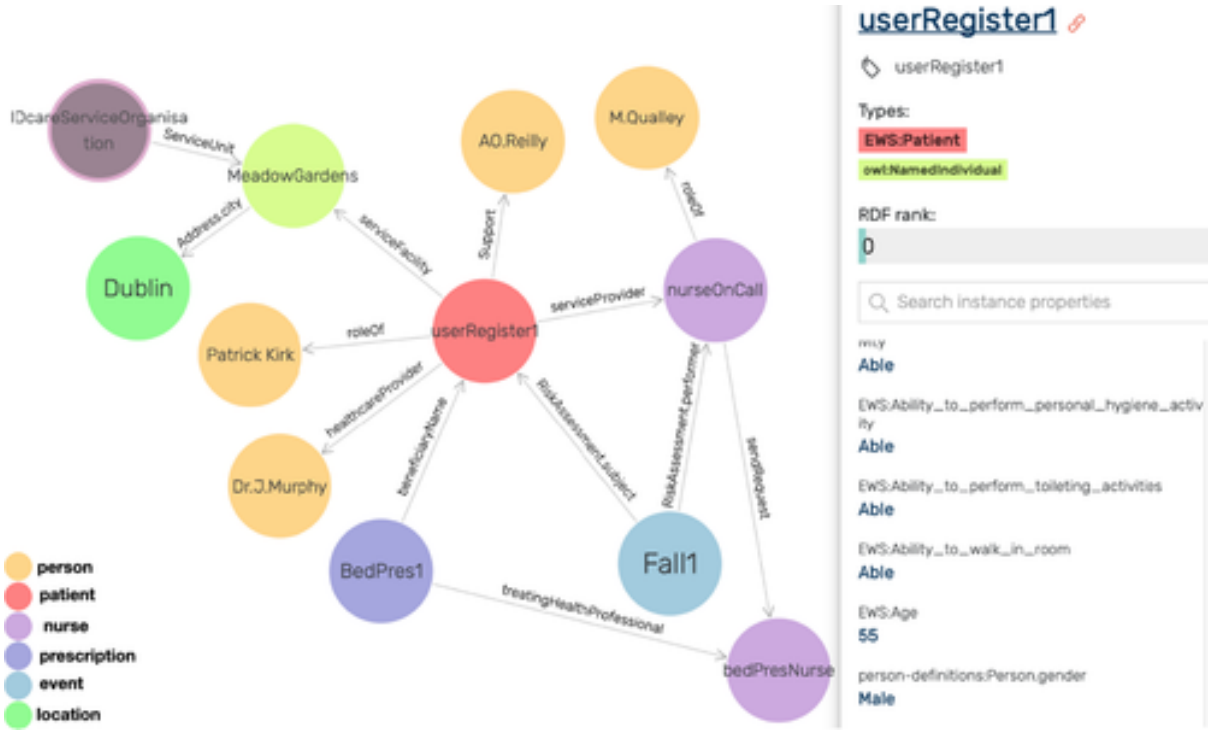

Figure 4

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Mockup example of nursing knowledge graph (NKG).

Check

Following the development of the initial case study within the knowledge graph, the technical team returned to clinical partners to review this initial development work. The check activity related to reviewing the change management and reconfiguration details of the case study material for inclusion in the knowledge graph. The MOU translation involved taking information summary details from existing paper records, which are heterogenous in presentation, and refining them in a processed way to convert to data for use in an MOM with structured and constraint data types. A demonstrator platform was thereby completed to illustrate linked data and provide details on explicit relationships to give new insights for knowledge generation in the longer term. We consider an NKG to be a knowledge graph

connected to and with different aspects of nursing services workflow. This enabled us to understand the data information knowledge wisdom progression in a specific context as adapted from Matney, Brewster, Sward, Cloyes, and Staggers (**2011**). Considering the nursing role and activity, we focused this check process on identifying key requirements for digital care delivery on a referral for falls prevention. Initial work focused on referral of a bed prescription (see Figure 4). We explored how the target group (e.g., nurse, patient, carer, healthcare profession), service (residential care, day care, emergency care), and organization (service provider) interacted, which divulged not only how they are connected but provided key insights into why they are linked together, for how long, and for what period of time. This offered scope to define a blueprint for understanding personalized health care in context. This approach also provides optimal scope for access, visualization, analytics, and definition of reports in the longer term to address service improvement initiatives, minimize potential risks, and support efficient and effective use of nursing workforce time at the local and organizational system level. This eventually facilitates a shift from siloed nursing information to selected data that can be linked to create knowledge and advance wisdom on specific domain topics (see Figure 4).

Act

Following analysis of the data collated and completion of the actions steps as outlined in Figure 4, it was agreed to create mockup applications to demonstrate to the nursing group how the applications could be linked to the knowledge graph to generate new insights. Figure 5 provides a screenshot of one application created for assessment as a demonstrator.

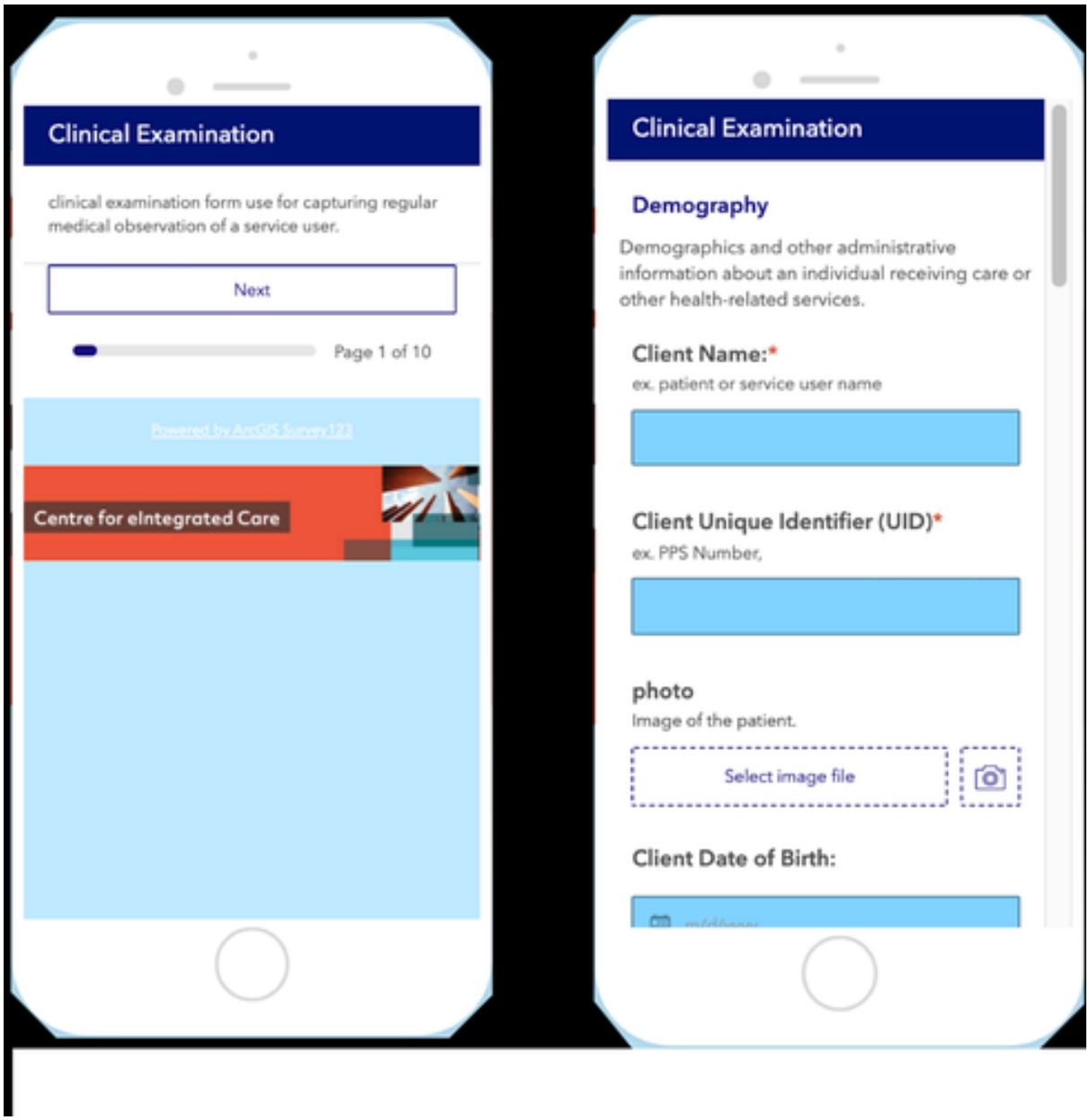

Figure 5

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Mock-up of the application for smartphone.

Discussion

From the literature and standards reviewed in this study, we believe there is a need to build capacity, capability, and skills in the adoption and use of health informatics standards in the domain of nursing. There is an absolute need for nursing to participate in addressing this knowledge gap with a view to contributing to the development of large-scale design science programs for sustainable health care. In the case of artificial intelligence, for example, fragmented and non-interoperable data cannot be interpreted by machines, and this hinders machine-based automated reasoning (He et al., **2020**). As digital transformation progresses and designers and developers translate from MOUs to MOMs, clear alignment and clinical judgment underpinning the seven levels of the interoperability process are needed (Benson & Grieve, **2016**; Blobel, **2018**) (see Figure S1). Otherwise future progression on visualization of diverse knowledge translation used to gain valuable insights into nursing big data science may be impeded.

In this article we argue the case that nursing knowledge and expertise are important, particularly at the junction of translation of the MOUs and MOMs. This is essential with the progression of digital services, where planned machine learning and algorithms will base their decision on these data. We found that an ontology-based knowledge graph is suitable to support and leverage formal representation of nursing activity (Zhang et al., **2020**). This can be achieved through formal translation from MOU paper-based templates converted into mobile applications as depicted in Figure 5 and supported by rigorously designed infrastructure to support data visualization as depicted in Figure 4.

Conclusions

By deploying knowledge graph research development underpinned with Open Innovation 2.0 methodologies and design science research, we can instigate a review of data and connect diverse knowledge that offers valuable insights into the data collated on service delivery. There is potential to explore relevant data to inform future nursing theory, research, and

scholarship to progress targeted activity such as the nursing contribution to self-management support action plans.

Acknowledgment

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