ENABLING INTEROPERABILITY THROUGH AN ONTOLOGY APPROACH IN THE HETEROGENEOUS DOMAINS OF COMPLEX CHRONIC CONDITIONS

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Abstract: Complex and chronic health conditions have domain knowledge that is multidisciplinary, inconsistent, non-standardized and poorly categorized making them heterogeneous. Consequently, challenges for collaborative care management are widely prevalent due to lack of interoperability. Ontologies have come to the forefront as effective method to improve interoperability in a domain due to their ability to enable higher levels of specification. The primary objective of this study was to develop, test and evaluate a model and a methodology for creating ontologies in heterogeneous domains of complex conditions, an area where there is great paucity for research. The methodology in this research applied a two-staged approach for enabling interoperability in the heterogeneous domain of two complex chronic health conditions, namely, multiple chemical sensitivity and chronic pain. Four hundred and eight and three hundred forty five multidisciplinary concepts were specified in the profile ontologies for multiple chemical sensitivity and chronic pain. A testing and an evaluation process conducted in this research demonstrated that a high percentage of the multidisciplinary clinicians (>80%) agreed on the overall usefulness of the ontologies in improving the collaborative environment. The results from the research are promising in terms of the potential applications of ontologies in heterogeneous knowledge domains.

1 INTRODUCTION

Chronic conditions such as multiple chemical sensitivity (MCS), chronic fatigue syndrome (CFS) and fibromyalgia (FM) are a significant burden to the healthcare system. In a report by Statistics Canada, at least 5% of Canadians have symptoms that cannot be medically explained (Verhaak et al., 2006). Multidisciplinary care teams have come to the forefront as an effective management strategy for these conditions (Dysvik et al., 2005); (Fox et al., 2008). Studies have shown the consequences of poor communication among multidisciplinary care providers resulting in poor care experiences for patients and errors in care management such as repetitive or redundant medical tests, misdiagnoses, delayed care and inaccurate treatment plans (Pace et al., 2004); (Schoen et al., 2008); (Kennedy, 2008). The domain knowledge for these conditions is obscure with lack of consensus among experts, non-standardized and multidisciplinary. There is a clear need to enable interoperability and better communication among multidisciplinary care providers to improve care environment for patients (Fox et al., 2008). An ontology approach to capturing domain knowledge is explored as a possible modus operandi to organizing knowledge in a heterogeneous knowledge base.

2 LITERATURE REVIEW

Ontologies have gained importance in recent years as a knowledge management platform in many areas including health care (Dominigue et al., 2001); (Baneyx et al., 2005); (Mostefai et al., 2006). Ontologies are preferred to conventional classifications due to the higher level of expressiveness that is possible in describing concepts and their relationships (Dominigue et al., 2001). Ontologies have been typically developed in stable knowledge domains (Lin et al., 2006); (Larson and Martone, 2009). Challenges in developing ontologies in heterogene-

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ous domains have been discussed in the literature. In this paper, heterogeneous domains are defined as domains that are poorly categorized, multidisciplinary, non-standardized and inconsistent.

Dominigue et al. (2001) identify the key requirement for an ontology approach to knowledge management as a community's perspectives being stable on an issue with "well defined roles", "specified criteria" and "codified procedures". Challenges related to developing ontologies when there is a lack of consensus in a community are discussed in the subsequent paragraphs.

A study by Larson and Martone (2009), the challenges of formalizing knowledge for neuroscience were explored. The authors claimed that formalizing knowledge about poorly understood biological systems presents many obstacles to the development of ontologies. This study highlighted the importance of developing a layer of standardization prior to attempting higher level specification such as the creation of ontologies in the domain.

In a study by Lin et al. (2006), the challenges of a mental health group of professionals working with emerging knowledge was discussed. This study describes the challenges and importance of building knowledge through ontologies in heterogeneous situations. This study presented the preliminary challenges that exist in the knowledge capture for a domain that has obscure definitions, lack of consensus, unstructured data, inconsistent use of vocabulary and assessment scales. A significant challenge encountered in this work was to bring structure to knowledge that continues to be generated in an ad hoc manner.

In a study by Qin and Paling (2001), the importance of developing ontologies in heterogeneous domain was examined. The research describes the creation of an ontology from a well defined and well used controlled vocabulary in order to provide a higher level of semantics to the concepts in the vocabulary. Digital objects, such as those in the Gateway to Educational Materials (GEM ontology) encompass multiple dimensions of characteristics which often play important roles for users in search of precise information in an efficient manner. The authors suggest that a conventional cataloguing code will be inadequate to describe these details in a lesson plan, as many of these elements do not even exist in the vocabulary. In this study, the authors developed an ontology with the intention of adding another layer of semantic operability to the terminologies found in controlled vocabularies.

The review of literature has highlighted the following areas of research needs in the domain of complex chronic conditions and the application of ontologies in heterogeneous domains. Studies have discussed the challenges of collaboration among clinicians in the domain of complex chronic conditions and the need to develop standardization and interoperability in this domain. The potential of ontologies is well recognized in the literature as effective platform to enable interoperability and standardization in a domain and finally researchers have recognized the challenges of developing ontologies in heterogeneous domains. Overall, the review has indicated that there is no research to-date that has developed ontologies in the heterogeneous domain of complex chronic conditions.

In this paper, we have discussed the development of ontologies in the heterogeneous domains of two complex chronic health conditions, multiple chemical sensitivity (Bartha, 1999) and chronic pain (Peng et al., 2008). Both conditions require a multidisciplinary care management scheme and have all the characteristics of heterogeneity defined in this paper.

3 METHODOLOGY

Model and methodology proposed in this research to develop a layer of pragmatic interoperability in the heterogeneous domain included a two-staged approach.

The first stage of the two-staged approach included the creation of a standardized and controlled clinical vocabulary. SNOMED CT® (2008), a widely used reference terminology was used to standardize the concepts and terminologies found in the patient charts. A pragmatic approach (Carlile, 2002) was applied in the development of the controlled vocabulary as the domain knowledge is heterogeneous.

The development of the controlled vocabulary involved the developing of standardized and controlled clinical vocabularies at the levels of syntactic, semantic and pragmatic interoperability. The method for creating the controlled vocabulary was driven by the purpose of generating the goal and usage of the vocabulary: chart audit and interviews with experts to identify key concepts in the domain of the complex condition (syntactic), standardization of the vocabulary (semantic), and testing and evaluation of the vocabulary by the users (pragmatic). The chart audit and interviews with experts helped generate the vocabulary. SNOMED CT® was used as a reference terminology to standardize the terms

retrieved in the chart audit process. The re-coding of patient profiles, evaluation and feedback from the domain experts tested and evaluated the vocabulary. A further step in the evaluation included feedback from clinicians in the community.

The two-staged approach applied in this research is shown in Figure 1.

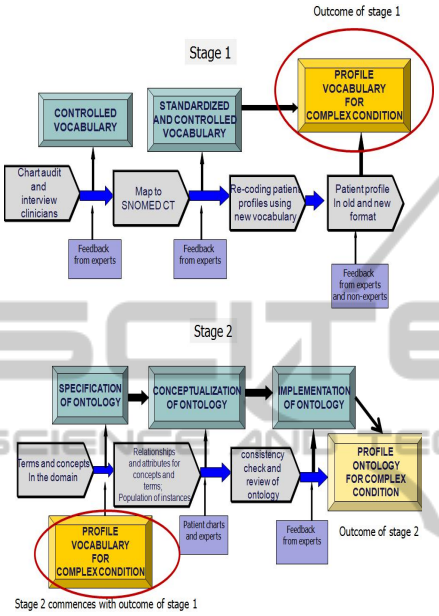

Figure 1: The two-staged methodology applied in the research.

The second stage of the two-staged approach was the creation of an ontology in the heterogeneous domain consisting of 3 phases: Development, testing and evaluation. The development phase included the experts in the domain specifying and organizing the knowledge in the domain. This phase primarily drew the knowledge from the controlled vocabulary. The testing phase included the clinicians browsing the profile ontology developed in this research to examine the concepts in the ontology, the relationships between concepts, concept attributes and the individuals populated in the ontology. Following this was an evaluation phase that included feedback from the domain experts on the overall usefulness of the ontology in patient care with emphasis on usefulness from a health discipline perspective, from other health disciplines and the multidisciplinary nature of interactions captured in the ontology.

3.1 Development of the Ontology

The generic framework for the development of an ontology was divided into three important phases: a specification phase, a conceptualization phase, and an implementation phase (Noy and McGuinness, 2000).

3.1.1 Specification Phase

Establishing the goal and scope was the first step in developing the ontology. The goal of an ontology determines the overall objective for developing an ontology. The goal of the profile ontology developed in this study was to create a comprehensive hierarchical controlled vocabulary and a representation of the multidisciplinary and multidimensional relationships that exist among the concepts in the controlled vocabulary. The scope of the ontology for this research was maintained in the first layer of organization, that is, in the domain of patient profiles. A patient profile or problem list generation is typically the starting point of a care management scheme for patients. The elements in this ontology were maintained on the knowledge that existed in this domain.

3.1.2 Conceptualization Phase

The conceptualization of the ontology commenced with the controlled vocabulary that specified the concepts that existed in the patient profile domain for complex health condition. The key concepts were explicitly related by establishing relationships and attributes in the domain. Multidisciplinary interactions in the management of symptoms were specified in the ontology through relations and attributes. Multidisciplinary classes were also created in the profile ontology which showed the involvement of various grouping of clinicians in the management of a specific grouping of multidisciplinary symptoms for patients. The knowledge in this phase was derived from the patient charts and from the domain experts. Instances from one-hundred patient profiles were populated in the ontology.

3.1.3 Implementation Phase of the Ontology

Protégé 3.4.2 was used to implement the patient profile ontology (Knublauch, 2004). The profile ontology was exported into the Web Ontology Language (OWL). A consistency check of the classes in the ontology was conducted. Consistency checking helped detect classes that cannot have instances.

The implementation phase also included the evaluation of the ontology by domain experts for accuracy, completeness and usefulness of the knowledge represented in the ontology. The evalua-

tion phase included the clinicians browsing the ontology using an ontology browser. They browsed various aspects of the ontology such as the classification scheme, multidisciplinary relations between concepts, instances, and standardization of concepts. Google ontology browser was used by clinicians to browse the ontology (Horridge et al., 2006). They provided feedback on the usefulness of the ontology through a survey questionnaire. Specifically, they offered feedback on the overall usefulness of the ontology, the relevance of the ontology in the context of patient care and the value of shared knowledge in the multidisciplinary domain. Individuals or instances are used in the profile ontology to present list of concrete concepts of relevance for each class.

4 RESULTS

Two complex and chronic health conditions, namely, multiple chemical sensitivity and chronic pain were selected to test the viability of the proposed methodology in heterogeneous knowledge systems. One-hundred patient charts were reviewed, 9 domain experts and 36 community clinicians participated in the development of the MCS controlled vocabulary. One-hundred patients, 8 domain experts and 42 community clinicians participated in the development of the chronic pain vocabulary. Seven domain experts from MCS group and 6 from chronic pain group participated in the development of the ontologies.

4.1 Profile Ontologies for MCS and Chronic Pain

The ontologies present a detailed taxonomic overview of the domain of complex health conditions. The profile ontology for MCS contained 408 classes describing the profile concepts for the condition of MCS. At the basic level there are five relevant super-classes under the primary areas of health focus identified for the condition of MCS: Medical, Physical, Psychosocial, Rehabilitation and Nutrition (Figure 2). The profile ontology includes definitions of over 70 properties, 46 data and 30 object properties.

The profile ontology for chronic pain contained 345 classes describing the profile concepts for the condition of chronic pain. At the basic level there are three relevant super-classes under the primary areas of health focus identified for the condition of chronic: Medical, Physical and Psychosocial. The profile ontology includes definitions of over 80 properties, with 51 data and 38 object properties.

The profile ontologies contained explication of all concepts included in the ontology such as the multidisciplinary nature of patient profile, the management scheme and the various concepts under each area of health focus. The properties in the ontologies introduce relations among concepts. A patient *HasOrganization* and the organization are inversely linked to the class Patient by *HasPatient*. The class Profile is linked to the class Management Scheme by property *hasCollaborativeManagement*. The class Psychosocial Profile is linked to the management scheme by property *ManagementRequired* which has individual *dietitian_referral* or *physician_referral*.

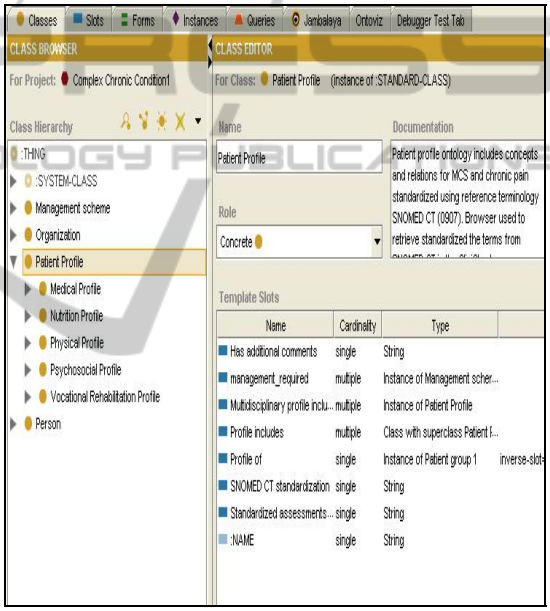

Figure 2: View of MCS ontology in Protégé showing the five super classes.

Standardized concepts are specified with their SNOMED CT ID number (Concept Unique Identifier) and with a list of synonyms. Class Fatigue has a SNOMED CT concept ID of 84229001 with parent concept being *Energy and Stamina* and synonyms *Weariness* and *Tiredness* as shown in shown in Figure 3. Examples of more intricate concepts that benefit from standardization and consistency relevant to this health condition include *heightened visual perception*, *heightened auditory perception*, *emotional hypersensitivity*, *impairment of balance*, *emotional regulation* or *emotional state finding* and *hypervigilant behaviour*. Similarly in the chronic pain ontology, standardized concepts are specified

with their SNOMED CT ID number (Concept Unique Identifier) and with a list of synonyms. Class *Lumbar spine - tender* has a SNOMED CT® concept ID of 298673002 with parent concept being *Finding of sensation of lumbar spine* with finding site as lumbar spine structure.

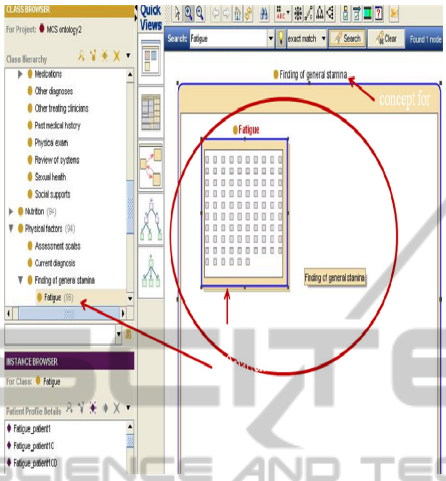

Figure 3: Query of a symptom "Fatigue" in the profile ontology.

Multidisciplinary classes were created in the profile ontologies which shows the involvement of various grouping of clinicians in the management of the multidisciplinary symptoms for patients with a diagnosis of MCS. For instance, *Multidisciplinary class A* involved management by a physician, a nurse, a psychologist or a psychotherapist, a vocational counselor and a physiotherapist or an occupational therapist. *Multidisciplinary class L* involved management by a physician, a nurse and a dietitian. The knowledge of these classes demonstrated to the experts that despite the diagnosis, the management schemes were driven by the presenting symptoms which could greatly vary for patients. This was evident in the knowledge that was retrieved from the 100 patient charts.

4.2 Evaluation of the Ontologies

Google ontology browser (Horridge et al., 2006) was used by clinicians to browse the ontology and offer their evaluation. They viewed the individual patient profiles, multidisciplinary information relevant to their discipline and other disciplines, in-depth query of symptoms and their management scheme.

Query of a symptom such as *Lumbar spine – tender* shows the number of patients with the symptoms and the super class of the concept in the ontology. The instances in profiles show the multifaceted nature of symptoms as substantiated under each area of health focus that exist in the domain of a patient.

Pain symptom as presented in the patient charts has been viewed in the patient charts by a psychotherapist, physician or physiotherapist from various angles of importance such as pattern of pain, anatomical site or in relation to the pain threshold. Figure 4 shows the view of a patient profile that shows the multidisciplinary care involved in the management of *Pain symptom*.

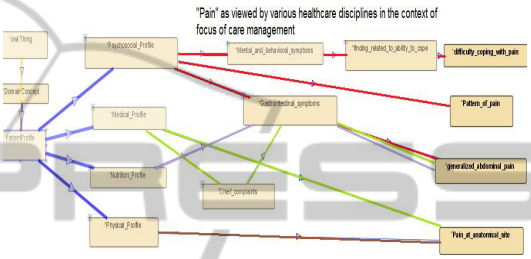

Figure 4: Multidisciplinary interactions in the categorization of Pain.

The clinicians also viewed information on various symptoms including the profiles under which a symptom was categorized, the number of patients that had a symptom and the standardization information for the symptoms.

Figure 5 shows the evaluation of the ontologies by the domain experts of both groups. The ontology had > 80% of agreement from the experts on its usefulness in direct patient care. The use of the multidisciplinary classes in the ontology brought a higher level of agreement from both groups of experts (62%). The ontology had a consistently small to moderate percentage of clinicians showing strong agreement on its usefulness on all categories of the questionnaire. The ontology also had a very small percentage of disagreement on all categories of the survey questionnaire.

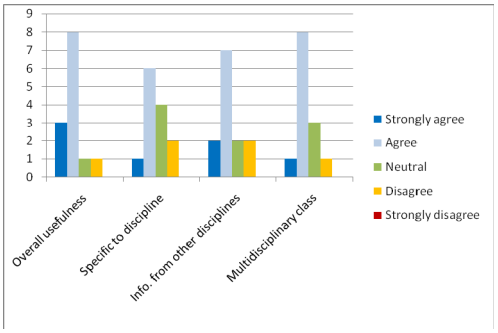

Figure 5: Evaluation of the ontologies.

5 DISCUSSION AND CONCLUSIONS

A novel methodology and model has been presented in this research for the development of ontologies in heterogeneous knowledge domains. The broad objective of the research was to enhance communication in the multidisciplinary care management of chronic, complex and lesser known health conditions. The ontology approach was selected to develop consistency, standardization, organization and interoperability of domain knowledge with the broad goal of improving collaboration and communication for multidisciplinary clinicians involved in the care of patients with complex chronic conditions.

The development of the profile ontologies in this study was divided into three phases: specification, conceptualization and implementation (Noy and McGuinness, 2000). The methodology includes several key components or criteria that were identified in past research such as acknowledging the heterogeneous nature of the domain knowledge (Larson and Martone, 2009) involving clinicians (experts and non-experts) in the process of development and evaluation and exploring the potential of the study by testing it in clinical workflow (Lin et al., 2006). However there are several limitations to this research such as the scope being limited to the domain of patient profile information, a convenience sample of participants, size of the sample, the fact that the potential of the boundary objects in improving communication or collaboration among clinicians or the impact on patient care was not explored. The results do indicate that this direction of research has significant potential and requires further exploration.

An ontology can reach a wider audience and has been deliberately selected to explicate the knowledge of lesser known and complex health conditions. Ontologies provide a pragmatic interoperable format for collaborative sharing of knowledge across communities of practice. The ontology has the potential to get richer as more users contribute new knowledge and as more patient instances are populated in the ontology. The overall agreement shown by experts in this study is very promising for the use of ontologies in the heterogeneous domains of complex health conditions.

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