An Ontology Based Framework for Modeling Healthcare Teams

By

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Abstract

Advantages of applying information and communication technologies to support complex team practices in healthcare domain have often been supported in the extant literature. The primary assumption is that before putting any technologies in place to support team functions, the team-based environment should be completely modeled.

To date, many frameworks have been proposed for modeling healthcare teams; however, most of the frameworks only focus on single or a few aspects of teamwork and the outcomes usually present overlaps, limitations and inconsistencies. As a result, there is an increasing demand for offering an overarching framework that integrates the multiple dimensions of healthcare teamwork into a synthetic whole and clearly conceptualizes the potentially important relationships and dependencies that exist over those dimensions.

In order to properly address the aforementioned challenge, this thesis applies ontological engineering to develop an overarching framework for integrating the multiple dimensions of teamwork concept in healthcare domain. For this purpose, we first illustrate a set of four stage methodological approach to provide explicit details on how to incorporate a theatrical foundation into the ontology. Then, the proposed approach is used to develop a derived ontological framework. Finally, accuracy and completeness of the

proposed ontology based framework is validated to show that it is able to accurately represent the domain is it being employed for.

The values and capabilities of ontology have already been studied and approved, and this technology is known as the best sources to represent a knowledge domain by means of concepts and accurately define the relationships among them.

Our aim in this thesis is to further research how to develop and evaluate a standard ontology based framework to facilitate the healthcare team modeling.

This thesis is dedicated to my beloved husband **Bahman** for his dedicated support and encouragement;
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Publications

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Nomenclature

Acronym	Definition
CAS	Complex Adaptive System
CSCW	Computer Supported Cooperative Work
EPR	Electronic Patient Record
HIS	Health Information System
ICT	Information and Communication Technology
ITEM	Integrated Team Effectiveness Model
MeSH	Medical Subject Headings
SNOMED-CT	Systematized Nomenclature of Medicine- Clinical Terms
SPM	Severe Pain Management
TOVE	Toronto Virtual Enterprise
UMLS	Unified Medical Language System
UTS	UMLS Terminology Service
WMS	Workflow Management System

Chapter 1: Introduction

1.1 Problem Statement

The concept of healthcare teamwork is not a new one, dating back to 1940 and early 1950 when team approach was supported by Silver and Cherkasky to deliver primary care service (HRSA). Acceptance and implementation of teamwork in healthcare settings have risen over time as the need for improving the quality of care; increased pressure of healthcare processes complexity and the necessity of cost control have strengthened the need for it (Heinemann 2002; De Vries et al. 1999). Today, most of the patient care requires some degree of teamwork between individuals from multiple professions and disciplines, with different knowledge levels and sometimes working in different physical locations. It has been argued that the inter-professional teams will contribute to holistic care (Gilmore et al. 1974) and the facilitation of decision making (Borrill et al. 2000), while improving resource utilization through reduction in work duplication and delays (Hallett and Birchall 1992).

As the use of teamwork has increased in the healthcare domain, some people started to question its values and benefits (Leatt et al. 1997; Kalra et al. 2000). One of the main reasons for this issue is the lack of conceptual clarity to the inherent complex nature of the healthcare team construct (Opie 1997). It is generally assumed that the health care

teams work in a collaborative manner (Hill 1995). Collaborative systems can be viewed as a complex adaptive system (CAS) which means a collection of individual agents who act in ways that are not always totally predictable, and whose activities are interconnected (Plsek 2003). The agents in such a system refer to all components of that system so in a healthcare team these agents might embrace the various dimensions of teamwork constructs including team processes, information resources, and members, all of which influence the final outcomes. A health care team is characterized by fuzzy boundaries and dynamic interactions and interconnections between these dimensions. Hence, the final outcome has always been influenced by a complex web of relationships among these dimensions (Plsek and Greenhalgh 2001). Understanding the relationships between the various dimensions of healthcare teams and the interactive behavior of those dimensions will help in designing information and communication technology to facilitate team functions.

There are several advantages of applying information technology to support healthcare teams including the potential to not only reduce errors and increase speed of care but also to improve the quality of care by accurately coordinating different care services (Malliarou and Zyga 2009). To date, many frameworks have been proposed for modeling healthcare teams; however, most of the frameworks only focus on one or limited set of aspects of teamwork and the outcomes usually present overlaps, restrictions, and incompatibilities. Further, none of the existing healthcare team models (Mickan and Rodger 2005; Lemieux-Charles and McGuire 2006) have succeed to

rigorously address the interrelationships and interdependencies that exist among the multiple dimensions of healthcare teamwork. As a result, there is an increasing demand for offering an overarching framework that not only integrates the multiple dimensions of healthcare teamwork but also that clearly conceptualizes the potentially important relationships between those dimensions.

A consensus on a standard framework can help reconcile discrepancies between different care contexts regarding what multiple dimensions of a healthcare team are and how those dimensions interact with each other to affect the overall team outcomes (Xyrichis and Ream 2008). However, there is a lack of a feasible framework in order to properly address the aforementioned challenge and provide suggestions for the enhancement of conceptualization and design of future healthcare team models.

1.2 Thesis Motivation and Contributions

One of the possible ways to develop the required framework is to make use of ontological engineering. An ontology creates a common vocabulary and allows us to formalize a knowledge domain by means of concepts, attributes to characterize them, and relations between the concepts (Leonardi et al. 2007). One of the advantages of ontologies is their reusability; it is easy to add new ontologies to a healthcare team ontological model to allow it to evolve over time. It is also easy to reuse parts of the healthcare team ontology for application in other domains. Testing the ontological model in domains outside healthcare will enhance the proposed model by adding new ontologies to it and discovering new relationships. Unfortunately, most of the existing ontology

development methods such as METHODOLGY and On-To-Knowledge just provide the tasks for ontology design but they lack the explicit details on how to incorporate theoretical foundation into ontology (Kuziemsky and Lau 2010).However , such rigor is necessary if ontologies are to precisely represent the complexity of healthcare team practices.

The contribution of this thesis is to develop an *Ontology-Based Framework for Modeling Healthcare Teams*. Overall, the contributions of this thesis are as follows:

- This research applies ontological engineering to develop the systematic framework to integrate the multiple dimensions of healthcare teamwork into a synthetic whole and clearly conceptualize the relations between those dimensions. This standard framework can serve as the foundation for different proposed models for expanding their taxonomy concerning multiple dimensions of teamwork concept.
- Provide detailed guidance on developing ontology concepts & relationships for modeling patient care teams by extending an enterprise ontology development methodology in the biomedical domain.
- Create comprehensive ontology terminology which can aid in refining the associated lexical knowledge in the domain of healthcare collaboration.
- Finally, introduce a satisfactory approach for validating the proposed ontological framework before implementation through an IS, to show how ontology is able to accurately represent domain it is being modeled for.

In summary through the field of study, this research is interested in answering the following questions:

- How could reasoning capability of ontological model provide relevant information to represent multidimensional structure of the healthcare teams?
- What is required in a methodology for developing an ontology of healthcare teams?
- How could the ontological model be validated and evaluated before design and implementation of information system?

1.3 Thesis Methodology and Organization

In order to answer the above questions, design science methodology was used in our research. According to Hevner et al. (2004), "design science research addresses research through the building and evaluation of model designed to meet the identified relevant business needs, where purposeful models are built to address heretofore unsolved problems and they are evaluated with respect to the utility provided in solving those problems". In other words, design science research uses a build-and-evaluate loop to support a problem solving paradigm. In this cyclical model, design process described as a sequence of specialized activities that produces an innovative model and in the next step, the evaluation of the model provides feedback information to support a better understanding of the problem in order to improve the quality of the model. Contributions from design science research can encompass developing a new model or framework that can be evaluated against the research goals. In this thesis, we developed a four stage

methodological approach and then used that approach to derive ontological framework in order to integrate the multiple dimensions of healthcare teamwork and define interrelationships among those dimensions. Finally we applied a proof-of-concept approach to evaluate and validate the accuracy and completeness of the proposed ontological framework. Our framework is generic enough to be applicable not only in healthcare but also in other domains outside healthcare. Simplicity and flexibility of the framework was considered as the key issue in its design. Overall, the following steps have been taken to carry out our research:

1. Review the literature on healthcare teams as well as relevant literature from teamwork in other domains outside healthcare in order to identify the potential gaps in existing work on teamwork modeling.
2. Analyse the identified gaps and examine the literature to understand the possible approaches to solve the problem.
3. Develop an overarching ontology-based framework for modeling the multidimensional constructs of healthcare teamwork.
4. Validate the proposed ontology based framework through implementing proof-of-concept validations to illustrate how proposed ontological models can deliver relevant information to address the identified gap.
5. Discuss the proposed framework, draw conclusions and identify potential future work.

This thesis is organized as follows:

In Chapter 2 we first define a background on healthcare teamwork and its underlying components. Afterwards, we discuss ontological modeling and some of its applied examples in healthcare domain, accompanied by a description of the methods and technologies which are potentially able to validate the model. Finally, we describe the related work and identified gaps in literature.

In Chapter 3 we present and discuss the generic methodology used in this research to address the identified gaps which have been found in previous chapter.

In Chapter 4 we introduce a novel ontology-based framework for integrating the multiple dimensions of a healthcare teamwork construct.

In Chapter 5 we evaluate and validate our proposed ontological framework through illustrating a set of competency questions for which the ontology must be able to provide relevant solutions.

Finally, in Chapter 6 we summarize our contributions, provide concluding remarks, and discuss possible future extensions to this thesis.

Chapter 2: Literature Review

As mentioned in previous chapter, the importance of healthcare teamwork has been described in the literature. In 2006 the Canadian healthcare services research foundation (CHSRF) stated that effective teamwork could enhance patient safety and improve patient care. In United States of America the Institute of Medicine (IQM 2001) has supported the change of care delivery from care provided by a single provider to care provided by multiple providers (e.g. primary care providers and specialists, psychologists, physical therapists, etc). Similar findings for improved understanding of healthcare teamwork are also apparent in Australian and British contexts, making collaborative care a priority for decision makers in health systems. It has been emphasized that single practitioner or discipline is no longer capable to meet all the health care requirements of an individual so it is crucial that the knowledge and skills of multiple providers be coupled and integrated into collaborative care teams (D'Amour and Oandasan 2005).

Although there is broad literature and organizational overviews about various dimensions of teamwork, the literature on inter-professional teams in care settings is relatively sparse and not well defined (Xyrichis and Ream 2008). To date, this body of

literature has failed to conclusively demonstrate what dimensions of healthcare teamwork should be taken into account when we try to model the team and how these dimensions interact with each other to influence team final outcome.

In this chapter we first provide a background on healthcare teamwork where we will discuss the general concept of teamwork for three typical health care team types (interdisciplinary, multidisciplinary and transdisciplinary), followed by a discussion on various dimensions of healthcare teamwork including team process, information recourses, team members and team outcomes. We will then define what ontological modeling means in order to examine how ontological engineering is able to model the various dimensions of healthcare teamwork and describe some of the ontologies which are being used to represent various areas in healthcare. Finally, we will discuss a number of methods and techniques that have already been developed for evaluation and validation of the ontological models. Figure 1 shows the outline of our literature review.

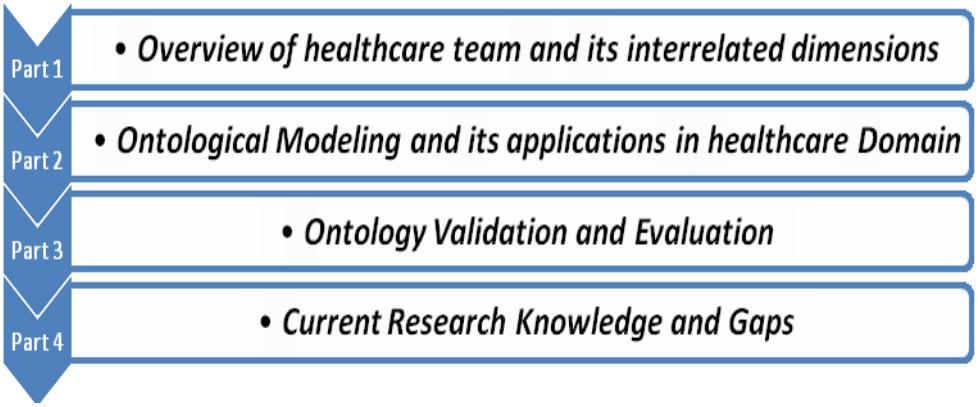

Figure 1. Outline of Literature Review

2.1 Overview of Healthcare Teamwork

2.1.1 Healthcare Team Definition

Teamwork has recently appeared as one of the facilitators in achieving more cost effective quality of care (Baker et al. 2006). Today, teamwork models are used by approximately 60% of primary care services in USA to coordinate an extensive range of health professionals to deliver quality care (Schoen et al. 2009). Duncanis and Golin (1979) defined team practice as "A functioning unit composed of individuals with varied and specialized training who coordinate their activities to provide services to a client or group of clients". Likewise, Xyrichis and Ream (2008) analyzed the concept of healthcare teamwork based on antecedents, attributes and consequences framework and defined it as "A dynamic process involving two or more health professionals with complementary backgrounds and skills, sharing common health goals and exercising concerted physical and mental effort in assessing, planning, or evaluating patient care." They also claimed that open communication, common decision making and autonomous collaboration are the underlying basis for teamwork. In the literature, they also suggested that the underling components of healthcare team practices are (Xyrichis and Ream, 2008):

- Two or more practitioners with complementary background and skills should be involved.
- The team must share common health goals for patient outcome.
- Team members must have an understanding of each other's professional role.

– There should be mechanism for informal and formal communication and information sharing among team members.

2.1.2 Team Structure

Healthcare teams are typically divided into three practice models: interdisciplinary, multidisciplinary and transdisciplinary teams. Often the distinctions between these terms are ambiguous and they are used interchangeably; however, each of these descriptive categories refers to unique characteristics and functions expected from a team working (Dyer 2003). What may best distinguish these three teams from one another is neither composition nor task, but rather the ways through which teams manage input from disparate disciplines, the degree of collaboration, the structure for interaction among team members and how much team a shared language achieved by multiple professionals (Miller 1994). Figure 2 shows the continuum of collaboration among the three aforementioned healthcare teams.

Figure 2. Continuum on Collaboration among Team Members

2.1.2.1 Multidisciplinary Team

Multidisciplinary teams are where professionals from different disciplines function together and share the same goal but they work usually quite individually and

independently of each other for assessing patients and providing treatment (Fewell 1983). This team type is characterized by infrequent meetings, sequential work and limited interaction. This means that there may be a meeting to discuss care progress but generally there is little communication among team members. Peterson (1987) compared the mode of interaction among members of a multidisciplinary team to parallel play which means separate but related with the medical record often being used as the tool for sharing information among team members.

2.1.2.2 Interdisciplinary Team

The second team type is an interdisciplinary team. According to definition of (Luszki 1958) "The interdisciplinary team is a group of persons who are trained in the use of different tools and concepts, among whom there is an organized division of labour around a common problem with each member using his own tools, with continuous intercommunication and re-examination of postulates in terms of the limitations provided by the work of the other members and often with group responsibility for the final product". In an interdisciplinary team, members work together interdependently to develop a common goal and jointed care planning where each member makes a unique but complementary contribution to required service delivery (Dutton et al. 2003). Garner (1995) stated that the interdisciplinary team practice expands the multidisciplinary team process through collaborative communication rather than shared communication so interdisciplinary teams are described by formal communication channels that inspire team members to exchange their information and learn from each other.

2.1.2.3 Transdisciplinary Team

Transdisciplinary teams are the result of the development of the team approach. Team members in transdisciplinary teams understand each others' perspectives and use them to develop a new and emergent way of viewing an issue. One of the main characteristic of a transdisciplinary team is that all decisions about assessment and treatment process are made by team consensus. Team members try to cross the professional boundaries to create common knowledge base. Clinically, members are involved in role release rather than role retention which means exchanging of expertise, respecting the perspectives, knowledge, and skills of those from other disciplines, occurs once other members can do what the specialist was specifically trained to do (King et al. 2009). Transition to a transdisciplinary team requires clarity of roles and responsibilities among team members, policy and procedures and systematic feedback mechanism (Antoniadis et al. 1991).

2.1.3 Team Processes

Despite the growing interest and of literature on the topics of team processes, there is little consistency in terminology and clarity regarding the goal for these processes. Team processes can vary greatly by time, membership, task, patient needs and context of work. Reviewing the literature allowed identification of processes of healthcare team that was repeatedly presented as collaboration, coordination, communication, decision logistic and information management.

2.1.3.1 Collaboration

Collaboration among team members has been proposed as the answer to many complex health care issues. However, this term has become a buzzword that too few healthcare providers can precisely define. Collaboration has been named and defined in the literature in a variety of ways. Terms such as interdisciplinary, inter-professional or team-focused collaboration are often used alternately (Dechairo-Marino 2001). There are almost as many definitions of collaboration as there are authors that have discussed its benefits. Sullivan (1998) described collaboration as "a dynamic, transforming process of creating a power sharing partnership for pervasive application in health care practice, education, research, and organizational settings for the purposeful attention to needs and problems in order to achieve likely successful outcomes" (p. 6). Hanneman et al. (1995) defined this concept as non-hierarchical joint ventures characterized by willing participation, shared goals and responsibility and mutual acknowledgement of care decision making. Similarly, Way et al. (2000) described collaborative care as "an inter-professional process for communication and decision making that enables the separate and shared knowledge and skills of care providers to synergistically influence the client/patient care provided". Boon et al. (2009) have made an effort to differentiate the terms collaboration and integration with a specific look at chiropractic and family physician teams in primary care settings and summarized components of interdisciplinary collaboration as a model of team care wherein professional working together while keeping their autonomy and having mutual role respect in absence of formal structure for

care delivery. Finally, Yeager (2005) explored an overall understanding of collaboration definition and mentioned its advantages as shorter delays, improved morale and job satisfaction, lower staff stress and fewer errors.

2.1.3.2 Care Coordination

Coordination is a critical factor of high performance care delivery in the nature of modern medicine. It is recognized in The Commonwealth Fund (2005) report as one of seven elements required to organize care services and information around the patient. Similarly, the Institute of Medicine in 2003 has explicitly introduced care coordination as one of 20 national priorities for improving the quality of health care. In fact, the processes of care not only require being coordinated among various care practitioners, they also need to be arranged between health providers and patients and their families to avoid extravagant duplication of diagnostic testing and provide cost-effective care (Bodenheimer 2008). McDonald et al. (2007) conducted a systematic review on coordination and identified more than 40 definitions for the term They combined the key elements comprising care coordination from many definitions to develop one working definition as "the deliberate organization of patient care activities between two or more participants (including the patient) involved in a patient's care to facilitate the appropriate delivery of health care services". Andersson et al. (2003) divided the process of coordination to three main areas:

2.1.3.2.1 Patient-Family Coordination: Patient-family centered activity of care coordination try to make sure that patient's preferences and requirement for health

services are met over time and facilitate patients and family members' engagement in their own care process.

2.1.3.2.2 Inter Coordination (External): Inter coordination is assigned to navigate patients appropriately through care system and determine where to send the patients and what information is needed to be transferred among healthcare professionals.

2.1.3.2.3 Intra Coordination (Internal): Internal coordination is responsible for managing personnel, information and other recourses to conduct all required patient care activities to deliver efficient care service to the patients.

2.1.3.3 Communication

The complex nature of health care work environment demands the skill and knowledge of several individuals to solve patient care problem. It has been demonstrated that accurate communication has a direct and strong relationship to patient satisfaction, reduction in length of stay and care cost (Hearn et al. 1998) while has a critical role for prevention of medical error (Alvarez and Coiera 2006). Webster's Dictionary defines communication as "the imparting or interchange of thoughts, opinions, or information by speech, writing, or signs." Communication studies in healthcare include Kuziemsky et al. (2009) who developed a framework for interdisciplinary team communication and described how the framework can help healthcare information system design to support team communication, Reddy and Spence (2008) who examined teamwork in the emergency department and Alvarez and Coeira (2005), who studied interruptive

communication in the intensive care unit. Among the wide variety of classifications suggested in the literature to describe different types of communication are (Pinto 1990):

2.1.3.3.1 Written vs. Oral Communication: Written communication is necessary to ensure all aspect of patient's care is documented. Reports resulting from the request for lab services, physical therapy for the patient or interdepartmental memo are some of the forms of written communication (White and Duncan 2001). Written communication plays an important role in providing information; however, due to time critical nature of work in healthcare teams, members often turn to oral communication to satisfy their instant information needs (Reddy and Spence 2008).Oral communication can be defined as a mutual and real-time experience among individuals includes verbal information delivery.

2.1.3.3.2 Internal vs. External Communication: Internal communications take place between team members to allow different professionals to bring their own expertise and skills, discuss about their medical problems and find the needed information which they are seeking. On the other hand, external communication is how teams coordinated their works with outside agencies or individuals. Communicating with the primary care physician of the patient or with the patient's family are some of the instances for external communication.

2.1.3.3.3 Formal vs. Informal Communication: Formal communication occurs during scheduled meetings and appointments. For example, formal communication may involve discussing potential patient treatment options with

other team members. Informal communication refers to communication over the telephone or in unplanned discussions concerning a topic of patient care.

2.1.3.4 Decision Logistics

Decision logistics refers to the process of evaluating available information, selecting a choice between a numbers of possible alternatives and reaching a conclusion. The decision logistic process in healthcare teams is a complex process since different professionals with different background and perspectives are involved. Further, in some environments such as emergency departments, decisions are made under the time pressure with incomplete information despite the need to need to acquire input from both internal and external authorities before making decision (Laxmisan et al. 2007). One necessary antecedent to team decision logistics was the willingness of the team individuals to remain open to new ideas and viewpoints and to incorporate feedback from all team members into the team plan for patient care (Kuziemsky et al. 2009). Negotiation and leadership are the two complementary processes that occur as a part of process of decision logistic.

2.1.3.4.1 Negotiation: Instant consensus is not usually achieved during the process of decision making; hence, negotiation occurs as part the decision making process to ensure that that consensus is reached among the team members. Despite the fact that negotiation may start within the context of a meeting among team members, it often extends to activities outside the team meeting. Negotiation that takes place between care providers and patient family is one example of this

process which leads to mutually satisfying care and stronger relationship between the family and care professionals (Robinson 1984).

2.1.3.4.2 Leadership: Leadership is a supporting factor for many processes, especially decision making. Although some healthcare teams can be identified as non-hierarchical with no single member of the team was appointed as the leader, some teams do have hierarchies based on medical role or seniority among team members (Sinclair et al. 2009). Senge (1990) suggested that the traditional role of leader as the one who made a final decision is no longer applicable for today's complex healthcare teams but rather leaders play a key role in facilitating decision making, developing share vision of the problem and promoting learning among team members. In general leaders have four main responsibilities in healthcare teams (John 2008):

- **Resource Management:** The leader is responsible for allocating resources or workload among team members in an appropriate manner to ensure that quality care is not compromised due to the lack of needed resources or overloaded staff.
- **Conflict Resolution:** The leader is helpful for resolving medical or inert professional conflicts among team practitioners through the set of commands or organized language.
- **Teamwork Behaviors:** The leader assures that the team meeting and other team work behavior occur. In the team meeting, leadership avoids random conversation among team members.

- **Role Clarity**: The leader ensures that all the team members know their roles and responsibilities and respect other team members.

2.1.3.5 Information Management

Today it is essential for healthcare professionals to both stay informed and inform their work environment to effectively manage care processes. In healthcare teams the flow of information can be complex. Information work has been recognized as a collaborative activity rather than merely an individual effort (Reddy and Dourish 2002). It is therefore imperative for healthcare teams to maximize their efficiency relating to information seeking and exchange among multiple members likewise precisely document their actions and decisions during team meetings (Demiris et al. 2008).

2.1.3.5.1 Information Seeking: Collaborative information seeking (CIS) was defined as ‘‘an information access activity related to a specific problem solving activity that, implicitly or explicitly, involves human beings interacting with other human(s) directly and/or through texts (e.g., documents, notes, figures) as information sources in an work task related information seeking and retrieval process either in a specific workplace setting or in a more open community or environment’’ (Hansen and Jarvelin 2005).

2.1.3.5.2 Information Exchange: Due to the difficulty of understanding all aspects of patient care (diagnosis and treatment), team members rely on each other to find needed information. Therefore, information flows among team members conceptualized by a repetitive practice of seeking and exchanging until the

required information is provided. Team members should share their information and knowledge in order to create a dynamic team structure adjusted to the latest changes in patient needs and care environment to deliver high quality service (Reddy and Spence 2006).

2.1.3.5.3 Documentation: healthcare team should accurately document their actions and decisions to facilitate sharing in order to reduce data redundancy.

2.1.4 Team Information Sources

Information sources supplies team members and work process with all available information to meet the patient's demand, but the challenging task involved here is how to navigate the diverse information resources to locate the needed information for the right process at the right time. In general, human, electronic and paper sources are the most common sources for healthcare teams.

2.1.4.1 Electronic Information: Refers to web-based applications, computerized patient record system (EPR), real time messaging, chat group and other form of electronic media creating a full electronic medical record of the patient.

2.1.4.2 Authority: In a team setting, various team members with different background bring their own particular expertise and perspective to a question. There is sometimes even a need to obtain input from external members including outside medical consultants or the patient's primary physician/team. As a part of the care process, team professionals want to find out not only what was done but also why it was done. Usually this part of the team context is not written explicitly

but rather it is implicit in the minds of the individuals who were engaged in those situations. Therefore team members are a source of useful information (Reddy and Spence 2006).

2.1.4.3 Document: It is common for paper based documents to be maintained along with the digital documents. Medication chart, patient record and various medical and nursing reference manuals and policy books are good examples for that.

2.1.5 Team Members

Team members systematically collaborate with each other to meet patient needs that are too complicated to be solved by one discipline or many disciplines in parallel. Usually there is no optimal configuration of different providers in healthcare team and a wide range of professionals and non-professional members play roles in team-oriented care. These roles vary based on specific external and internal contextual factors including team's mission and common goals, the degree of contact between the provider and the patient and the complexity and broad spectrum of patient's conditions and demands (Torrens 2010). Membership on a health care team should be ideally arranged by the specific disciplines and skills that are required for the effective care delivery. Some members may only be needed on an occasional basis, while others may regularly function together on a full-time basis. Duties range from assistance with the activities of daily living, such as basic personal care to performing controlled medical acts such as diagnosis and treatment. Anderson (2004) suggested a set of values or behaviors that is the foundation of member's relationship in collaborative care.

2.1.5.1 Trust and Respect: It is necessary for all members to have an understanding of each member's role and responsibilities and to be able to rely upon the competencies and skills of other members. Mutual trust and respect among all team members establish an impressive working relationship that ensures high-quality of patient outcomes.

2.1.5.2 Responsibility and Accountability: Well-Defined guidelines that develop agreed procedures could help to remove uncertainties among team members and provide a supportive framework specific to patient outcome and team practice issue.

2.1.5.3 Knowledge: Knowledge is a central component for the development of trust. When care providers have confidence in the skills and abilities of other team members, the patient's requirement would be met properly by individual members whose duties are apposite to their proficiency and education.

2.1.5.4 Open Communication and effective Cooperation: "The ability to present information in a manner that is relevant, concise and timely is critical to the development of a collaborative relationship" (Way et al. 2000). Willingness to open communication and efficient cooperation can be facilitator among team member for sharing knowledge and transferring responsibility to achieve the optimal goal.

2.1.6 Team Outcome

Today, substantial attention has been concentrated on the effectiveness of healthcare teams and various studies have connected the team performance to positive patient

outcomes (Temkin-Greener et al. 2004). For example, in palliative care, good communication among team members has been revealed to influence care effectiveness, resulting in patient and family satisfaction, effective disease management, patient achievement of goals and objectives, the reintegration of the patient into community and better patient discharge planning (Kuziemsky et al. 2009). It has been demonstrated that, in acute care unit, lack of coordination among care practitioners caused increased mortality rate and excessive hospital days and expense (Baggs et al. 1992). In intensive care setting, the ability of effective leadership and conflict resolution has brought about shorter patient period of stay and higher care quality (Shortell et al. 1994). However, measuring the outcome of healthcare teamwork continues to be a challenging part of medical and quality improvement studies since, similar to the healthcare team concept, outcome is also multifaceted and poorly conceptualized, making analogy across researches difficult and somewhat controversial. Various individual researchers have contributed to the effort by examining different strategies for assessing the team outcome. From organizational studies, team effectiveness model of Cohen and Bailey (1997) discriminated between objective outcomes such as performance and behavioral and subjective outcomes as attitudinal. The Integrated Health Care Team Effectiveness Model presented by Lemieux-Charles and McGuire (2006) tailored these outcomes to healthcare system within objective outcomes refer to measurable improvements in patient, organizational, staff and patient behavior outcomes while subjective outcomes are attitudinal aspects of team effectiveness. Schofield and Amodeo (1999) conceptualized

multiple aspects of team outcome by developing a tripartite categories of outcomes that distinguishes between patient care (e.g., quality of care, patient satisfaction), personnel (e.g., training, job satisfaction), or management (e.g., cost effectiveness) outcomes. In 1989, the Medical Outcomes Study presented subjective patient outcome into the route of outcomes assessment. In addition to, organization such as National Committee for Quality Assurance (NCQA) has published practical sets of process indicators to assess the quality of care. Consequently, all of these efforts resulted in wide variety of outcome indicators; make it difficult for care providers to choose best practices to assess their performances (Dassow 2007).

2.2 Ontological Modeling

Ontological modeling has been considered as a key method in knowledge engineering because it provides a formal representation of real world entities by defining concepts and the relationships between them (Leonardi et al. 2007).Ontological research encompasses a number of research areas including: Semantic Web, Artificial intelligence, systems engineering, software engineering, biomedical informatics, library science, context aware systems, enterprise bookmarking and information system interpretability. The term ontology comes from philosophy and begun attracting attention since the early 1990's to explain the theory of existence of beings in the world. The computer science community adopted ontology to define the commonly accepted knowledge of a specific domain in a machine-readable format. In these circles, a definition by Gruber (1993) is commonly referenced in literature as "a specification of a conceptualization". Typically,

ontology defines concepts representing common sets of real world entities and their relations and constraints to provide a common understanding of the domain that can be shared between people and different applications, therefore facilitating semantic and data interoperability, sharing and reuse of the knowledge among collaborating agents (Pinto and Martins 2004). Another group of ontology definitions went a step forward and established the process followed to develop the ontology (Bernaras et al. 1996). Basically, a series of approaches have been developed for designing ontologies including On-To-Knowledge and METHONTOLOGY (Corcho et al. 2003). Some ontology methods were developed for specific domains such as enterprise modeling. The Enterprise Ontology (Uschold et al. 1998) and the TOVE (Toronto Virtual Enterprise) project ontology by Fox et al. (1996) are some of instances of ontological methods in that domain. Besides these specific ontology methodologies, Pinto and Martins (2004) described a generic ontological engineering process that includes: specification, conceptualization, formalization, implementation and maintenance. In general, some of the reasons that inspired ontological developments are (Noy and McGuinness 2001):

- To share common understanding of the structure of information among people or software agents.
- To enable reuse of domain knowledge.
- To make domain assumptions explicit.
- To separate domain knowledge from the operational knowledge.
- To analyze domain knowledge.

2.2.1 Ontological Modeling in Healthcare Domain

As discussed earlier, many application domains are being represented using standardized ontologies which enabled domain experts to share and annotate information in their fields. Ontologies are designed to be used in areas that not only need to process the content of information but also require to reason about it (Valls et al. 2010). Because of the complexity of the concepts involved and the level of detail needed to describe healthcare processes, the medical domain is one of the most active ones in defining and using ontology (Cimino and Smith, 2006). Much of the existing ontology work in healthcare has focused on defining medical terminology with a clear and consistent meaning which promotes the exchange of information between various institutions, different professionals, or systems. Some examples of widely used medical ontologies concentrated on developing domain terminology are GALEN (Rector and Rogers 2006), Medical Subject Headings, MeSH, (Nelson et al. 2001), Systematized Nomenclature of Medicine, Clinical Terms, SNOMED-CT, (Spackman et al. 1997), Unified Medical Language System, UMLS (Nelson et al. 2002) and ON9 (Gangemi et al. 1998). Care planners and healthcare applications can exploit of these ontologies in very different tasks, such as sharing common terminology and taxonomy, visualization, data classification and knowledge reuse and decision support in medical settings (Nebot and Berlanga 2009). However, as these ontologies grew in size they become more difficult to use for specific applications. Aside from those high level ontologies, some specific ontologies also exist such as the Foundational Model of Anatomy (Rosse and Mejino Jr

2003) and Gene Ontology (Harris et al. 2004) which respectively define the concepts and relationships that relate to the structural organization of the human body and function of genes across species. On the other hand, the new stage of electronic health has resulted in a number of issues such as needed interoperability of medical applications and services whereby the effective consolidation of various health information domains and the well timed access to appropriate information resources is highly required (Kotovsky et al. 1998). Therefore, the application of ontologies in HIS design as a shared platform for integrating the information and process requirements for care delivery has been promoted. In the past few years we have witnessed a range of applications and studies in the area of ontology for information system design (Kuziemsky et al. 2009 and 2010).

2.2.2 Ontology Evaluation and Validation

The need for evaluation of ontologies has emerged since 1994 and has been growing ever since (Sure 2004). No single satisfactory unifying ontology evaluation approach has been proposed to date. Ontology evaluation and validation can be viewed as a diagnostic task to assess the quality of presented ontology using a specific measure of application (Brank et al. 2005). Evaluation can be conducted during design and development or prior to use when the ontology is finished (Kalfoglou et al. 2003). Approaches to ontology evaluation include type, purpose and level of evaluation, or qualitative, quantitative measures. Referring to ontology as any kind of graph of meta data, three main groups of measures for ontology evaluation were introduced as structural which focus on measuring structural properties of the ontology as a graph; functional measures, that are related to

the intended use of an ontology and of its components and usability-related measures, that concerned with meta data and annotations of the ontology (Gangemi et al. 2005). Based on type and purpose of the ontology, validation approaches are divided into: comparison to a golden standard, the results of ontology implementation in specific application, comparisons with a source of data and user evaluation according to predefined standards (Brank et al. 2005). Relying on the level of validation, approaches are classified into: lexical, vocabulary, or data layer that focus on hierarchy or taxonomy, precision and recall, concepts and vocabulary, structure and architecture and etc (Brank et al. 2005). Qualitative approaches for ontology validation compare the ontology to a standard often using subjective means (Gomez-Perez 1994). A number of criteria have been identified by (Fox et al. 1993; Gruber 1993) for ontology validation including:

"**Completeness:** Can the ontology represent the information necessary to support some task?

Generality: To what degree is the ontology shared between diverse activities?

Efficiency: Does the ontology support efficient reasoning?

Perspicuity: Is the ontology easily understood by the users so that it can be appropriately interpreted across the system?

Precision/Granularity: Does the representation support reasoning at various levels of abstraction and detail?

Minimality: Does the ontology contain the minimum number of objects?

Scalability*:* Does the representation scale to support large applications?"

However, Fox et al. (1996) introduced competency questions as the most useful criteria for ontology validation. For any task in which the ontology is to be applied, the task compels a set of queries that the ontology should be able to answer. In fact, these queries will serve as the litmus test to evaluate the expressiveness of the ontology and see if the ontology contains the relevant information to provide solutions for those questions. Ideally, the competency questions should be defined in a hierarchal manner whereby higher-level questions should provide needed solutions for lower level questions.

2.3 Related Work and Literature Gaps

Ontologies can be viewed as the best means of representing reality which is the foundation of any information systems design (Fonseca 2007). Designing information systems for healthcare teams to assist team functions have proven to be difficult since numerous HIS projects fail upon execution due to fact that systems being widely established based on wrong assumptions (Berg 2003). Therefore, it can be claimed that the quality of the intended IS will totally rely on the quality of the ontologies they are based upon (Weber 2003). A standard ontology based framework for modeling collaborative systems such as healthcare teams would supply professionals with the capability to design a better IS framework.

Existing research on healthcare teams has focused on single or a few dimensions and has not described the integration of the multiple dimensions of healthcare teamwork. Workflow management systems (WMS) exist and have been applied in healthcare such as (Mueller et al. 1999). However, the WMS have largely focused on workflow

coordination of patient specific guidelines in single settings and not on methodological approaches to model teams across multiple settings. Similarly, group decision support systems exist but they are designed to support predefined tasks and not for integrating healthcare team various components. The field of computer supported cooperative work (CSCW) has provided insight on technology enabled collaboration. However, that research is largely conceptual and emphasizes the need for methodological research on how to model healthcare teams. Overall there are few studies both inside and outside of healthcare that focus on the integration of multiple dimensions of healthcare teams to design information and communication technologies (ICT) to support basic team functions (Te'eni et al. 2001).

One extension of ontology research is ontology driven IS design. Key work in ontology concept development includes (Kuziemsky et al. 2008; Kuziemsky and Lau 2010) who developed a conceptual framework for designing and implementing an ontology to support both day-to-day case management and education of palliative Sever Pain Management (SPM). Similarly, (Kuziemsky et al. 2009) presented an exploratory framework for interdisciplinary team communication and provided details for team meta-ontology of structures, processes and outcomes to describe how this framework can support HIS design for e-teams.

Moreover, in the context of ontology validation, Fox et al. (1996) have developed a method and set of competencies to evaluate ontology design and task support for enterprise models and supply chain management and has enhanced our ability to develop

quality models of those domains. In addition to what we have discussed earlier in this chapter, the literature is suggesting research on the following areas:

- Developing a systematic framework for integrating the multiple dimensions of the healthcare team and clearly defining the possible interrelations between those dimensions. It would be also helpful if the generic framework can be tailored to specific characteristics of different healthcare team types (Lemieux-Charles et al. 2006).
- Providing explicit details on how to incorporate theoretical foundation into ontology in healthcare domain in order to model the patient care teams in different settings where teams exist (Kuziemsky and Lau, et al. 2010).
- Bringing conceptual clarity to the multiple dimensions of healthcare team practices with the aim of improving the consistency in research and facilitating the communication in clinical and academic environments (Xyrichis and Ream 2008).
- Evaluating the expressiveness and completeness of the ontological models before IS design and implementation to assure that the ontology contains relevant information to accurately represent the domain in which it is employed (Fox et al. 1996).

The topics that we have discussed so far together with the current research knowledge and gaps in the literature are all summarized in the following table.

Table 1. Current Research Knowledge and Gaps

Topic	Current Knowledge	Current Gaps	References
Healthcare Team Models	Focus on Single or a Few Aspects of Teamwork	Results Usually Present Overlaps, Limitations and Inconsistencies	Lemieux-Charles et al. (2006)
Ontology Development Methods	Provide Tasks for Ontology Design	Need for Explicit Details on How to Incorporate Theoretical Foundation into Ontology	Kuziemsky et al. (2010)
Multiple Dimensions of Teamwork	Broad Literature on Organizational settings Rarely Well-defined Literature on Healthcare Domain	Lack Of Consistency in Terminology and Conceptual Clarity Regarding Multiple Dimensions of Healthcare Teamwork	Xyrichis et al. (2008)
Ontology Validation Methods	Ontology Validation After Design and Implementation of IS	Lack of Satisfactory Approach for Validating Initial Ontological Model	Fox et al. (1996); Fonseca (2007)

Chapter 3: Research Methodology

Design science research was used as the overarching methodology in this thesis. In our research, we followed the three main steps of the cyclical approach of design research including : (1) Identification and specification of the problem area in a domain of research, (2) Developing the framework as a design artefact; and (3) Validation and evaluation of the applied framework (Hevner et al. 2004). Figure 3 displays build-and-evaluate loop of design science methodology.

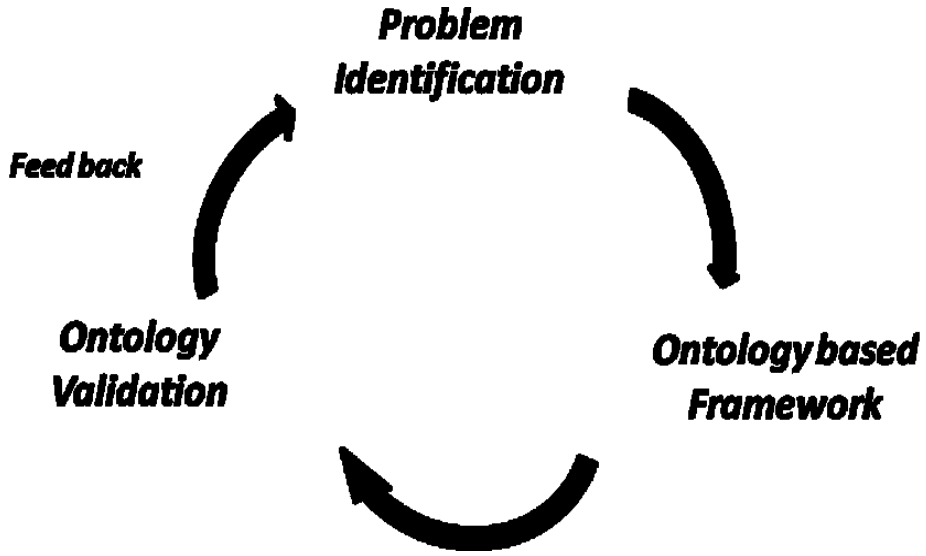

Figure 3. The Applied Design Science Methodology

In the first stage of the design science approach we made an effort to identify and describe the literature shortcomings in team based modeling. Identifying the problem was conducted through a literature review on teamwork in healthcare domain together with analyzing existing health care team models in order to understand the gaps in the context of modeling the healthcare teams.

In the second stage of the design science approach we followed an iterative approach in developing a comprehensive framework in order to address the identified gaps in previous stage. As discussed before, one of the possible ways to develop this novel framework is to make use of ontological engineering.

So far, different ontology development methodologies have been proposed including On-To-Knowledge and METHONTOLOGY. Apart from specific ontology development methods, Pinto and Martins (2004) describe a general ontology design process that has five stages including: specification, conceptualization, formalization, implementation and maintenance. On the other hand, in the domain of enterprise modeling, some ontology developing approaches were reported such as Enterprise Ontology and the Toronto Virtual Enterprise.

Among the existing ontology development methodologies, we drew upon the TOVE methodology because of its strong emphasis on validation stage (competencies). TOVE methodology (Gruninger and Fox 1996; Gruninger 1996) for modeling enterprise processes and supply chain management has the following stages:

- *Capturing the motivating scenarios*: TOVE approach to ontological engineering starts with specifying the main scenario which is the intended applications in which the proposed ontological model will be employed. Hence, ontological engineering should begin with defining these applications or specific problems in order to define ontology's scope.
- *Developing informal competency questions*: In this stage the motivating scenario will be defined in the form of series of questions called competencies that the ontology must be able to answer.
- *Defining ontology terminology*: The third stage is to extract the main concepts and define their attribute and relations (usually in first order logic).
- *Formulate formal competency questions:* The identified questions are formalized based on formally defined terminology from the previous stage.
- *Specifying axiom:* This stage specifies constraints over the ontology terminology and limits the probable interpretations of the ontology terms. In fact, axioms are necessary and sufficient conditions to express the competency questions and their solutions.
- *Evaluation of ontology completeness:* Final stage checks the competency questions from staged 4 and represents the condition under which solutions to those questions are complete.

In order to properly support our research scope, we adapted TOVE methodology into biomedical domain and modified its six stages to four main stages. We also supplemented

each stage by defining particular tasks, applied methods and achieved outcomes. Figure 4 illustrates our four stage ontology-based approach for modeling healthcare teams.

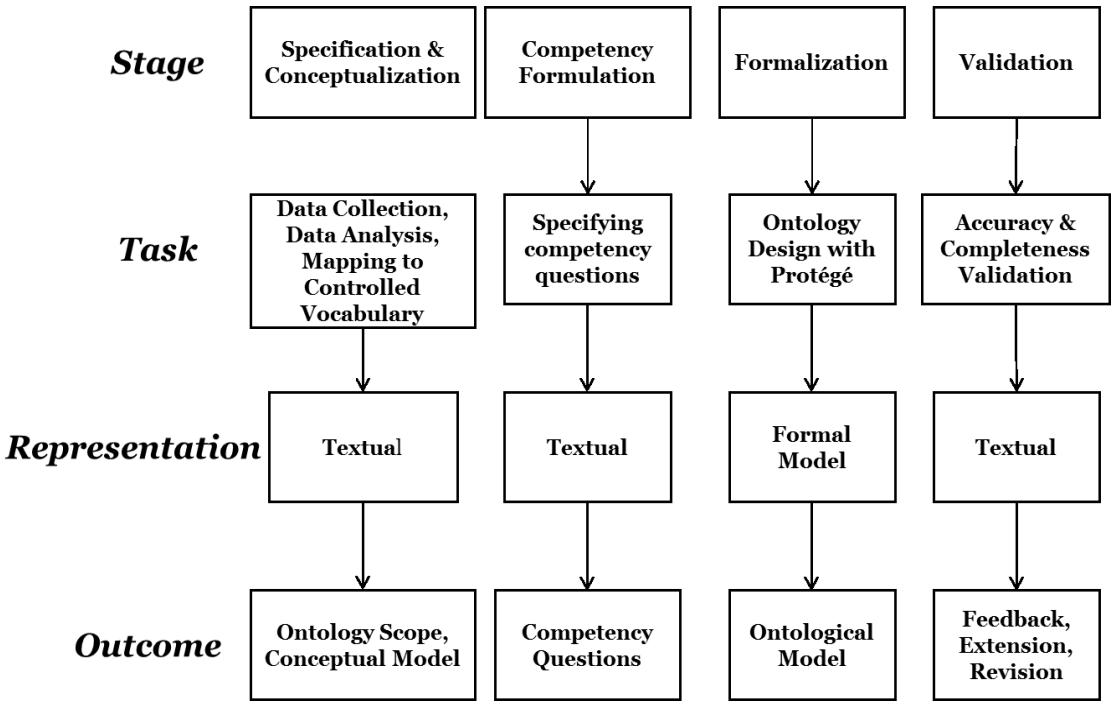

Figure 4. Four Stage Methodological Approach (Adapted from Kuziemsky and Lau, 2010)

Finally, in the third stage of the design science approach, the accuracy and completeness of the healthcare team ontological framework was validated to show how proposed framework could meet the scope and purpose it is being applied for. The main outcomes of this stage are detailed analysis and evaluation accompanied by relevant documentations which can provide good feedback for better understanding the problem area or model revision or maintenance (Chapter 5).

Chapter 4: Results

As mentioned in chapter 2, the literature is lacking a comprehensive ontology-design framework specifically developed for integrating the multiple dimensions of healthcare teamwork. In order to overcome this literature gap, we propose our framework based upon the TOVE methodology, which is an organization ontology for enterprise modeling. We adapted the TOVE methodology to the biomedical domain and also modified its six ontology stages to four stages including: *Specification and Conceptualization, Competency formulation, Formalization* and finally *Ontology Validation* (Chapter 3). The four stages collect and organize knowledge in the biomedical domain area to develop a derived ontological framework. We believe that the proposed ontological framework will fill the literature gaps by providing a comprehensive model represents multiple dimensions of healthcare teamwork and accurately defines the relationships between. The following section provides more details about different stages of our ontology-based framework.

4.1 Stage 1: Specification and Conceptualization

Specification identifies the purpose and scope of the ontology while conceptualization provides the concepts, vocabulary and relationships for ontology design in a specific

knowledge domain. There are three tasks done in this stage: data collection, data analysis and mapping to controlled vocabulary, each of which will be discussed below.

4.1.1 Data Collection

A literature review was the main source to collect data in our knowledge domain. A literature review was done on healthcare teams as well as relevant literature from teamwork in domains outside healthcare such as organizational settings in order to obtain a comprehensive understanding of the current state of research in the field of teamwork. Our search for publications was conducted using the following search terms: 1) team or teamwork; 2) healthcare team or inter-professional care team; 3) interdisciplinary, multidisciplinary and transdisciplinary teams. Using teamwork definition as a starting point, we continued the literature search through academic journals; Medline data base and other models of healthcare teams to identify multiple dimensions of healthcare teams and their relationships.

In this stage, we start defining the scope and domain of our ontology by asking very basic and broad questions. At any given time during data collection, potential answers to these questions can help limit the scope of the ontological model (Noy and McGuinness 2001).

1. What is the scope that the ontology will intend to cover?
2. For what applications we are going to use this ontology?
3. For what types of questions should the information in the ontology deliver answers?

As discussed in the research contributions in the first chapter, our ontology aims at integrating the multiple dimensions of healthcare teams in order to propose a comprehensive model tailored to specific healthcare team types including interdisciplinary, multidisciplinary and transdisciplinary. The ontological model can be used as a foundation for healthcare information system design in order to support team tasks. Inherently, the concepts in our ontological model describe different dimensions of healthcare teams and identify how these dimensions affect team final outcomes. In addition, the ontological concepts clearly define the specific characteristics of the aforementioned healthcare teams.

4.1.2 Data Analysis

The collected data was summarized into main concepts using qualitative content analysis. Qualitative content analysis is a research technique concentrated on the characteristics of data with special focus to the content or contextual meaning of the text. This method interprets meaning from the content of text data through the systematic classification process to represent similar meanings in more manageable categories (Hsieh and Shannon 2005). The predominant concepts that emerged from data analysis were organized according to the root concept *Team Structure* with seven meta-concepts: *Process, Information Resources, Member, Outcome*, *Governance, Composition* and *organizational context*. The rationale for choosing these meta-concepts is that in order to model the team based environment we need to first define the main processes that occur as part of clinical practice, the members responsible for conducting those processes and

the information needed to support the processes. Identifying a process without knowing its final desirable outcomes or influential factors on that process such as composition and organizational context will not provide the necessary support for developing complete team based model. Figure 5 illustrates the mindmap of the meta-concept of the healthcare team ontological model.

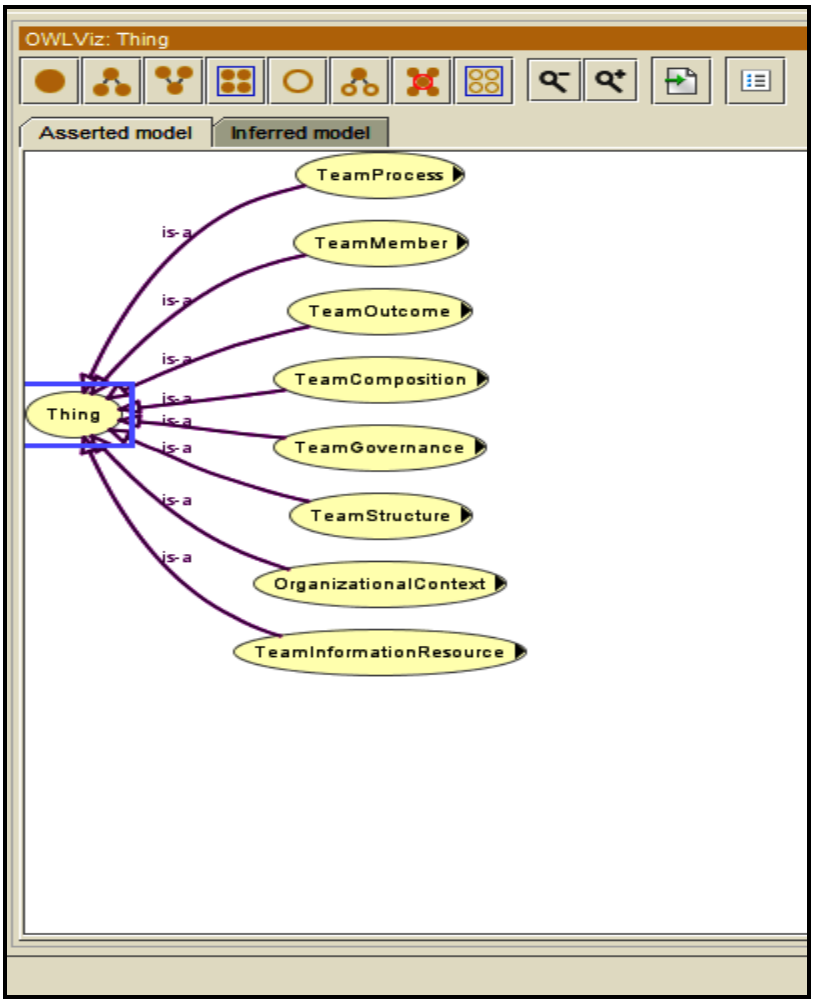

Figure 5. Meta-concept Mindmap of Healthcare Team Ontology

In addition the following table shows an example of how the literature was organized into final concepts in our ontology through qualitative content analysis method.

Table 2. Collected Source Leading to Final Concepts

Row	***Resource***	***Data***	***Final Concept***
1	Research Literature- Senge, P., 1990. The leaders new work: building learning organizations. Sloan Management Review, 7.	The complex issues involved in the process of care delivery necessities the dedicated role to develop a common vision and sustain more analytical thinking among team members.	***Leadership***
2	Research Literature- Kuziemsky, C.E. et al., 2009. An interdisciplinary team communication framework and its application to healthcare 'e-teams' systems design. Journal of BioMed, 9, 43. Research Literature- Toussiant, P.J., Coiera E., 2005. Supporting Communication in Health Care. International Journal of Medical Informatics, 74, 779-781.	Health care complex work environment demands the expertise and knowledge of different individuals or specialists be integrated to solve patient care problems. So far health informatics research has attempted to concentrate on outlining and storing information despite the fact that up to 90% of information transactions in medical systems involve information exchange	***Communication***
3	Research Literature - Reddy, M., Spence, P.R., 2006. Finding answers: Information needs of a multidisciplinary patient care team in an emergency department. In Proceedings of the American Medical Informatics Association Fall symposium (AMIA'06), Washington, DC.	Healthcare teams often work in rich information environments. As the patient information often located in different resource, health providers usually face problem finding right information at the right time at the right place. Therefore, to be able to manage large amounts of information to handle care services, collaborative teams require an integrated structure to rapidly collect and share data among multiple professionals.	***Information Management***
4	Research Literature- Oandasan, I. et al., 2006.Teamwork in healthcare: Promoting effective teamwork in healthcare in Canada. *Report from Canadian Health Services Research Foundation*.	The functioning of healthcare teams changes depending on the patient requirement lead to a variety of team types. Teams can be consisted of small number of providers with limited interaction to variety of professional collaborate with each other to address a common problem. Each of team may follow different level of interaction and collaboration mode.	***Team Structure***

5	Research Literature- Torrens, P.R., 2010. The healthcare team members who are they and what do they do? Published in Collaboration Across the disciplines in Healthcare, Chapter1, Jones and Bartlett Publishers, LLC.	Nowadays care services usually provided by widely varied care providers who worked together as a whole to create cohesive final outcome. In a healthcare team, individual professionals acting as team players are responsible for their own area of skills and knowledge while accountable for integrating multiple disciplinary boundaries to meet multifaceted and complicated patient problem.	***Team Member***
6	Research Literature- Jeffcott, S.A., Mackenzie, C.F., 2008. Measuring team performance in healthcare: Review of research and implications for patient safety. *Journal of Critical Care*, 23, 188–196.	Patient safety literature accentuated that poor teamwork leading to adverse events. So assessing and evaluating team performance seem crucial to enable assessment and monitoring of healthcare team effectiveness.	***Team Outcome***

Once we defined our concepts, the next task was to describe their internal structure to explain the linkages and relationships among those concepts. Analyzing the literature resulted in identification of various properties that exist across the ontological concepts.

In an ontological model, properties are binary relations on ontology concepts that link two concepts together. For example, the property *Has Information Resource* might link the concept team structure to the concept information resource, implying that healthcare teams are equipped by diversified information resources. Or the property *Has Member* might link the concept team structure to the concept team member indicating which members are belonging to that healthcare team. Properties may have a specified domain and a range. In those cases, the concept in the origin of the relation represents the *domain* and those in the destination shows the *range.* Table 3 illustrates an example of how some of the raw data organized into final properties.

Table 3. Collected Source Leading to Final Properties

Row	***Resource***	***Data***	***Property***	***Domain***	***Range***
1	Research Literature-Sands, D.Z., 2008. Challenges in Healthcare Communications How Technology Can Increase Efficiency, Safety, and Satisfaction. *Cisco Internet Business Solutions Group IBSG*.	"In the healthcare teams there are several subsets of professions each which bring about different roles and responsibilities for the members. For example all the members are not the same in what they do, nor do they conduct the same process as all other members".	***perform***	Member	Team process
2	Research Literature-Reddy, M.S., Spence, P.R., 2008. Collaborative information seeking: A field study of a multidisciplinary patient care team. *Information Processing and Management*, 44, 242-255.	"There are also a number of values/behaviors that underlie collaborative practice models. These include: Trust among all team members establishes a quality working relationship. Knowledge is a necessary component for the development of trust. Shared responsibility suggests joint decision making for patient care outcomes. Mutual respect for the expertise of all team members is the norm".	***Characterized By***	Member	Member trait
3	Research Literature-Torrens, P.R., 2010. The healthcare team members who are they and what do they do? Published in Collaboration Across the disciplines in Healthcare, Chapter1, Jones and Bartlett Publishers, LLC.	"At the same time, the increasing number of information resources and systems has created a problem. Different pieces of the patient information are located in different resources, often for good reasons. For instance, digital images may be in one resource and lab results in another resource".	***Has Information Resource***	Team structure	Information Resource
4	Research Literature-Anderson, M., 2004. Literature review for guidelines development. *A discussion paper prepared for the Multidisciplinary Collaborative Primary Maternity Care Project*. Ottawa: MCP2.	"Many communication channels are used in healthcare, each with different properties. These channels may be synchronous or asynchronous, mobile or fixed, secure or non-secure. Because of this, members must decide which channel best suits the issue about which they need to communicate".	***Has Communication Channel***	Member	Communication Channel

4.1.2.1 Team Process Meta-concept

In literature on work design, a process is defined as "A specific ordering of work activities across time and place, with a beginning, an end, and clearly defined inputs and output" (Davenport 1992). In general, a process is an activity of networks that have been defined to achieve a specific output based on the given inputs. Generally each process is performed by integration of multiple activities and interaction of several members, even though it can be conducted by only one member and through one activity.

Although the functioning of healthcare teams varies depending on the needs of the patient, the healthcare team processes identified from the literature are: *Communication; Collaboration; Coordination; Decision logistics* and *Information management*, each of which has its own sub concepts (Described in Chapter 2, **2.1.3.1 -2.1.3.5**).

In a healthcare team, every process associates with team members and team information resources. In fact, each process is performed by team members and uses or creates some information resource. In healthcare teams the result of each process is stored in the form of series of one or several types of information resources such as electronic or paper based documents.

Moreover, Cohen and Bailey (1997) introduced the *Task Feature* concept as the other associated factor to team processes. They defined task features as those characteristics of task that can be directly controlled by authorities to put the conditions on team process. Interdependence, Procedure clarity, Rules and Policy, and Work cycle considered as the most promising factors related to team process. Any changes to task feature factors can

directly affect the team process and through its impact on team process might indirectly influence the overall outcomes. For example increasing team interdependence results in higher level of members' satisfaction and finally improves the process of decision logistic (Lemieux-Charles et al. 2006).

Generally speaking, a healthcare team process starts when a patient comes to the team; continues when patient passes through the diagnosis and treatment stage and finally ends when patient leaves the team (Dang et al. 2008). We named these four stages as the *Continuum of Care Service* in our ontology. In fact, the Continuum of Care Service limits the scope of healthcare team processes and implies that the team processes should cover all of the following stages. The starting point of the continuum is the admission stage, when a patient comes into a team. In this stage all the necessary information related to patient including medical history, insurance information and emergency contacts will be checked for availability and consistency. Then the patient goes through the assessment stage in which care providers might do some tests to support the problem diagnosis. Afterward, the treatment stage follows to treat the patient's disease. Finally at the opposite end of continuum is the discharge stage when a patient leaves the team.

Overall the following properties are defined for the Team Process meta-concept:

- *Is Influenced By:* Team Process ⟶ Task Feature
- *Cover:* Team Process ⟶ Continuum of Care Service
- *Create:* Team Process ⟶ Team Information Resource
- *Is Performed By:* Team Process ⟶ Team Member

- *Directly Affect:* Team Process ⟶ Team Outcome
- *Intitiated By:* Team process ⟶ Admission Stage
- *Terminated By:* Team Process ⟶ Discharge Stage

4.1.2.2 Team Information Resource Meta-concept

In a healthcare team, there is usually a variety of resources to support the care processes such as pharmaceutics, equipment, material and information. But in our current study, we focus solely on information resource due to the fact that it plays a critical role not only in decision making but also in completing other essential team processes such as coordination. The information resources should be complete, well integrated into the patient's overall record and easily accessible for all team members (Torrent 2010). Because of the broad range of information resources available to a healthcare team, information is often available when the team members required it; however, team members often have to look for different resources to find and gather the needed information at the right time to appropriately perform team processes. In general, the most utilized information resources in healthcare team are: Electronic, Document and Authority (Described in Chapter 2, **2.1.4.1 - 2.1.4.3**). Information is transmitted among the team members using communication channels which will be discussed later.

The following properties are defined for the Team Information Resource meta-concept:

- *Is Accessible To:* Team Information Resource ⟶ Team Member
- *Is Created In:* Team Information Resource ⟶ Team Process

- *Transmitted through:* Team Information Resource→ Communication Channel
- *Directly Affect:* Team Information Resource ⟶Team Outcome

4.1.2.3 Team Member Meta-concept

The meta-concept of member in the healthcare team ontology may be populated by multiple professionals representing a variety of disciplines depending on the team models. In our ontology the first group of members is *physicians* who have a central role and important responsibility for making decisions in the process of diagnosis and care delivery. The second group of members is *nurses*. The International Council of Nurses defined nursing role as "autonomous and collaborative care of individuals of all ages, families, groups and communities, sick or well and in all settings. Nursing includes the promotion of health, prevention of illness, and the care of ill, disabled and dying people. Advocacy, promotion of a safe environment, research, participation in shaping health policy and in patient and health systems management, and education are also key nursing roles". In addition to previous groups, "*support service providers"* or allied health providers such as technical and administrative staff, counselors or social workers, physical or mental therapist will have important roles in improving the primary care services (Torrent 2010).

Each of the team members may have different concerns, tasks, and motivations but they have to follow a set of values or behaviors such as trust, respect, responsibility and accountability (Described in Chapter 2, **2.1.5.1- 2.1.5.2)** as a basis of member relationships to provide effective patient care services. Moreover, it seems necessary for

all the members to always bring their own special knowledge, skills and experiences to the problem to achieve creative solutions (West 1997).

Team members communicate with each other using *Communication Channels.* Communication channels are bidirectional links established among team members in different roles to enable them to exchange information. Through communication channels, members in a given organizational role can receive the information they are interested in and can distribute information to others in order to combine their different skills as interdependent team. Usual communication channels utilized in a healthcare team are divided into two main categories (Sand 2008):

- *Synchronous channels:* Including telephone and face to face meeting enable team memebers to communicate freely at the same time. Especially, these channels are useful for sharing time sensetive or large amount of information.
- *Asynchronous channels:* Such as email, fax, and blogs enable each member to communicate when it is convenient. These channels are mostly used for non-emergency cases.

Overall the following properties are defined for the Team Member meta-concept:

- *Characterized By:* Team Member ⟶ Member Trait
- *Perform:* Team Member ⟶ Team Process
- *Has Authority To Access:* Team Member ⟶ Team Information Resource
- *Has Communication Channel:* Team Member ⟶ CommunicationChannel
- *Directly Affect:* Team Member ⟶ Team Outcome

4.1.2.4 Team Composition Meta-concept

In our ontological model, team composition encompasses several factors including: Age, Size, Gender, Disciplinary diversity, Frequency of meetings, and Willingness to collaborate. It has been shown that team composition can directly affect the team outcomes; however, none of previous healthcare team effectiveness studies have succeed to rigorously explain which aspects of team composition have the greatest influence on team outcomes (Lemieux-Charles et al. 2006). Team composition has an effect on team structure too. For example, regarding the factor of frequency of meetings, we can say that interdisciplinary teams are characterized by frequently scheduled meetings that encourage team members to share information, engage in group decision making and learn from each other to develop a common treatment plan; however, in contrast to interdisciplinary team, members in multidisciplinary team just have meetings when they want to discuss their own individual progress or if a change is needed to the patient treatment plan.

Varied results have been found on the connection of disciplinary diversity with the team final outcome. Some studies demonstrated that increasing diversity will result in better patient outcomes (Dutton et al. 2003) while others suggested that more diverse teams were less satisfied with team functioning (Vinokur-Kaplan 1995).

In the context of team size, previous research (Steiner 1972) suggested that curvilinear relationship exists between team size and team outcome which means, up to

the specific point, team size has positive effect on team outcome; however, when the team size crosses that point, negative impact will be exposed.

Gender is another factor influences how well the team members work together. Lichtenstein and D'Aunno (1996) suggested that, mixed gender team will positively affect member's appraisal of how compatibly team functioned as a whole which in turn leads to increased job satisfaction among members. Overall team composition is related to:

- *Directly Affect:* Team Composition ⟶ Team Outcome
- *Has Effect On:* Team Composition ⟶ Team Structure

4.1.2.5 Organizational Context Meta-concept

Organizational context refers to those characteristics of the external environment in which healthcare teams are embedded. The literature has increasingly witnessed that organizational factors have a great impact on healthcare team performance **(**Walsh et al. 1999). It has been approved that organizational structure within which a health care team operates can indirectly affect the team final outcomes (Lemieux-Charles et al. 2006).

Indirectly Affect: Organizational Context ⟶ Team Outcome

Organizational context can influence the healthcare team effectiveness in a variety of ways including:

- Clear organisational *supervision and reward systems* can provide supportive environment enabled healthcare teams to function more effectively.

- The powerful *feedback mechanism* creates opportunity for healthcare teams to assess their performances more easily.
- Appropriate organizational *training system* helps inter-professional teams to learn how to work together.
- Organization should provide *financial, technological and human assistances* to support team implementation.

4.1.2.6 Team Outcome Meta-concept

Outcome is defined as the ending results of the team performance. To date, a wide variety of outcome variables have been proposed for measuring the healthcare team effectiveness; however, the literature lacks a consistent and standardized assortment of outcome metrics allowing professionals to choose the best set of outcomes to assess team performance (Dassow 2007). In medical settings, clinical and cost effectiveness are often examined without well-defined criteria for assessing team final outcomes. As a result, it is difficult to compare the different researches to find out which teams are most effective. To define the outcome meta-concept in our ontological model, using different classification of team outcome criteria, we draw upon Schofield and Amodeo (1999) categories of outcomes including patient outcomes, member outcomes and organization outcomes.

- *Patient outcome*: Refers to both objective patient outcomes such as measurable advances in patient clinical status and subjective patient indicators including patient and family satisfaction.

- *Member outcome*: Refers to both clinical quality of offered services and improvement in team members behaviors such as job satisfaction, commitment to responsibilities, response time to required services, absenteeism, trust in management.
- *Organizational outcome*: Financial impact on healthcare system, efficiency and productivity are some the prominent examples assigned to the organizational outcomes.

Overall the following properties are defined for the Team Outcome meta-concept:

- *Is Directly Affected By:* Team Outcome ⟶ Team Process
- *Is Directly Affected By*: Team Outcome ⟶ Team Information Resource
- *Is Directly Affected By:* Team Outcome ⟶ Team Member
- *Is Directly Affected By*: Team Outcome ⟶ Team Composition
- *Is Indirectly Affected By:* Team Outcome ⟶ Task Feature
- *Is Indirectly Affected By:* Team Outcome ⟶ Organizational Context

4.1.2.7 Team Structure Meta-concept

So far, we have defined the multiple dimensions of the healthcare teamwork construct. Integrating and incorporating all the above addressed meta-concepts and their relationships contribute to the design of our root concept healthcare team structure.

Teamwork is defined in the literature by Mohrman et al. (1995) as “A group of individuals who work together to produce products or deliver services for which they are mutually accountable. Team members share goals and are mutually held accountable for

meeting them, they are interdependent in their accomplishment, and they affect the results through their interactions with one another. Because the team is held collectively accountable, the work of integrating with one another is included among the responsibilities of each member".

As it is obvious from the definition, healthcare team is composed of several members with specialized knowledge and complementary skills collaborating with each other to conduct team processes to achieve satisfactory outcomes for clients/patients. In order to properly accomplish its commitments, healthcare team is equipped with some resources which should be always available for the team members to perform their roles. Although all the team members are mutually accountable for team ultimate targets, complex issues involved in the process of care delivery and decision making require a healthcare team to pick up a leader for developing and sustaining a common vision of team goals for entire members. The following properties are defined for the Team Structure meta-concepts:

- *Has Information Resource:* Team Structure ⟶ Team Information Resource
- *Has Process:* Team Structure ⟶ Team Process
- *Has Leader:* Team Structure ⟶ Leader
- *Has Member:* Team Structure ⟶ Team Member
- *Composed Of :* Team Structure ⟶ Team Composition
- *Achieve:* Team Structure ⟶ Team Outcome

In our ontological model, the team structure concept consists of three most common healthcare team types including: interdisciplinary, multidisciplinary and transdisciplinary

teams. Although all of these team structures similarly inherit the entire recommended properties from team structure, each structure has their own specific characteristics which will be discussed in more details in the following section through the team governance terminology.

4.1.2.8 Team Governance Meta-concept

In the literature, the terms interdisciplinary, multidisciplinary and transdisciplinary are often used interchangeably; however, the three terms do not have a same meaning but rather refer to different degrees of teamwork. The governance meta-concept in our ontological model is intended to compare and distinguish between these three specified teams with the aim of developing multiple models of team structure tailored to unique characteristics of each team

In general, special distinctions among the triple healthcare team types refer to:

- ***Collaboration Mode***: Refers to three specific degrees of collaboration and responsibility sharing among team members.
  - *Independently:* Used by a multidisciplinary team in which different professionals usually function separately and just meet to discuss their progress.
  - *Jointly But Keep Assignment*: Used by an interdisciplinary team in which team members work jointly to address a common problem and develop team intervention plans but still keep their distinct professional assignments.
  - *By Team Consensus:* Used by a transdisciplinary team in which individuals transcend disciplinary boundaries and share a common conceptual framework

through which all decisions in the areas of patient assessment, treatment and team evaluation will be made by team consensus.

- ***Role****:* Is defined as "An abstraction of capabilities used by an actor in dealing with a process" (Dang et al. 2008). Team members play one or several roles, each of which is addressed with a series of goals that the role is created to fulfill.
  - *Separate but interrelated role:* Multidisciplinary team composed of multiple members with separate role who work alongside each other. In this team, each member is responsible for the part of the service associated with his or her own professional discipline.
  - *Interdependent role:* Within interdisciplinary team, all the members come together as a whole and follow each other to develop goals or address a common problem.
  - *Role release:* Another characteristic of a transdisciplinary team is that each member becomes so familiar with other roles that team tasks to some extent become commutable. For example, a specialist helps other members to obtain expertise related to the specialist's area of skills. This means that other team members should accept that they can do what the specialist was specifically trained to do.
- ***Goal****:* Each team has one or several goals that they aim to achieve. These goals can include:

- *Individual goal:* In multidisciplinary team various professions individually set the desired goals.
- *Shared goal:* In interdisciplinary and transdisciplinary teams, first a set of common goals are agreed by the team, and then team members coordinate their inputs to meet and develop the shared goals.

In general, the following properties are defined for the Interdisciplinary Team concept:

- *Has Information Resource:* Interdisciplinary Team → Team Information Resource
- *Has Process:* Interdisciplinary Team ⟶ Team Process
- *Has Leader:* Interdisciplinary Team ⟶ Team Leader
- *Has Member:* Interdisciplinary Team ⟶ Team Member
- *Composed Of:* Interdisciplinary Team ⟶ Team Composition
- *Achieve:* Interdisciplinary Team ⟶ Team Outcome
- *Setting Goals:* Interdisciplinary Team ⟶ Shared Goal
- *Plays:* Interdisciplinary Team ⟶ Interdependent Role
- *Collaborate:* Interdisciplinary Team ⟶ Jointly But Keep Assignments

Overall, the following properties are defined for the Multidisciplinary Team concept:

- *Has Information Resource:* Multidisciplinary Team → Team Information Resource
- *Has Process:* Multidisciplinary Team ⟶ Team Process
- *Has Leader:* Multidisciplinary Team ⟶ Leader
- *Has Member:* Multidisciplinary Team ⟶ Member
- *Composed Of:* Multidisciplinary Team ⟶ Team Composition

- *Achieve:* Multidisciplinary Team ⟶ Team Outcome
- *Setting Goals:* Multidisciplinary Team ⟶ Individual Goal
- *Plays:* Multidisciplinary Team ⟶ Separate But Interrelated Role
- *Collaborate:* Multidisciplinary Team ⟶ Independently

The following properties are defined for the Transdisciplinary Team concept:

- *Has Information Resource:* Transdisciplinary Team ⟶ Team Information Resource
- *Has Process:* Transdisciplinary Team ⟶ Team Process
- *Has Leader:* Transdisciplinary Team ⟶ Leader
- *Has Member:* Transdisciplinary Team ⟶ Member
- *Composed Of:* Transdisciplinary Team ⟶ Team Composition
- *Achieve:* Transdisciplinary Team ⟶ Team Outcome
- *Setting Goals:* Transdisciplinary Team ⟶ Shared Goal
- *Plays:* Transdisciplinary Team ⟶ Role Release
- *Collaborate:* Transdisciplinary Team ⟶ By Team Consensus

4.1.3 Mapping to Controlled Vocabulary

Once all the ontology concepts and relationships were defined we mapped them to a formal medical terminology in order to give each concept a unique concept identifier.

Among the different available formal medical terminologies, we decided to use the Unified Medical Language Source (UMLS) due to its numerous advantages. UMLS is a comprehensive vocabulary that integrates multiple terminologies including SNOMED,

NCBI taxonomy, Gene Ontology, the Medical Subject Headings (MeSH), OMIM, the Digital Anatomist Symbolic Knowledge Base, and Clinical Terms Version 3. The UMLS integrates more than 60 families of biomedical vocabularies and provides names for 900,000 concepts and 12 million relationships among these concepts (Bodenreider 2004). Each concept in the UMLS is defined by a concept unique identifier (CUI). The UMLS concepts are not only interrelated but also may be linked to other external resources such as GenBank. Importantly, the UMLS vocabularies are available for users at no fees for research. We browsed the UMLS Terminology Service (UTS) to search if an associated CUI was associated with the concepts in our ontology and then if a match existed, we manually mapped the identified CUI to related concepts (see Table 3). The main idea for mapping the concepts to CUI was to make our ontology interpretable to the standard terminology wherever possible and also to identify deficiencies in UMLS terminology with respect to healthcare teams. Table 4 shows the associated UMLS unique concept identifiers and their descriptions related to concepts in our ontological model.

Table 4. UMLS Semantic Identifiers and their Descriptions

Name	***Taxonomy***	***CUI***	***UMLS Description***
Admission activity	Team process 4.1.2.1	C0809949	The condition of being allowed to enter
Collaboration	Team process 4.1.2.1	C0262116	The process by which two or more parties work jointly towards common goal
Communication	Team process 4.1.2.1	C0009452	Exchange or transmission of thoughts, messages, or information, as by speech, signals, writing, or behavior.
Communication Oral	Team process 4.1.2.1	C0871012	Expression of information in oral form

Conflict Resolution	Team process 4.1.2.1	C0150526	Process of reducing or removing antagonisms among individuals, groups, organizations and political entities.
Coordination	Team process 4.1.2.1	C0700114	The act of bringing into common action, movement, or condition.
Decision making (Decision Logistics)	Team process 4.1.2.1	C0011109	Making a choice among options, implementing the choice, and evaluating the effects of the choice, such as selecting and purchasing a specific item, or deciding to undertake and undertaking one task from among several tasks that need to be done.
Diagnosis (Assessment)	Team process 4.1.2.1	C0011900	The determination of the nature of a disease, or the distinguishing of one disease from another. Assessment may be made through physical examination, laboratory tests, or the likes. Computerized programs may be used to enhance the decision-making process.
Documentation	Team process 4.1.2.1	C0920316	Systematic organization, storage, retrieval and dissemination of specialized information, specifically for a scientific or technical nature.
Information Exchange	Team process 4.1.2.1	C0870706	Term was used to refer to a myriad of communicative and other exchanges
Information Seeking	Team process 4.1.2.1	C0596775	Actively investigating, obtaining or discovering information
Leadership	Team process 4.1.2.1	C0023181	Function of directing actions or attitudes of an individual or group with more or less willing acquiescence of the followers.
Patient Discharge	Team process 4.1.2.1	C0030685	The administrative process of discharging the patient from hospital
Treatment	Team process 4.1.2.1	C1522326	Subject to a process with the aim of readying for some purpose, improving, or remedying a condition
Written Communication	Team process 4.1.2.1	C0237440	Expression of information in written form
Electronic Document	Team Information Resource 4.1.2.2	C0681509	Material recorded in a format that requires an electronic device to view or modify the content

Information Resource	Team Information Resource 4.1.2.2	C1512758	Sources of healthcare information such as libraries, databases, and websites.
Communication Media (Channel)	Team Member 4.1.2.3	C0009458	The means of interchanging or transmitting and receiving information
Nurses	Team Member 4.1.2.3	C0028661	Professionals qualified by education at an accredited school of nursing and licensed by state law to practice nursing; provide services to patients requiring assistance in recovering or maintaining their physical or mental health
Physicians	Team Member 4.1.2.3	C0031831	A doctor, a person who has been educated, trained and licensed to practice the science of medicine
Patient Outcome	Team Outcome 4.1.2.5	C1547647	No Definition
Interdisciplinary Treatment Approach	Team structure 4.1.2.7	C0870721	Combination of two or more disciplines in the prevention, diagnosis, treatment, or rehabilitation of mental or physical disorders.
Generic Role	Team Governance 4.1.2.8	C1705810	The usual or expected function of something
Objective (Goal)	Team Governance 4.1.2.8	C0018017	Aims towards which an individual or a group aspire or effort is directed

As seen from the table above, the UMLS terminology does not cover all the defined concepts. For instance, we could not find the associated terms and related CUI for the concepts of: multidisciplinary team, transdisciplinary team, the process of inter-intra or patient-family coordination, formal or informal communication process, and organizational context or task feature factors.

4.2 Stage 2: Competency Formulation

In the first stage of our ontological framework we have answered three broad questions to limit the scope of the ontology. As the third question says, we expect that the information in this ontological model provide the answers to three main areas: 1) multiple dimensions of heath care teams and their relationships, 2) How these dimensions affect team final outcome and finally 3) distinctions among three most common healthcare team types. After analyzing the literature and defining ontology concepts and their internal structure (concept relationships), the second stage of the framework will drill down into each of these areas in the form of a series of more detailed questions called competencies. Competency questions try to fully configure the reasoning requirements and the range of information that the ontology must describe. Possible solutions to competency questions can provide clearer picture of scope and domain of the ontology. Following is the series of competency questions proposed for the healthcare team ontology:

Structure Competency

The first group of competency questions breaks down the required information about the multi-dimensional structure of a healthcare team. This group of competency questions tries to draw attention to different dimensions of a healthcare team that needs to be considered to model the team based environment. In our ontological model the first group of competencies was called *Structure Competency*.

Since teams often would start their work by focusing on desired outcomes and then ensuring the needed processes are in place to achieve those outcomes, structure

competency questions initially start with asking about team desired outcomes and then reverse engineering to identify the required processes to achieve those outcomes. The third question tries to identify when a team process should start and when it can be finished. In fact, this question wants to clarify the continuum of care service that the healthcare team process should cover.

The next two questions intend to know which members belong to each healthcare team and who is responsible to conduct specific team processes. For example, we might want to know how many members does the interdisciplinary team have and who is responsible for performing the process of external communication. The next questions have been asked to identify what kinds of information resources are available for a healthcare team and who has the authority to access them when conducting team processes. For example, we might need to know what kind of information resources a doctor has authority to access throughout the process of decision making. In addition, as the literature revealed each member in a healthcare team have access to multiple communication channels through which she/he can communicate with other members, therefore, the next question tries to recognize the accessible communication channel among team members. Finally, because of the importance of the role of leadership, the last question wanted to emphasize the number of leaders each healthcare team has in order to develop a common vision of the team goals among members.

1. Which outcomes does the healthcare team try to achieve?
2. What processes does the healthcare team use?

3. What continuum of care service should the team process cover (When should the team process start and when should it finish?
4. What are the members of a particular healthcare team?
5. Who is responsible for conducting each particular process?
6. What kinds of information recourses does a healthcare have?
7. In order to perform a specific process, what kinds of information resources does a member have authority to access?
8. What are available channels for team members to communicate through?
9. How many leaders does the healthcare team have?

Behaviour Competency

The second group of competency questions is named *Behavior Competency*. In linking the multidimensional structure of a healthcare team to its final outcomes, we should be able to clearly define how each dimension of a healthcare team affects the desired outcomes. The behavior competencies try to provide clearer picture of the relationships between different identified dimensions of team structure and the team final outcomes.

For example the first four questions want to identify how changes in healthcare team processes, available information resources, members actions or task feature would affect the team overall outcomes respectively. In addition, in the final question, we want to understand how external factors such as organizational context can affect the healthcare team outcomes.

1. What is relationship between team process and team outcome?
2. How do the information resources affect the team final outcome?
3. How is healthcare team final outcome impacted by team member?
4. What is relationship between task feature and final outcome?
5. How is team outcome influenced by organizational context?

Classification Competency

The third group of questions is named *Classification Competency*. These questions try to clarify the distinctions among the three aforementioned health care team types. In fact, the third group of competencies asking about specific characteristics of each healthcare teams in order to classify them in more details.

- How are the goals set in interdisciplinary and transdisciplinary teams?
- How are the goals set in multidisciplinary teams?
- How do the members collaborate with each other in an interdisciplinary team to provide care services?
- How do the members work with each other in multidisciplinary team to provide care services?
- How do the team members collaborate with each other in a transdisciplinary team?
- How do the members share roles in an interdisciplinary team to address a common problem?

- How do the members play their roles in a multidisciplinary team to solve the team issues?
- How do the members share a role in a transdisciplinary team?

4.3 Stage 3: Formalization

This stage of the framework converts the conceptual model achieved in the first step into formal model. In fact, the outcome of specification and conceptualization stage is a textual data that provides starting point for developing the formalized model.

Formalization stage organizes the ontology concepts by developing hierarchies and relationships such as IS_A or PART_OF relationships for the ontology. In addition to, during the stage of formalization a set of restrictions are defined for ontology concepts to declaratively restrain the possible inference for the meanings of those concepts.

Protégé OWL software is the tool used for developing the formal ontological model of healthcare team. Protégé OWL is a free, open source and standalone ontology development tool that support developers to create, visualize, and manipulate the ontologies in Web Ontology Language formats. Commonly there are two tabs used in Protégé: the first one is the *Classes Tab* used to define the classes, edit the class hierarchy and assign restriction over the ontology terminology. The second tab is *Object Properties* which can be used to create property hierarchy, specify the characteristics of properties and define the domain as well as the range of the properties.

One of the key features of the Protégé software is that it has a library of dozens of plugins that provide more functionality to the system. Pellet Reasoner and OWLViz are

two useful plugins used for this research. Pellet provides various services such as logical consistency checking, concept satisfiability, automatic classification and realization (Sirin et al. 2007) while OWLViz allows ontology classification hierarchies to be visualized. Figure 6 shows an example of how OWLViz displays class hierarchy for healthcare team ontological model.

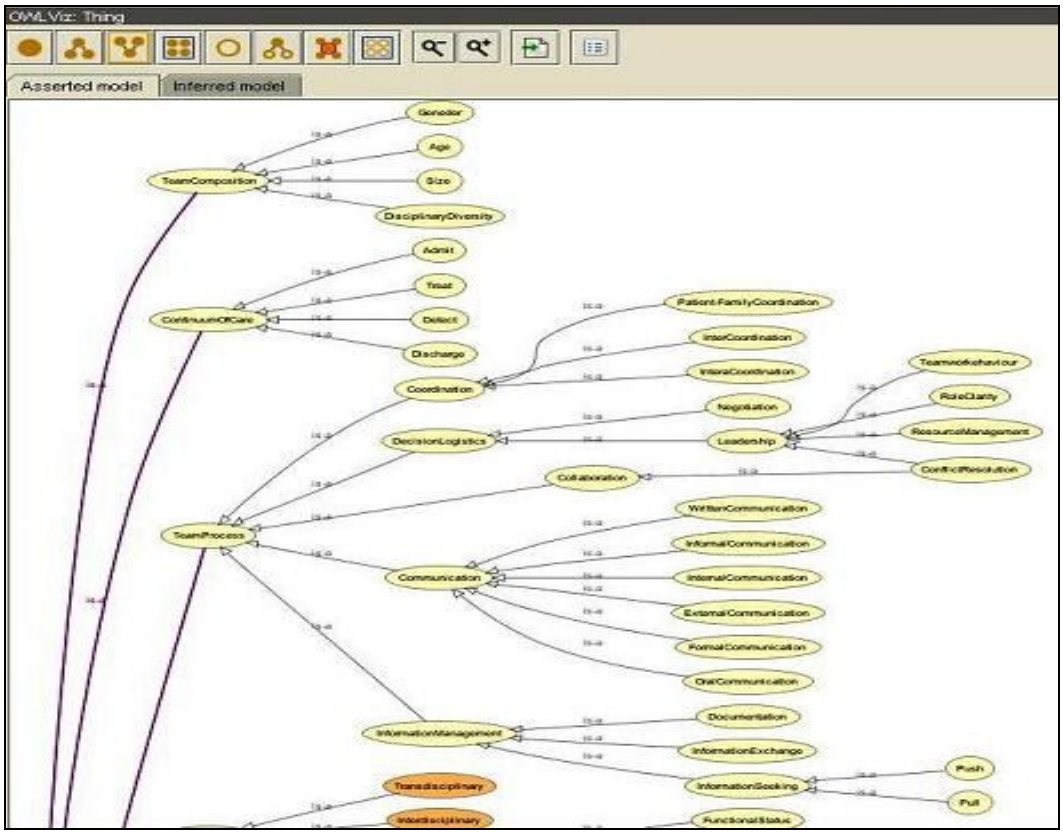

Figure 6. Example of OWLViz Hierarchy Display for Healthcare Team Ontology

We started developing our formal model by defining the classes in our ontology. Classes describe the concepts in a domain of interest. In OWL each class implies the conditions that must be met by an individual for it to be part of the class. Classes may be organized into a superclass-subclass hierarchy which is also called taxonomy. Subclasses

represent their super-classes in a more specific way. Classifying the ontology terminology in a subsumption hierarchy figure out if a particular individual is an example of certain class or not.

For example, the class of team process would contain all the processes that a healthcare team is involved in. As discussed before, a process is defined as an activity of networks performed by interaction of multiple members to achieve a specific output. Based on what was already defined for the concepts of Communication, Collaboration, Coordination, Decision Logistics, and Information management (Described in Chapter 2, **2.1.3.1 -2.1.3.5**), we can see that all of these concepts can meet the requirements for membership of the team process class. So, the super-class team process is subdivided to 5 main subclasses. By themselves each of these subclasses may contain some specific individuals. For instance, the subclass coordination process is composed by inter-coordination, intra-coordination and patient-family coordination. Each of these individual concepts represents their super-class (coordination process) in more details. The inter-coordination indicates how a team coordinates its work with outside individuals or agencies. The intra-coordination explains how teams manage its internal personnel and resources and finally patient-family coordination states how the patient's preferences and requirements are met by the healthcare team. The subclass decision logistics is composed of leadership and negotiation concepts indicating that the process of negotiation and leadership are two necessary supporting processes to decision logistics process.

There are several possible approaches in developing a class hierarchy (Uschold and Gruninger 1996):

- **Top-down** process initiates with defining the most general concepts in the domain and afterward the concepts will be specialized into more details.
- **Bottom-up** process starts with the definition of the most particular classes of the hierarchy and in the next step aggregates these classes into more general concepts.
- **Combination** process is a combination of the top-down and bottom-up approaches.

None of these methods are necessarily any better than the other but rather they completely rely on the personal view point of the ontology developer (Rosch 1978). In the healthcare team ontological model, we used the combination approach in which we appropriately either specialize or generalize the main concepts characterized in the first stage (Stage 1). We might start with a few top level concepts such as team process or a few particular individuals such as conflict resolution. Then we related these concepts to the middle level concepts such as leadership. Figure 7 demonstrates a possible breakdown between the different degrees of generality for the Team Process class in the healthcare team ontological model.

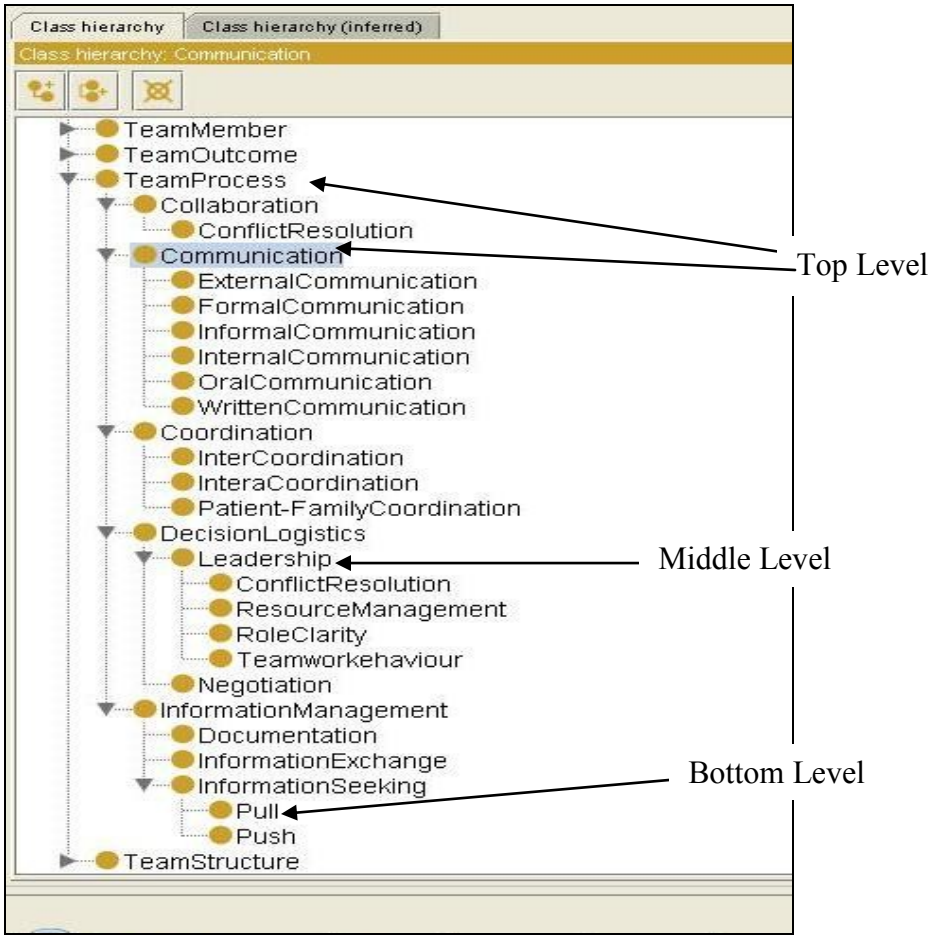

Figure 7. Different Level of Process Taxonomy

Classes alone will not provide sufficient information to answer the competency questions from the stage 2. Therefore, once we have defined our concepts in the class hierarchy, we must add the properties which have been identified in the first stage to our formalized model using *Object Property Tab* in Protégé software. As discussed before, properties are binary connections that define the inter-relationships between classes or individuals helped us to depict the interior construct of ontology concepts. For each property in the object property list, we can determine which class it describes and what

domain or range it specifies. For instance, we can see that the class Team Member and Team Process are connected with a *Perform* property from Member (Domain) to Process (Range) with the inverse property *Performed By* or the class Team Member connect to Information Resource class through *Has Authority To Access* property from Member to Information Resource with the inverse property *Is Accessible To.* Figure 8 shows some of the properties that we have discussed so far together with their domain and range.

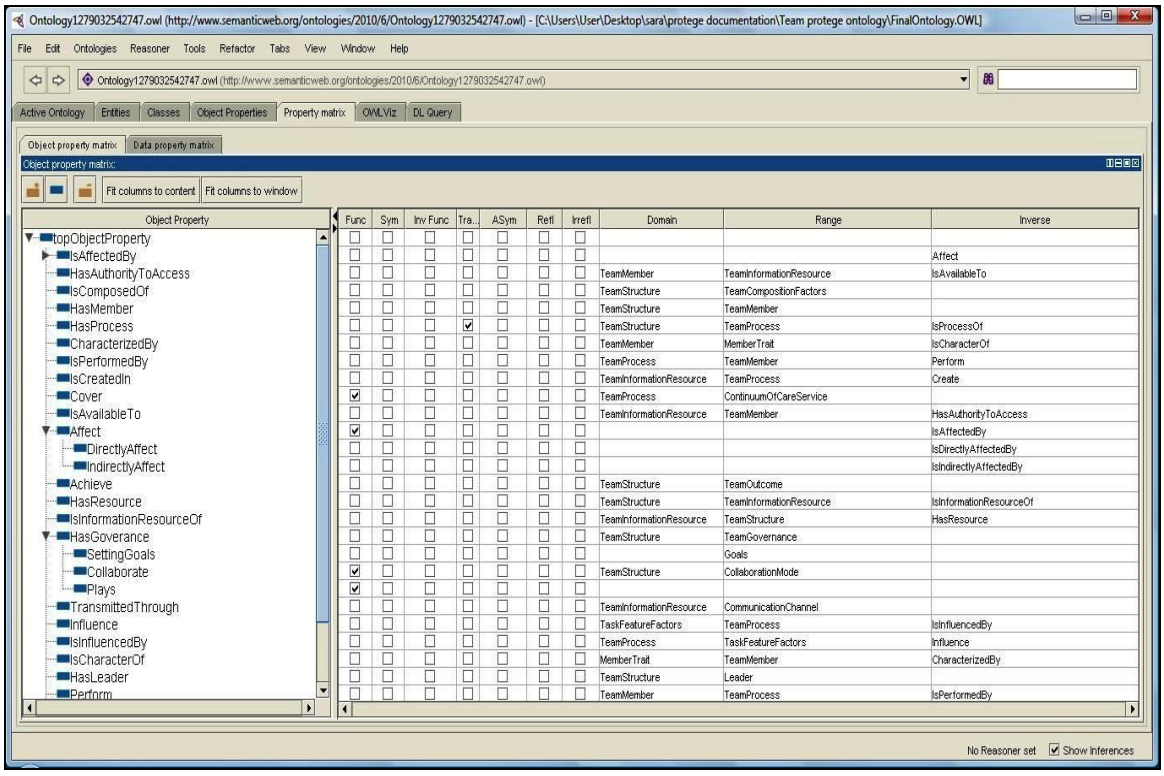

Figure 8. Property Hierarchy View for Healthcare Team Ontology

In the next step, a set of restrictions were defined over the ontology concepts to prevent unexpected interpretation of the predefined concepts. It should be noticed that restrictions play an essential role to represent and solve competency questions in the final stage by providing informative semantics for the system. Applied restrictions in this

model fall into two major categories. The first group is Quantifier Restrictions such as Existential and Universal restrictions and the second one is Cardinality Restrictions. An existential restriction is the most common type of restrictions in OWL ontologies. It describes "a class of individuals that have at least one relationship along an indicated property to the member of a specified class" (Horridge et al. 2009). For example, the existential restriction over *has resource* property which connects Team Structure to Information Resource (*Has resource some information resource*) describe the class of individuals that have at least one has resource relationship to individuals that is a member of class Information Resource. In more lay terms, this restriction indicates that healthcare teams must have at least one of the available information resources including document, electronic or authority. On the other hand, universal restriction, which is also known as *All restriction* limits the relationships of a given property to the members of specified class. For example, the restriction *Cover only Continuum of Care Service* between Team Process and Continuum of Care Service class implies that the healthcare team processes cannot exceed admission, assessment, treatment or discharge stages. In Protégé 4.0 the keyword "some" is used to assign existential restrictions while "only" denoted to universal restrictions.

The second group of utilized restrictions in our ontological model is Cardinality Restrictions. Cardinality Restriction specifies the number of relationships that an individual must participate in for a given property (Horridge et al. 2009). Minimum Cardinality Restriction indicates the minimum number of relationships that an individual

must have while Maximum Cardinality Restriction describes the maximum number of relationships that an individual can take part in. For example, the restriction *has member min 2* between Team Structure and Team Member class specifies that at least 2 members are required to create a collaborative team structure. However, *Has leader max 1* restriction between the team structure class and individual leader can be considered as a declarative instance for maximum cardinality restrictions which represents that more than one leader position is not assumed for the healthcare team. The restrictions for a class are displayed and edited using the "Class Description View" in Protégé shown in Figure 9.

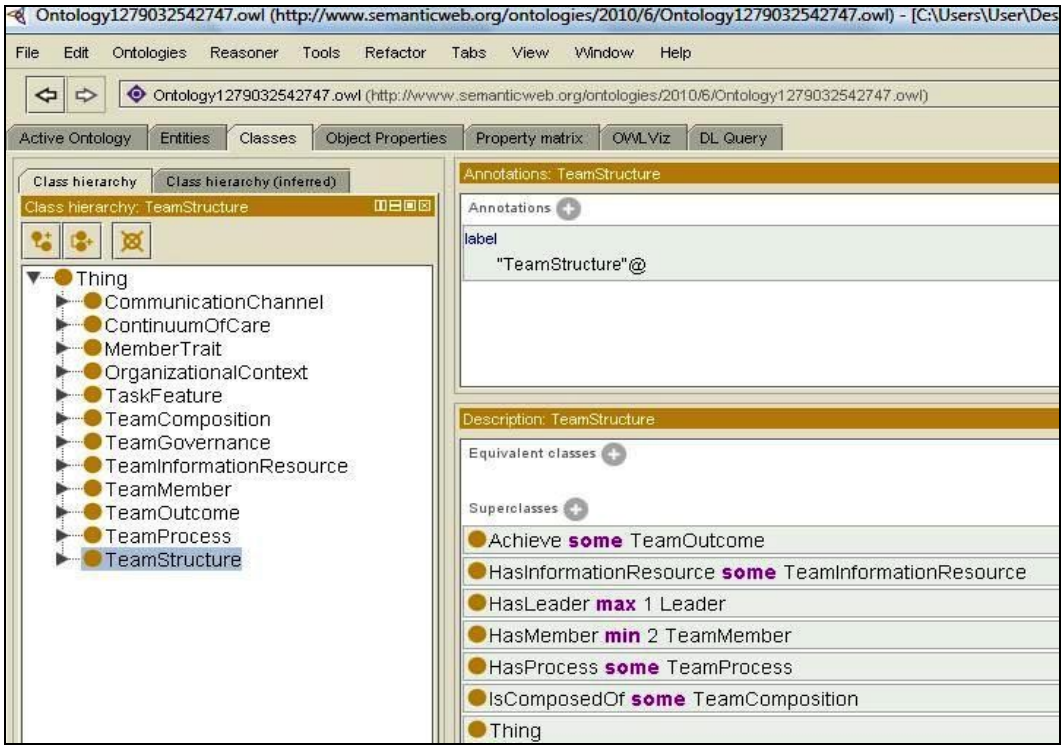

Figure 9. Description View of Team Structure Class

Chapter 5: Proof-of-Concept Implementations

Ontology validation is the final stage of our ontological framework. In this stage, first the logical consistency between defined classes was validated. Then, the predefined competency questions were checked to determine whether the healthcare team ontological model is complete and expressive enough to provide necessary and sufficient information to answer and solve those questions. Providing relevant information in response to ontology questions represents that ontology could meet and support the scope and purpose in which it is employed (Gruninger and Fox 1996). It is important to mention that the proof-of-concept implementations are based on the predefined competency questions from the second stage of our framework.

5.1 Accuracy Validation of Ontological Model

After developing the ontological model through Protégé software in the third stage of this framework, the Pellet ontology reasoner was run to check consistency and detect inconsistencies in the ontology. As discussed before a reasoner performs various services, such as permitting automatic classification, determining whether or not classes are consistent or identifying subsumption relationships between classes. The reasoner can automatically compute the classification hierarchy and also check the logical consistency

of the ontology. Once it has completed running, the reasoner can be queried for information about the ontology through 'DL Query' button. In Protégé 4.0 the 'manually constructed' class hierarchy is called asserted hierarchy while the class hierarchy which is automatically computed by the reasoner called 'inferred hierarchy' (Horridge et al. 2009). To check any inconsistencies in the healthcare team ontology, we need to invoke the 'Classify...' button in the Reasoner drop down menu. When the inferred hierarchy has been computed by Reasoner, the icon for inconsistent concepts will be changed in red alarming that some mistakes have occurred. The intention for comparing the asserted hierarchy with inferred hierarchy is to ensure that on running reasoner, the class hierarchy would be still maintained. A comparison of two hierarchies shows that there are no inconsistencies in our ontology.

5.2 Completeness Validation of Ontological Model

After ensuring the consistency of the ontology, we can find the associated restrictions with each concept in class description view. In the final stage of our framework, we repeat the competency questions again and follow each question with prolog axioms.

5.2.1 Structure Competency

1. ***Which outcomes does the healthcare team try to achieve*?**

At the time healthcare teams start their work they initially focus on desired outcomes and then decide what to do to achieve those outcomes. Therefore the first question has been asked to identify the team desired outcomes. An existential restriction is defined using the

property *Achieve* between team structure as a domain and outcome as the range. The provided answer by the ontology reasoner is *Team Structure Achieve Some Team Outcome* indicating that patient, member and organizational outcomes (discussed in 4.1.2.5) are those desired outcomes that any of our healthcare teams try to achieve.

2. ***What processes does the healthcare team use*?**

After identifying the team desired outcomes, the next question reverses engineering to identify those processes that should be in place to provide patient care. An existential restriction is defined using the property *has process* between team structure as a domain and team process as a range. As discussed in 4.1.2.1, the processes of communication, coordination, collaboration, decision logistics, information management and their sub-processes are assigned to the meta-concept of team process. The provided answer *Team Structure Has Process Some Team Process* indicates the needed processes that the healthcare teams engage in to provide the care services.

3. ***What continuum of care service should the team process cover (When should the team process start and when should it finish?***

The universal restriction is defined using the property *Initiated By* between team process and admission stage indicating that all the healthcare team processes should start when a patient is admitted by the team. Further, the universal restriction is defined using the property *Terminated By* between team process and discharge stage indicating that healthcare team processes only ends when a patient leaves the team. Finally, the universal restriction is defined using the property *Cover* between team processes and continuum of

care service indicating that healthcare team processes should cover all the four stage of care service including admission stage, assessment stage, treatment stage and finally discharge stage. Overall, the provided answer *Team Process Initiated By Only Admission Stage And Terminated By Only Discharge Stage And Cover Only Continuum Of Care Service* creates the union of three universal restrictions to answer the question above.

4. What are the members of a particular healthcare team?

The forth question tries to identify which members are belonging to each healthcare team. A minimum cardinality restriction is defined using the property *has member* between team structure as a domain and member as a range. As discussed in 4.1.2.3, the meta-concept of member can be populated by physician, nurse, or support service providers. Overall, the provided answer *Team Structure Has Member Min 2 Member* indicates that each healthcare team is composed of at least two members depending on the team. For example for the specific team type the exact cardinality restriction can be defined such as Transdisciplinary Team Has Member Exactly 3 (Nurse OR Physician OR Counsellor) indicating that the example team is composed of the union of 3 members: a nurse, a physician and a counsellor.

5. Who is responsible for conducting each particular process?

This question has been asked to identify which process is conducted by whom in a healthcare team. An existential restriction is defined using the property *Perform* between team member as a domain and team process as a range. The provided answer *Team Member Perform Some Team Process* indicating that team members are responsible for

performing each of the team process. For example, it can be said that in a specific healthcare team the Nurse (as an instances of team member) Performs Some External Communication (as an instances of team process) indicating that one of the responsibilities of a nurse is to perform the process communication with outside individuals and/or agencies.

6. ***What kinds of information recourse does a healthcare team have?***

This question tries to figure out what types of information resources are available in any of our healthcare teams. An existential restriction is defined using the property *has information resource* between team structure as a domain and information resource as a range. The provided answer *Team Structure Has Information Resource Some Information Resource* indicating that as discussed in 4.1.2.2 each of our healthcare teams might be equipped by three kinds of information resources including electronic, document and authority.

7. ***In order to perform a specific process, what kinds of information resources does a member have authority to access?***

This question wants to identify what types of information resources each healthcare team member has authority to access. A universal restriction is defined using the property *has authority to access* between team member as a domain and team information resource as a range with inverse property *Is Accessible To*. The provided answer *Team Member Has Authority To Access Only Team Information Resource* or *Team Information Resource Is Accessible To only Team Member* indicating that each of the team member has authority

to access only some specific kinds of available information resources. Through this property the access to some particular information resources can be restricted to specific team members. For example it can be said that an electronic patient record (as an instances of information resource) is only accessible to physician (as an instances of team member).

8. What are available channels for team members to communicate through?

This competency question has been asked to identify through which channels healthcare team members communicate with each other. An existential restriction is defined using the property *Has Communication Channel* between team members as a domain and communication channels as a range. Overall, the provided answer *Team Member Has Communication Channel Some Communication Channel* indicating that depending on the situation multiple communication channels may be used by team members in order to exchange information. For example, the restriction doctor (as an instance of team member) has communication channel synchronous channel (as an instance of communication channel), indicates that one of the channels that can be utilized in urgent communication cases might be the phone or face to face meeting.

9. How many leaders does the healthcare team have?

The last question of structure competency tries to identify how many leaders a healthcare team needs during each process. The maximum cardinality property is defined using *Has Leader* between team structure as a domain and leader as a range. Finally, the provided

answer *Team Structure Has Leader Max 1 Leader* indicating that the role of leader usually is assigned only to one member.

5.2.2 Behaviour Competency

After identifying the multiple dimensions of the healthcare team structure and their internal relationships, in this part, through behaviour competencies, we want to figure out how each of these dimensions would affect the team desired outcomes.

1. ***What is relationship between team process and team outcome?***

The existential restriction is defined using the property *directly affect* between team process and team outcomes. The provided answer by ontology reasoning *Team Process Directly Affect Some Team Outcome* indicates that proper or improper accomplishment of team processes would directly affect the team final outcomes.

2. ***How do the information resources affect the team final outcome?***

The existential restriction is defined using the property *directly affect* between team information resource and team outcomes. The provided answer *Team Information Resource Directly Affect Some Team Outcome* indicates that availability or lack of needed information resources would directly affect the team outcomes.

3. ***How is healthcare team final outcome impacted by team member?***

The existential restriction is defined using the property *Is Directly Affected By* between team outcome and team member. This property is the inverse to the *directly affect* property introduced above. The provided answer *Team Outcome Is Directly Affected By*

Some Team Member indicates that team final outcome is directly affected by team member's performances.

4. What is relationship between task feature and final outcome?

The provided answer *Task Feature Influence Some Team Process And Indirectly Affect Some Team Outcome* indicating that task feature factors would influence the team processes (using the property influence between task feature as a domain and team process as a range) and through its impact on team processes might affect team final outcome (using the property indirectly affect between task feature as domain and team outcome as range). So, task feature factors indirectly affect the team outcomes.

5. How is team outcome influenced by organizational context?

Finally the provided answer *Team Outcome Is Indirectly Affected by Some Organizational Context* indicates that organization factors indirectly affect the team outcomes as discussed in 4.1.2.6.

5.2.3 Classification Competency

As stated before, we expect that the third group of competencies will be able to clarify the distinctions among the three typical healthcare team types: interdisciplinary, multidisciplinary and transdisciplinary teams.

1. How are the goals set in an interdisciplinary and a transdisciplinary teams?

The universal restriction is defined using the property *Setting Goals* between interdisciplinary and transdisciplinary teams and the concept of Shared Goals. The provided answer *Setting Goals Only Shared Goals* indicates that in interdisciplinary and

transdisciplinary teams instead of setting multiple individual goals for each team member, a series of shared goals are defined for the whole team.

2. ***How are the goals set in multidisciplinary teams?***

The universal restriction *Setting Goals Only Individual Goals* indicates that in contrast to two other teams, in multidisciplinary team different members individually set their own goals.

3. ***How do the team members collaborate with each other in a interdisciplinary team to provide care services?***

The universal restriction is defined using the property *collaborate* between Interdisciplinary Team and the concept of Jointly but Keep Assignments. So, the provided answer *collaborate Only Jointly But Keep Assignments* implies that members in interdisciplinary team work jointly to provide care service but still keep their distinct individual assignments (discussed in 4.1.2.8).

4. ***How do the team members work with each other in a multidisciplinary team to provide care services?***

The universal restriction is defined using the property *Collaborate* between Multidisciplinary team and the concept of Independently. The provided answer *Collaborate Only Independently* indicates that in multidisciplinary team, different members usually work quite independently from each other to provide a common care service.

5. ***How do the team members collaborate with each other in a transdisciplinary team?***

The universal restriction is defined using the property *Collaborate* between Transdisciplinary team and the concept of By Team Consensus. The provided answer *Collaborate Only By Team Consensus* indicates that in transdisciplinary team, care services will be only provided by consensus among all team members.

6. ***How do the members share role in an interdisciplinary team to address a common problem?***

The universal restriction is defined using the property *Plays* between Interdisciplinary team and the concept of Interdependent Role. The provided answer *Plays Only Interdependent Role* indicates that in interdisciplinary team the roles of all the members in conducting team processes are completely interdependent.

7. ***How do the members play their roles in a multidisciplinary team to solve the team issues?***

The universal restriction is defined using the property *Plays* between Multidisciplinary team and the concept of Separate but interrelated role. The provided answer *Plays Only Separate but interrelated role* indicates that each member in multidisciplinary is responsible for the part of the service associated with his or her own professional discipline.

8. How do the members share roles in a transdisciplinary team?

The universal restriction is defined using the property *Plays* between Transdisciplinary team and the concept of Role Release. The provided answer *Plays Only Role Release* indicates that one of the specific characteristics of transdisciplinary team is that in which members are so familiar with the roles of other team members that can also do the roles of them.

In conclusion, our ontology was able to fully address all the defined competency questions because, as shown above, this ontology could completely provide relevant information in response to defined competencies in three intended areas.

Responding to structure competencies, our ontology was able to completely answer the questions about multiple dimensions of healthcare team structure that need to be considered in order to model the team based environment. It was also able to define the relations and dependencies between the identified dimensions such as what are the team desired outcomes, what processes should be in place to achieve those outcomes, who is responsible for conducting those processes, what information is needed throughout the process accomplishment, through which channels information transmit in the team and etc (refer to 5.2.1).

In linking the multidimensional structure of healthcare team to final outcomes, our ontology was able to fully answer the behavior competency questions about how each of the team dimensions could affect the team final outcomes (refer to 5.2.2).

Finally, our healthcare team ontological model was able to clearly answer the questions about the specific characteristics and narrow distinctions among the three most common healthcare team types including interdisciplinary, multidisciplinary and transdisciplinary teams (refer to 5.1.3).

Chapter 6: Discussion and Conclusion

Healthcare teamwork has been shown as an important facilitator in achieving positive and cost-effective patient outcomes. Designing information and communication technologies to support team services is particularly important in healthcare as failures in providing timely services can have adverse effects on patient outcomes. Before putting any technologies in place, the team based environment should be completely modeled. To date, many frameworks have been proposed to model the multidimensional structure of a healthcare team; however, much of the research on this issue has focused on single or a few aspects of teamwork, while integration of multiple dimensions of healthcare teamwork has been largely ignored.

To provide insight on the aforementioned challenge, this thesis has applied ontological engineering to develop an overarching framework to clarify the multiple dimensions of the healthcare team as well as the relationships between those dimensions. For this purpose, first a set of four stage ontology design methodological approach was illustrated to provide detailed guidance on how to incorporate the theoretical foundation into ontology in healthcare domain. Then, the proposed approach was used to capture and organize knowledge to develop a derived ontological framework to integrate multiple

dimensions of healthcare teamwork and their relationships. Finally, the proposed ontology-based framework was validated through series of competency questions to examine if the framework was able to properly address the identified gaps in literature.

The novelty of this thesis resides in the fact that while multiple research designs used to model different single aspects of healthcare teamwork, enough attention hasn't been paid to integrate the multiple dimensions of healthcare teamwork into a synthetic whole. Although the proposed ontological framework was specifically designed for a healthcare team, it can be also applicable in other domains due to its high degree of generality, reusability and optimization in detail.

The results of this thesis can be also served as a lens-of-analysis or a foundation for various models such as ITEM (Lemieux-Charles and McGuire 2006) by offering a comprehensive framework that not only identified the possible important relationships between multiple dimensions of teamwork context and final outcomes but also clearly defined the linkage between multiple dimensions themselves. In addition to, our research has gone beyond offering a single, general model of healthcare team but we were able to develop multiple models tailored to specific characteristics of three most common healthcare team types (interdisciplinary, multidisciplinary and transdisciplinary) with aim of providing clearer depiction of the narrow distinctions among these collaborative teams.

The four stage methodological approach in this thesis was based upon an existing ontology design methodology TOVE (Fox et al. 1996) in the field of enterprise modeling. We extended TOVE methodology by adapting this methodology into healthcare domain

and outlining specific tasks and outputs for each stage. Table 5 illustrates the comparison between TOVE methodology and our healthcare team ontology design approach.

Table 5. Synopsis Table

TOVE Methodology	Corresponds to	Added Value
Capturing Motivating Scenario	**Specification**	✓ Adapted to healthcare domain
Defining Ontology Terminology	**Conceptualization**	✓ Applying qualitative content analysis as a complementary fit ✓ Mapping to controlled vocabulary (UMLS) for the purpose of interoperability and standardization
Formulate Competency Questions	**Formulation**	
Defining Axioms Based on FOL	**Formalizations**	✓ Using Protégé Software due to its advantages discussed in Chapter 4 ✓ Developing hierarchies and relationships such as IS_A and PART_OF for the ontology
Evaluation of Ontology Completeness	**Ontology Validation**	✓ First accuracy evaluation of framework ✓ Second evaluating its completeness

In addition, the ontology terminology resulted from this thesis can aid in refining the associated lexical knowledge in the field of healthcare team collaboration and can serve as a basis by different biomedical repositories such as UMLS to expand their terminology to better represent many of the more specific healthcare team concepts.

Finally, the results from this research have also made contributions to the research and design of HIS to support team practices. As discussed before, representation of reality is the first step in any IS design and ontologies are known as the best means for achieving the intended representation. Hence, it can be claimed that the quality of information systems will only be as good as the ontologies they are based upon. So, we need enhanced methodological approaches for developing ontologies to adequately represent a domain area. It is important to point out that the ontological framework

proposed in this thesis does not only define a common terminology but also represents all the information about the structural knowledge of a healthcare team and their interrelations which permits the use of this kind of ontology to design and develop of IS framework.

6.1 Future Work

The possible directions for future work based on this research might include expanding the ontology to model the specific healthcare teams through real case studies and examining how the proposed ontological model can be implemented as a prototype to facilitate IS design to support healthcare teams. Further, the identified contextualization concepts in the first stage of our framework (sections 4.1.2.1 and onwards) can be used by UMLS for expanding its vocabulary to better represent healthcare teams.

6.2 Limitation

The first limitation of this thesis is that ontology was created by a single person and usually a collaborative approach that reflects diverse viewpoints of multiple individuals is preferred.

In addition, literature research was the main source for us to collect data and we didn't have access to other helpful resources such as real-time observations, practice experience or patient charts to extract more precise information about the healthcare team situation in a real work environment.

Another limitation is that we formalized our framework using one specific ontology developer tool (in our case Protégé OWL). Future research should also involve annotating our ontological framework using other modeling languages.

Finally, in the context of ontology validation, competency questions were the only method used in this thesis to internally validate the proposed ontological framework. Further validation through empirical narratives or other empirical means can be done for external validation.

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