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An ontological model of the practice transformation process

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ABSTRACT

Patient-centered medical home is defined as an approach for providing comprehensive primary care that facilitates partnerships between individual patients and their personal providers. The current state of the practice transformation process is ad hoc and no methodological basis exists for transforming a practice into a patient-centered medical home. Practices and hospitals somehow accomplish the transformation and send the transformation information to a certification agency, such as the National Committee for Quality Assurance, completely ignoring the development and maintenance of the processes that keep the medical home concept alive. Many recent studies point out that such a transformation is hard as it requires an ambitious whole-practice reengineering and redesign. As a result, the practices suffer change fatigue in getting the transformation done. In this paper, we focus on the complexities of the practice transformation process and present a robust ontological model for practice transformation. The objective of the model is to create an understanding of the practice transformation process in terms of key process areas and their activities. We describe how our ontology captures the knowledge of the practice transformation process, elicited from domain experts, and also discuss how, in the future, that knowledge could be diffused across stakeholders in a healthcare organization. Our research is the *first effort* in practice transformation process modeling. To build an ontological model for practice transformation, we adopt the *Methontology* approach. Based on the literature, we first identify the *key process areas* essential for a practice transformation process to achieve certification status. Next, we develop the practice transformation ontology by creating key activities and precedence relationships among the key process areas using process maturity concepts. At each step, we employ a panel of domain experts to verify the intermediate representations of the ontology. Finally, we implement a prototype of the practice transformation ontology using Protégé.

1. Introduction

The US primary care system is struggling. Increasing demands and expectations, coupled with diminishing economic margins, have created a challenging work environment [1]. A key to the sustainability of primary care has been attributed to an approach called the "patient-centered medical home" (PCMH). PCMH is defined as a method for providing a comprehensive primary care which facilitates partnerships between individual patients and their personal providers, and when appropriate, the patient's family [2]. The key characteristics of PCMH are to foster the ongoing relationship with a personal physician, to promote physician-directed medical practice, to develop whole person orientation, to create care coordination, to assure quality and safety, to provide enhanced access to care, to support team care, and to support value-added payment. For example, a provider may know all of his/her patients by first name, but without a backup system, the provider's interactions with the patients cannot be documented and shared with the rest of the care team. Similarly, if an answering service cannot document all of its interactions with patients and provide evidence of the responses provided to patient queries, then no follow-up is possible. Without the crucial element of a formal call-back system in place, the coordination of care will suffer. This challenge is especially acute in the case of patients with complex chronic diseases. The provider cannot assure its patients of optimal care, no matter how personal and high-quality the interactions between patients and providers may be [3]. As the PCMH approach is quite different from the traditional model of practice, changes are needed in a practice to transform from the traditional delivery model to the PCMH model [4]. These changes constitute the practice transformation process (PTP) (see Table 1).

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Table 1
Introducing practice transformation process [4].

Traditional Model of Practice	Practice Transformation Process (Converting Traditional Model to PCMH Model)	PCMH Model of Practice
Systems often disrupt the patient-physician relationship		Systems support continuous healing relationships
Care is provided to both sexes and all ages; includes all stages of the individual and family life cycles in continuous, healing relationships		Care is provided to both sexes and all ages; includes all stages of the individual and family life cycles in continuous, healing relationships
Physician is center stage		Patient is center stage
Unnecessary barriers to access by patients		Open access by patients
Care is mostly reactive		Care is both responsive and prospective
Care is often fragmented		Care is integrated
Paper medical record		Electronic health record
Unpredictable package of services is offered		Commitment to providing directly and/or coordinating a defined basket of services
Individual patient oriented		Individual and community oriented
Communication with practice is synchronous (in person or by telephone)		Communication with the practice is both synchronous and asynchronous (e-mail, Web portal, voice mail)
Quality and safety of care are assumed		Processes are in place for ongoing measurement and improvement of quality and safety
Physician is the main source of care		Multidisciplinary team is the source of care
Individual patient-physician visits		Individual and group visits involving several patients and members of the health care team
Consumes knowledge		Generate new knowledge through practice-based research
Haphazard chronic disease management		Purposeful, organized chronic disease management
Experience based		Evidence based
Struggles financially, undercapitalized		Positive financial margin, adequately capitalized

The current state of PTP is somewhat *ad hoc* and *no methodological basis exists* for transforming a practice into a patient-centered medical home. There exist several PCMH certification agencies, such as NCQA, BCBS of Michigan Physician Group Incentive Program, The Accreditation Association for Ambulatory Health Care, The Joint Commission to certify (http://www.jointcommission.org/assets/1/18/Joint_Commission_PCMH_model.pdf), etc. As the NCQA's certification program is the largest [5], we use this program as the basis for our research.

Practices and hospitals somehow achieve a certification level and send their information to a PCMH certification agency like the National Committee for Quality Assurance (NCQA) and BCBS of Michigan for practice certification [5], or wait for the Joint Commission visit to certify the hospital, completely ignoring the development and maintenance of the processes that keep the PCMH concept alive. Recent studies [6–8] point out that the change is hard, as it requires an ambitious whole-practice reengineering and redesign. Such a practice transformation includes new scheduling and access arrangement, new coordination planning, group visits, new ways to improve quality care, development of team-based care, multiple uses of information systems and technology, and other activities.

In this paper, we focus on the complexities of PTP and observe that one way to address the problem would be to create a *scientific* and *robust ontological model* that standardizes the practice transformation process. Ontologies have been used extensively in medical applications, such as developing clinical pathway guidelines, care pathways, and clinical decision support. Our goal is to develop an ontology that helps standardize the practice transformation process. Such an ontology will include a multitude of key process areas that are needed to transform the practice, as well as the precedence relationships among them. These can then be used by the practice to understand what steps are needed for transformation, so that it can attain NCQA's certifications.

The International Standards Organization (ISO) defines a standard as "a document that provides requirements, specifications, and guidelines that can be used consistently to ensure that materials, products, processes and services are fit for their purpose" (http://www.iso.org/iso/home/standards.htm). The standardization process includes two phases: *generation* and *diffusion* [9]. During the generation phase, standardization is launched, with different sponsors coming together to sketch the goals and purpose of the initiative. During the diffusion phase, the standardization results are distributed among the affected individuals.

An ontology helps share common understanding of the structure of information, enables reuse of domain knowledge, makes explicit domain assumptions, and analyzes domain knowledge [10]. These are the major motivations behind developing the ontology for practice transformation. If the ontology can accurately capture the PTP standards elicited from expert panels, we believe that it would provide an effective platform for diffusing the standards across key stakeholders in a healthcare organization, so that it can ascend to higher levels of process maturity and PCMH recognition. The ontology would facilitate the diffusion of PCMH standards by making it easier for end users to: understand the domain concepts, their meanings, attributes, instances, etc.; browse the concepts classification taxonomy; search for specific PTP KPAs and their activities; become aware of the domain rules and constraints; and reuse and apply the underlying knowledge base so as to conform to the PTP standards.

We have employed a concept called "process maturity level," which is quite well known in the process maturity literature The process maturity concept suggests that a process can become mature by progressing from some initial level (a state) to a more advanced level (a state). The notion of evolution utilizes stages of growth, suggesting that the process transitions through a number of intermediate states on the way to higher maturity states. In our practice transformation domain, practices also evolve through such stages of growth. Using the concept of practice transformation maturity levels, we have developed a grid that relates NCQA's certification levels with transformation process maturity levels. Such a grid provides a visual map for the practices to utilize the ontology for their transformation.

Before the PCMH transformation standards can be diffused among healthcare practitioners, however, they need to be generated. During the generation phase, the sponsors and other stakeholders need to identify the goals, objectives, and requirements for PTP standardization. We believe that an ontology is ideal for the practice transformation process. Developing an ontology entails eliciting the requirements for standardization using well-established knowledge acquisition techniques, properly specifying the requirements, conceptualizing and formalizing the ontology, and implementing the ontology so that the domain knowledge of practice transformation standards can be shared across users in a healthcare organization. Currently no such standardized model exists in the literature for practice transformation. Our research is the first effort in practice transformation process modeling.

We employ the *Methontology* approach [11–13] to develop our ontology because it is ideal for conceptualizing the KPAs, their taxonomies, and all other domain concepts in a structured format. Our adoption is also supported by the observation that the Methontology approach is a very mature methodology based on the IEEE standard 1074-1995 [14]. The methodology includes the following phases: knowledge acquisition, requirements specification, conceptualization, implementation, evaluation, and documentation.

In the specification phase, we identify the purpose, scope, and end users of the ontology. In the knowledge acquisition phase, we elicit the knowledge of practice transformation activities from various expert panels through different interaction modalities such as face-to-face, emails, webinars, and phone calls. In the conceptualization phase, we organize and structure the domain knowledge of PTP standards in terms of KPAs (Key Process Areas), KPA taxonomy, KPA composition, KPA rationale, KPA activities, relevant work products, glossary of terms, binary relation diagrams, etc. The representations used in the conceptual model are independent of the language used to finally implement the ontology. Finally, we implement the ontology as a proof-of-concept prototype using Protégé 3.5. Implementing it as a prototype in Protégé is the first step in making the PTP knowledge explicit; in the future, it would allow developers to edit/extend the coded knowledge. Extending the ontology with additional restrictions, as well as necessary and sufficient definitions, would allow developers to evaluate the knowledge base for redundancies, inconsistencies, and incompleteness; users could browse the KPA taxonomies and quickly find concise information about the PCMH transformation standards.

In Section 2 we review the historical perspective of *medical home* – a precursor to PCMH – and discuss how it evolved into the PCMH concept. Section 3 motivates the readers to recognize the need for understanding the practice transformation process through the lens of standardization. Section 4 elaborates our standardization attempt via an ontology design and development effort, starting from a review of the extant literature, to collecting practice transformation knowledge from practices, clinics, and content experts familiar with NCQA's recognition process, to providing a grid that links *practice transformation process maturity* levels with *PCMH recognition levels*, and finally to implementing the practice transformation ontology using Protégé. In Section 5, we discuss the limitations and future directions of our work. We conclude the paper in Section 6.

2. Background and significance

The first known documentation of the term "medical home" appeared in *Standards of Child Health Care* in 1967 [15]. It defines a *medical home* as one central source of a child's pediatric records and emphasizes the importance of centralized medical records to children with special healthcare needs. Nationally, in the seventies the medical home concept began to evolve from a centralized medical record to a method for providing primary care at a community level, recognizing the importance of addressing the needs of the total child and family in relationship to health, education, family support, and the social environment. The concept assumed a bottom-up approach rather than a top-down approach and shifted toward prevention, wellness, and early intervention. In the eighties, the medical home concept evolved and gained greater recognition. The barriers to implementing a medical home for all children became apparent.

The Institute of Medicine [16] articulated that the 21st century health care system must support safety (avoid injuries to the patients); be effective in providing service based on scientific knowledge; be patient-centered in providing care that is responsive to individual patient preferences; be timely by reducing waits and harmful delays; be efficient by avoiding waste; and be equitable in providing care that does not vary in quality due to personal characteristics, geographic locations, and socio-economic status. In response to this report, the leadership of seven national family medicine practices initiated the Future of Family Medicine project in 2002. The goal of the project was to transform and renew the specialty of family medicine to meet the needs of people and society in a changing environment. The project proposed a "new model" of practice [4,17] which includes the following characteristics: *personal medical home*, *patient-centered care*, *whole-person orientation*, *a team approach of care*, *elimination of barriers to access by patients*, *advanced information systems*, *improved office facilities*, *care provided within a community context*, *focus on quality*, *equitable reimbursements* and *commitment to provide family medicine's basket of services*. Table 2 describes the characteristics of the new model in detail.

Several primary care-oriented associations (American Academy of Family Physicians, American Academy of Pediatrics, American College of Physicians, and American Osteopathic Association), representing 333,000 physicians, created the "PCMH model" in 2007 [18] as an approach to providing comprehensive primary care for children, youth, and adults based on the idea of the new model.

With this new model in mind, NCQA introduced its version of the PCMH model, evolving from Physicians Practice Connection (PPC) in 2006 to PPC-PCMH in 2008, to PCMH 2011, and finally to PCMH 2014. These models included many of the characteristics shown in Tables 1 and 2. NCQA also launched a program to recognize medical practices that function as PCMH (http://www.ncqa.org/Programs/Recognition.aspx). Other models like BCBS and The Joint Commission have followed this path. Even though these programs have currently been adopted by many PCMH advocates, the transformation process is still ad hoc.

3. Motivation for standardization

Ninety-four PCMH demonstration projects (http://www.pcpcc.net/pcpcc-pilot-projects) were in the works since 2009 as identified by Bitton et al. [19], spanning from single payer setups such as Geisinger [20], Community Care of North Carolina [21], and Group Healthcare [22] to multi-payer setups such as Colorado multi-stakeholder [23], Maine PCMH [19], and others. The practices in these setups were included on the basis of pre-specified capabilities of medical homes. Payments in these practices followed mostly the standard *fee-for-service* model with some *per-member-per-month* payment plans. Practice transformations in these studies were handled by practice consultants who either use their own internal models that identify operational aspects of a well-functioning medical home or use a chronic care model developed by Wagner [24] and Wagner et al. [25] to help the practices transform. Many single payer pilots did not use any defined transformation model.

The changes at the model level (e.g., NCQA's move from PPC model to PPC-PCMH, PCMH 2011, and PCMH 2014) and introduction of other PCMH paradigms, such as BCBS PCMH Initiatives

Table 2
Characteristics of the "New Model" of family medicine practice [4,17].

"New Model" characteristics	Characteristics defined
Personal Medical Home	The practice serves as a personal medical home for each patient, ensuring access to comprehensive, integrated care through an ongoing relationship
Patient-centered care	Patients are active participants in their health and health care. The practice has a customer service orientation that embraces the importance of meeting patients' needs, reaffirming that the fundamental basis for healthcare is "people taking care of people."
Whole-person orientation	A visible commitment to whole-person care through such mechanisms, as developing cooperative alliances with services or organizations, that extend beyond the practice setting, but are essential for meeting the complete range of needs for a given patient population. The practice has the ability to help guide a patient through the healthcare system by integrating their care—not simply coordinating it
A team approach	An understanding that health care is not delivered by an individual, but rather by a system, which translates to the development of a multidisciplinary team approach for delivering and continually improving care for an identified population
Elimination of barriers to access	Elimination, to the extent possible, of barriers to access by patients through implementation of open scheduling, expanded office hours, and additional, convenient options for communication between patients and practice staff
Advanced information systems	The ability to use an information system to deliver and improve care, to provide effective practice administration, to communicate with patients, to network with other practices, and to monitor the health of the community. A standardized electronic health record, adapted to the specific needs of family physicians, constitutes the central nervous system of the practice
Attractive, convenient, and functional offices	Offices should be redesigned to make them attractive, convenient, and functional in order to meet a variety of patient needs and expectations
Care provided within a community context	A culturally sensitive, community-oriented, population-perspective focus
Commitment to provide family medicine's basket of services	A commitment to provide patients with family medicine's full basket of services – either directly or indirectly through established relationships with other clinicians
Focus on quality	Ongoing assessment of performance and outcomes and implementation of appropriate changes to enhance quality
Equitable reimbursements	Payment mechanisms that provide for equitable reimbursement for services from public and private payers

and the Joint Commission's PCMH model, have increased complexities at the practice transformation level. Moreover, Bitton et al. [19] observed that the transformation process used in these demonstration projects was highly informal and was purely dependent on the projects and consultant experience. According to Nutting et al. [6], "the NDP experience suggests that transformation to a PCMH requires continuous, unrelenting process of change. It represents a fundamental re-imagination and redesign of practice, replacing old patterns and processes with new ones" (p. 255). Demonstration designs seriously underestimated the magnitude and time frame for the required changes and overestimated the readiness and expectation of the information technology. They observed that the transformation process toward a PCMH requires adoption of a substantially different approach to patient care. For example, transformation can involve a move from physician-centered care to a team-approach care, where care is being shared among other adequately prepared office staff. A similar view was echoed by Crabtree et al. [26]:

> "Overall, the NDP experience suggests that for most practices, it will take much more time than anyone imagined to transform into a PCMH, although it is difficult to know just how much more given that so few NDP practices completed the transition in 2 years even with intense facilitation. It is apparent that for most practices, the process will take a high degree of motivation, communication, and leadership; considerable time and resources; and probably some outside facilitation" (p. S83).

Transformations in these projects include many interdependent activities, such as new scheduling and access arrangements, new coordination arrangements, development of team-based care, group visits, quality improvement activities, new strategies for patient engagement, and many other activities. Transformation does not occur in a steady and predictable pace, but rather in interrelated steps. Also, the magnitude and pace of change required to transform a practice into a PCMH generates *change fatigue*. The work needed for the change is daunting and exhausting. Change fatigue can ruin a practice and can often create staff burnout. Nutting et al. [7] suggest that a practice's ability to keep pace with rapid developmental changes depends very much on the practice's ability to learn and develop (called adaptive reserve). According to Homer and Barton [27], "although numerous reports indicate practice change is feasible – particularly with technical support and either insulation from or alignment with financial incentives – sustained transformation appears difficult" (p. 625). Most physicians also lack training and experience to implement a medical home model [28]. They also do not have great interest in broadening their service offerings to include the comprehensive care coordination required in a medical home model.

The good news for primary care practices is that many new research and consulting practices have opened to guide primary care practices through the transformation process using a variety of proprietary tools and services [29]. These tools and services include clinical registry with evidence-based care plans; reporting functions that help quantify performance; inter- and intra-practice care coordination tools; collection, aggregation, storage and sharing of clinical data; education and resources related to evidence-based clinical practice guidelines, quality improvement, practice management, payment and financing, HIT, patient portal; and various clinical topics to help support member practices.

Even though these consulting and research organizations support practices for handling their transformation processes and move toward a higher level of PCMH recognition, so far no one has focused on understanding how to handle these transformation complexities in a standardized way. Each consulting and research organization approaches the transformation process uniquely and in an ad hoc manner. Wise et al. [30] note the frustrations associated with those approaches:

> *"I did all these webinars—TransforMED, Medfusion—all of them, to find out what I could get for PCMH. I'm sure my staff is sick to death of all these webinars*" (Practice manager) (p. 408)

> *"[The PCMH] is a lot to take in, and I get lost with all of it, sometimes. I have to learn all of this, and then I have to teach the doctor.*" (Practice manager) (p. 409)

4. Ontology development for practice transformation

Following the software process modeling literature [31–35], where the emphasis has been on standardizing the software development process and promoting repeatability and measurability, we are interested in promoting task standardization for the PCMH care delivery model. In this section, we offer a step-by-step design of an ontological model for the practice transformation process. We argue that such an ontology can provide a standard description of the practice transformation process; it can be mapped to a variety of PCMH models. Fig. 1 describes the Practice Transformation Process Ontology with respect to actual practice transformation in practices.

A transformed practice [36] provides *greater accessibility* (e.g., advanced access scheduling systems, availability by e-mail and phone); *coordination of care* (engaging the practice in non-visit based communication with patients, families, and many other providers of care); and *management of information* (assuring that information about patients is maintained securely and is able to support appropriate care both within and outside of the practice; working with structured data; and developing ongoing performance reporting and improvement efforts based on those data). Such a transformed practice typically shows significant improvement in the performance of preventive services, as seen in the program evaluation studies conducted by [37–39] and also in the processes of care for numerous chronic conditions [40,41]. NCQA-certified practices will have physicians who will not personally provide all care; rather, they will take on the responsibility to manage and coordinate care by developing information systems, advanced protocols under which newly trained staff operate, and tracking systems to ensure that patients reliably get what they need, when they need it, and in the most appropriate setting.

We base our methodology to create the PTP ontology on the *Methontology* paradigm, which has its roots in activities identified by the software development process [11–13,42,43]. "Methontology provides guidelines for specifying ontologies at the knowledge level, as a specification of a conceptualization" [13,p.37]. Explicit specification of a conceptualization means that the ontology is a description of the concepts and relationships that exist in the domain of discourse. Our ontology captures the PTP domain knowledge, but not any problem-solving methods that an organization could employ to meet PTP standards and achieve NCQA certification. We specify our domain ontology using a set of intermediate representations, which bridge the gap between our understanding of the real-world domain and the formal model of the ontology. The rest of the section is built on the steps outlined in *Methontology*, coupled with standard knowledge acquisition techniques [44].

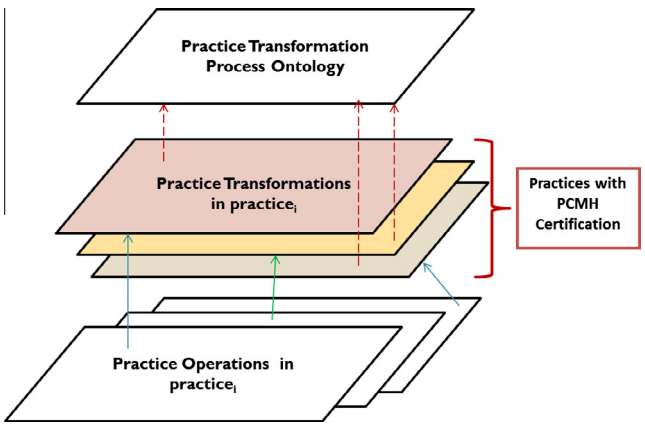


Fig. 1. A high-level view of practice transformation process ontology.

4.1. Stage 1. Capture domain knowledge

The practice transformation domain (for PCMH 2014 model) uses two concepts: *Goal* and *Goal tree*. Even though we are working with the PCMH 2014 model, our discussion applies to earlier PCMH models as well.

4.1.1. Goal

A goal is a broad statement applied to a project. Goals determine "what" the project will accomplish. Projects can have more than one goal. Goals should be meaningful, minimal, and comprehensible. By meaningful, we mean that the goals should be described in such a way that they can be met. By minimal, we mean that the number of goals in a project needs to be reasonable so that they can be addressed. Finally, a goal should be precisely formulated, avoid complicated sentence structures, and address only one topic.

4.1.2. Goal tree

A goal tree can be created by decomposing a goal into its sub-goals. In Fig. 2, the root goal node of the goal tree is "PCMH 2014" which is needed to improve the quality of care. The PCMH 2014 goal is composed of a set of sub-goals called *Standards*. Each Standard is composed of a set of lower level goals called *Elements*. Each *element* includes a set of lower level specific goals called *Factors*. Fig. 2 shows the goal tree where the nodes are standards, elements, or factors. In order to keep the figure readable, we only show the standards in detail; the names of the elements and factors are not shown in the figure.

The PCMH 2014 model has six *standards* (see Fig. 3). Standards are goals that must be met by a practice to get recognized. Each element, on the other hand, provides details about a specific performance expectation of the standard. For example, the "enhance access and continuity" standard is composed of three elements: "patient-centered appointment access," "24/7 access to clinical advice," and "electronic access." There are many factors for each element. For example, the "patient-centered appointment access" element (a goal) includes "providing same-day appointments for routine and urgent care," "providing routine and urgent-care appointments outside regular business hours," "providing alternative types of clinical encounters," "availability of appointments," "monitoring no-show rates," and "acting on identified opportunities to improve access" factors. All goals (standards, elements and factors) need to be satisfied for NCQA certification.

NCQA evaluates all factors of all standards to determine how well the practice meets the root goal of achieving a certain recognition level. When an element includes multiple factors, the scoring indicates the number of factors that the practice must meet to achieve a recognition level. Some elements in the standards are considered to be a "must-pass" objective by NCQA. A "must-pass" element is considered to be a basic building block for a patient-centered medical home. This is shown by an asterisk prefix for an element in Fig. 3. Practices must earn a score of 50% or higher for all six "must-pass" elements in the PCMH 2014 model. Some factors in the model (not shown in Fig. 3) are considered critical. A *critical factor* is a factor that must be met for a practice to receive a score for an element. NCQA requires the practices to present the following for each factor: documented process, reports, records or files, and materials like clinical guidelines, web sites, brochures, videos, and pamphlets. Using the standards, elements, and factors for its PCMH model, NCQA has developed an elaborate scoring mechanism that helps score a practice for different levels of PCMH recognition.

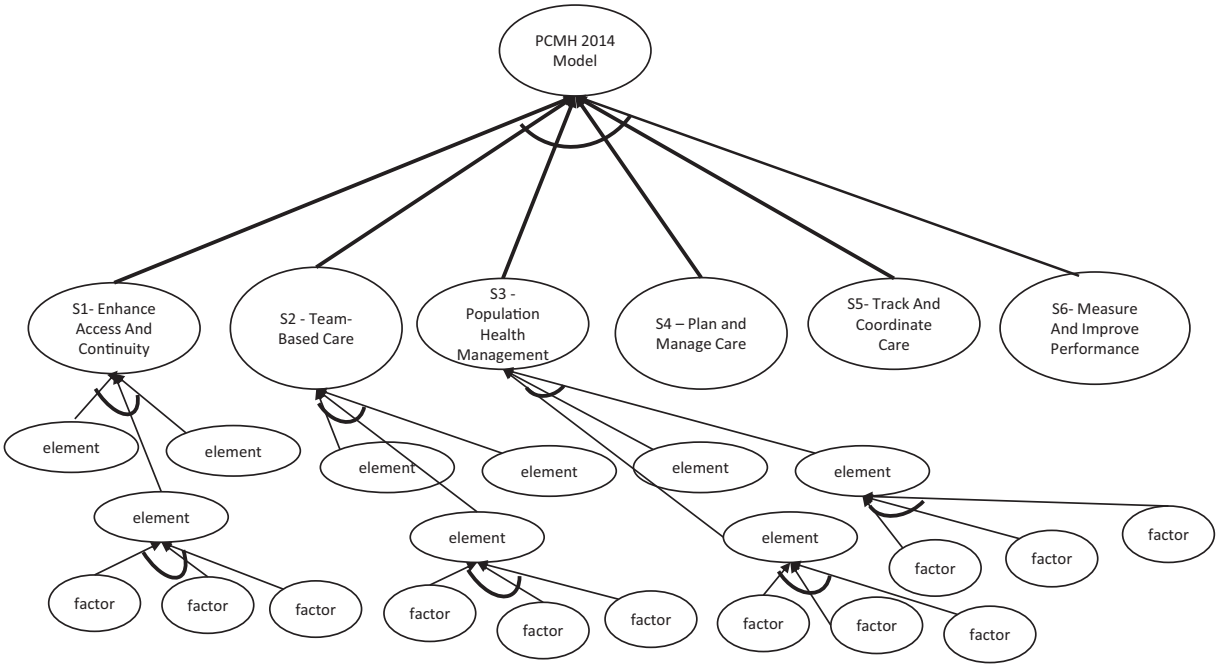


Fig. 2. A partial goal tree for NCQA's PCMH 2014 model.

1: Enhance Access and Continuity	Pts
A. ***Patient-Centered Appointment Access**	**4.5**
B. 24/7 Access to Clinical Advice	3.5
C. Electronic Access	2
	10

2: Team-Based Care	Pts
A. Continuity	3
B. Medical Home Responsibilities	2.5
C. Culturally and Linguistically Appropriate Services (CLAS)	2.5
D. ***The Practice Team**	**4**
	12

3: Population Health Management	Pts
A. Patient Information	3
B. Clinical Data	4
C. Comprehensive Health Assessment	4
D. ***Use Data for Population Management**	**5**
E. Implement Evidence-Based Decision-Support	4
	20

Scoring Levels
Level 1: 35-59 points.
Level 2: 60-84 points.
Level 3: 85-100 points.

4: Plan and Manage Care	Pts
A. Identify Patients for Care Management	4
B. ***Care Planning and Self-Care Support**	**4**
C. Medication Management	4
D. Use Electronic Prescribing	3
E. Support Self-Care and Shared Decision-Making	5
	20

5: Track and Coordinate Care	Pts
A. Test Tracking and Follow-Up	6
B. ***Referral Tracking and Follow-Up**	**6**
C. Coordinate Care Transitions	6
	18

6: Measure and Improve Performance	Pts
A. Measure Clinical Quality Performance	3
B. Measure Resource Use and Care Coordination	3
C. Measure Patient/Family Experience	4
D. ***Implement Continuous Quality Improvement**	**4**
E. Demonstrate Continuous Quality Improvement	3
F. Report Performance	3
G. Use Certified EHR Technology	0
	20

***Must Pass Elements**

Fig. 3. PCMH 2014 model showing standards and elements. (source: NCQA)

4.2. Stage 2. Develop intermediate representations

Conceptualization is an important aspect of Ontology development. *Methontology* organizes and converts an informally perceived view of a domain into a semi-formal specification using a set of intermediate representations (IRs) [43] with graphs and tables in multiple steps. The intermediate representations for Practice Transformation domain include the Key Process Area (KPA) concept, KPA Taxonomy, KPA Composition, glossary of terms, binary relation diagrams, KPA instances, formal axioms, rules, etc. At each step of creating the IRs, we utilized several practice transformation experts, as described below. We also obtained IRB (Institutional Review Board) approval for the project.

4.2.1. Step 1. Create KPA concept

The ***Key Process Area (KPA)*** concept, described by [32,45,46], represents a cluster of related key activities, which when performed collectively, achieve a set of goals at the factor level of the goal tree shown in Fig. 2. Each activity is defined as a type of action at a specific place and time. These key activities, according to Paulk et al. [45] "describe 'what' is to be done, but they should not be interpreted as mandating 'how' the process should be implemented. Alternative activities may accomplish the goals of the process area." (p. 39). Each KPA has a definition component as described below.

KPA definition. The KPA definition describes the purpose of the KPA. For example, the definition of the *Scope Design and Verification*

KPA is "to develop a plan to determine the scope of the practice's transformation project targeting a certain NCQA's PCMH recognition level. This includes understanding the eligibility of the practice, its network of practices, and size of the practice itself." The definition also distinguishes the KPA to be useful either in the initial practice transformation (tagged as "Transformation"), or in practice transformation sustainability (tagged as "Sustainability"), or in both. The basic premise of our argument is that the quality of a transformed practice is largely determined by the quality of the transformation process tasks used for its improvement. We argue that the primary goal of a transformation process should be to facilitate and enhance the deliberate, standard, and planned development of a practice toward greater effectiveness, quality, and reliability so that it leads to higher levels of PCMH certification recognition and enhanced patient care.

As there are 131 goals at the factor level in the PCMH 2014 model, it is quite easy to understand why practices feel that practice transformation to achieve these goals is so complicated. While NCQA has proposed the PCMH 2014 model, it has yet to make clear what KPAs a practice must employ in order for it to get transformed and eventually get recognized. The concept of KPA is not new in the PCMH world. Concepts close to it have appeared in recent articles on practice transformation models [3,22,30,47] and on websites such as HealthTeamWorks (http://www.healthteamworks.org/index.aspx), TransforMED (http://www.transformed.com/), and (American College of Physician's Practice Advisor – http://www.practiceadvisor.org/join-now/features). Recently, the Agency for Healthcare Research and Quality (AHRQ) developed a practice facilitation model [48], which includes several key areas such as *readiness assessment*, *workflow redesign*, *measuring clinical performance*, *chart audits*, etc. It is obvious that the development of KPAs for practice transformation is still quite ad hoc.

The development of KPAs for our practice transformation model is informed by the knowledge gathered from existing practice transformation models [22,30,47–49], and HealthTeamWorks, TransforMED, and ACP's Practice Advisor. We also consider the KPAs of quality-oriented process models in software development such as Capability Maturity Model (CMM) [45], Capability Maturity Model Integration (CMMI) [33,46]; in human resource management such as People CMM [50]; in IT service project management such as IT Service model [51,52], and in data warehousing such as Data Warehousing Process Maturity (DWP-M) Model [53]. We identified 41 KPAs for this intermediate representation of our ontology. Some example KPAs and their definitions are presented in Table 3.

Knowledge verification. To evaluate the completeness of the KPAs at this step, in April 2011 we used a panel of three experts who are high-level managers from a large, non-profit hospital in southwestern region of United States. These hospital administrators include a senior-level manager of a rehabilitation center in a hospital overseeing physical, speech, and occupational therapies and hospice care and two vice presidents of the same hospital – one for clinical services and the other for patient services. We started our interviews with a presentation of the nature of our research. We described our initial model verbally and explained the notion of key process areas. We then provided them with a questionnaire that contained all the 41 KPAs with their names and definitions. Their task was to select the KPAs that they thought were appropriate for creating a medical home in their hospital. We also asked them to add any new KPAs that we may have overlooked. Even though the hospital did not have a PCMH setup yet, each manager was eager to get there and was well versed in the terminologies of the PCMH model.

Between the three of them, the experts picked a total of 35 KPAs; six of the KPAs were not selected by any of the experts. Because none of the experts had gone through an actual practice transformation at their hospital, they could not be absolutely certain about the usefulness of those remaining 6 KPAs. But they assured us that we were on the right path and, for that reason, we decided to retain all the 41 KPAs for the next intermediate representation.

Table 3
A partial list of KPAs and their definitions.

KPA	KPA definition
Scope design and verification	The objective of the KPA is to develop a plan to determine the scope of the practice's transformation project targeting a certain NCQA's PCMH recognition level. This includes understanding the eligibility of the practice, its network of practices, and size of the practice itself
Program Planning	The purpose for the KPA is to establish reasonable plans for performing the practice transformation projects and for managing the patient care process. The task also promotes the awareness of practice transformation costs and benefits in the organization
Project Planning	The purpose of the KPA is to establish reasonable plans for performing the transformation process tasks and for managing the transformation project. The KPA also promotes the awareness of PCMH recognition and its costs and benefits in the practice
Staffing	The objective of the KPA is to develop a plan to staff the transformation project team with various types of people usually needed in the PCMH transformation process and for its sustainability
Business justification	The objective of the KPA is to identify the anticipated costs and benefits associated with the transformation process projects and also PCMH recognition project

4.2.2. Step 2. Create KPA taxonomy

The feedback from the expert panel helped us understand how our KPAs needed to be improved. We reorganized the KPAs by developing a KPA taxonomy, which classifies the KPAs into four different ***KPA categories*** (Fig. 4). The first category focuses on KPAs that affect the overall supervision of the practice transformation process. The second category includes KPAs needed to manage transformation activities linked to IT support of the practice. The third category contains KPAs useful to manage transformation activities of a practice's data environment. Finally, the fourth category covers KPAs directly responsible for practice transformation tasks. The benefit of creating categories was to evaluate and instantiate the KPAs more systematically. Four KPAs (clinical metadata management, product engineering, integrated metadata quality management, and metadata change management) were dropped for the next intermediate representation as they were deemed not very useful for practice transformation. As a result, we reworked on our list of KPAs and settled with 37 KPAs.

Knowledge verification. In order to evaluate the model built so far, we decided to collect retrospective verbal data [35] from experts and analyze them using protocol analysis technique [54]. Our study included two experts (S1 and S2) from a multi-site Federally Qualified Health Clinic (FQHC), and two experts (S3 and S4) from a multi-site for-profit health clinic. Both organizations are NCQA-recognized PCMH Level-3 facilities, located in two different cities in southwestern United States. The experts include a clinic director, a site manager, and two managers directly responsible for PCMH recognition. The subjects had intimate knowledge of their organization's quality programs and were in charge of their organizations' NCQA-recognition initiatives.

In retrospective protocol analysis, participants verbalize what they have done by recalling the steps they performed to complete a task. Our experts were asked to narrate retrospectively the detailed steps their organizations had taken to reach PCMH Level-3. During the period between June 2012 and October 2012,

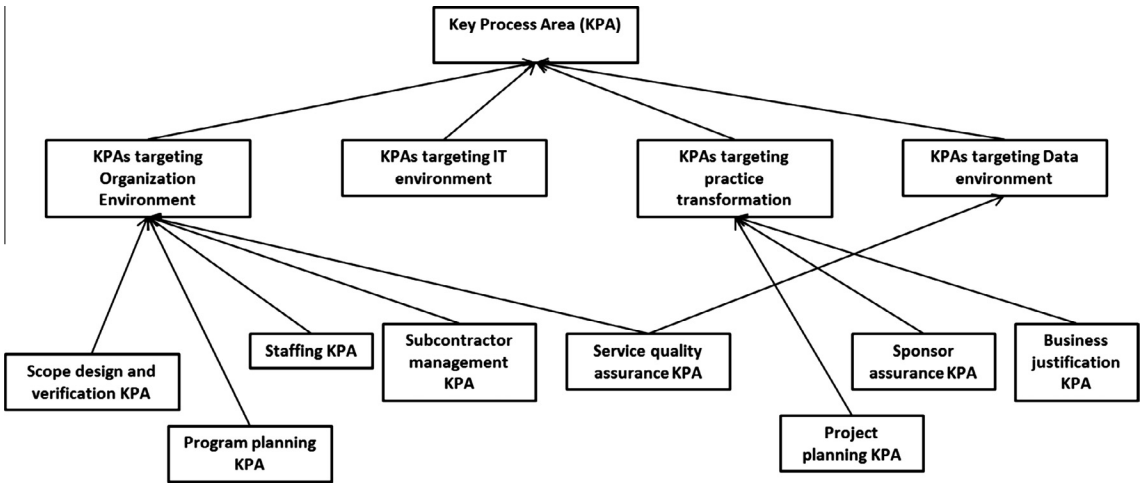


Fig. 4. A partial taxonomy of the KPAs.

we obtained from the four experts relatively rich verbalization data. The objective of our analysis was to ascertain if KPAs can explain the complexity of the practice transformation processes used in these organizations.

To collect the retrospective protocol data, we followed a standard set of steps used in knowledge acquisition [44]. Several emails were sent to the subjects to explain our research objectives, along with what they could expect during the knowledge acquisition interview. Subject verbalizations were tape-recorded as they recalled the process to get their organizations recognized as level-3 PCMH. Each session lasted for 2 to 3 h. The tape recordings were then transcribed. The verbal data was segmented using a standard segmentation technique [55] to extract protocols. These protocols provide verbal transcripts of the subjects' experiences with their organization's practice transformation process to achieve PCMH Level-3 recognition. A brief extract of the protocols for subject S1 is presented in Fig. 5. We collected an average of 109 protocols per subject.

To see if the model clearly defined the practice transformation process, we verified the model by using the protocols captured from the subjects. Coding rules were developed for the 37 KPAs we had identified in the previous step. Each rule was designed to focus implicitly or explicitly on terms or phrases in protocols that represent the KPA. For example, the rule below focuses on the *staffing* aspect of the practice transformation process.

Rule: If the protocol has terms like "staffing," "staff time," "creating teams," or some phrases that point to use of staff, then code this protocol as STAFFING.

All protocols were then searched to see which rules are applicable. If the antecedent terms of rules were found, the protocol was tagged by a KPA name (a label). A protocol can be tagged by multiple labels. An excerpt of these coding activities with our protocols is shown in Fig. 5. We highlighted the segments of the protocols, matched them with the antecedents of the coding rules, and then tagged them in the comments box with labels such as inter-group coordination KPA, staffing KPA, and peer review KPA (as shown in the top right in Fig. 5). In an attempt to understand the completeness of our model, we performed the following steps [54,55]: (a) find the protocols that are not predicted by the model; (b) notice the absence of predicted KPAs in the protocols; and (c) analyze the labeled transformation process protocols to ascertain the extent of use of KPAs by the expert panel members. We observed that unpredicted protocols occurred when subjects commented on different aspects of their practice and its practice transformations, and the NCQA's PCMH model. On average, 14.75% of the protocols per subject could not be coded. A close inspection of these protocols shows that they were mostly comments and opinions by the subjects.

Because of the sheer length of verbal protocols and the effort needed to code and analyze such protocols, protocol studies usually employ only a few subjects [56,57]. The verbal protocol

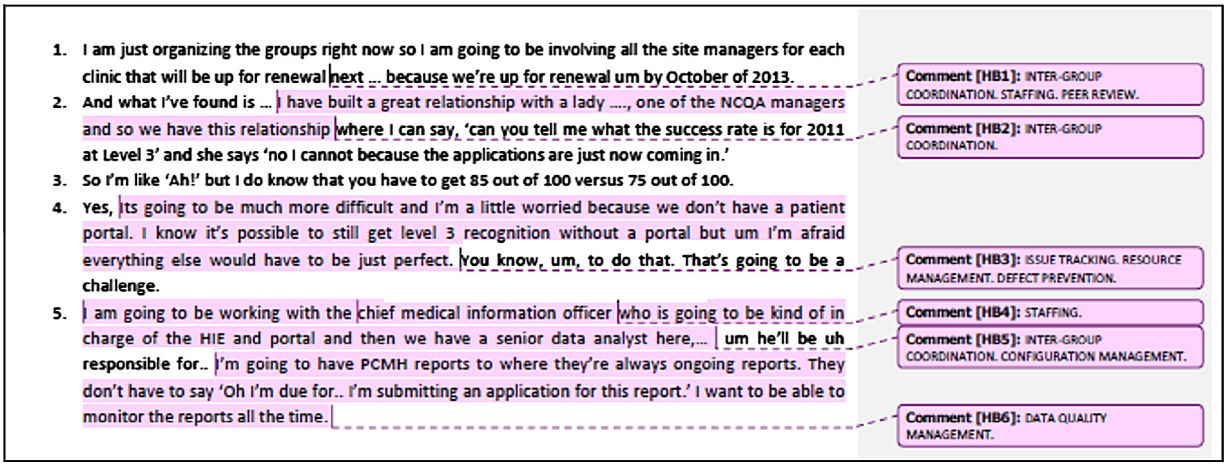
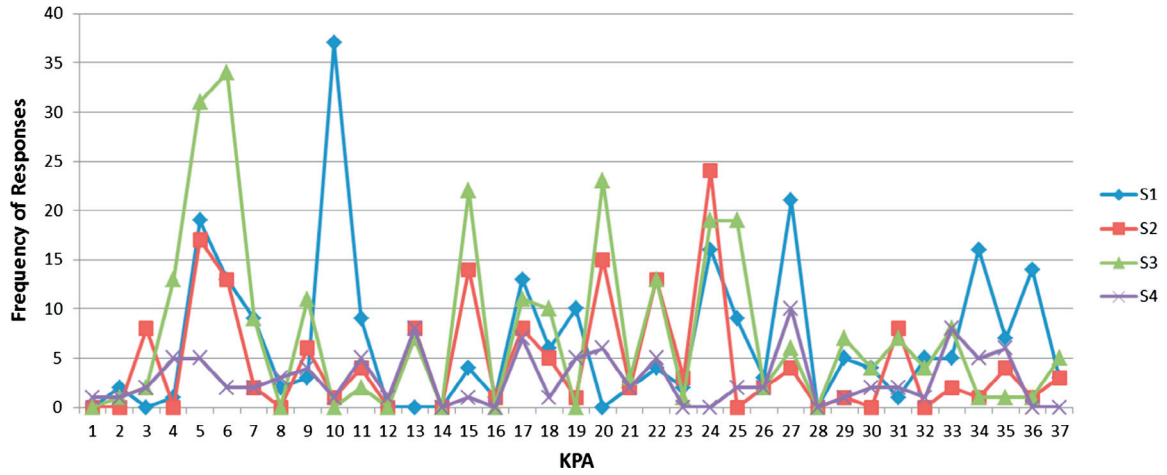


Fig. 5. A brief protocol extract with codes for subject S1.



Legend:

1. Sponsor assurance	13. Organization process focus/transformation process focus	25. Configuration management
2. Program planning	14. Recovery management	26. Training program
3. Project planning	15. Stakeholder management	27. Data quality management
4. Business justification	16. Integrated infrastructure management	28. Quantitative process mgmt.
5. Staffing	17. Inter-group coordination	29. Data change management
6. Requirements mgmt.	18. Data quality assurance	30. Service level management
7. Scope design	19. Peer review	31. Financial service mgmt.
8. Project tracking	20. Information delivery mgmt.	32. Quality improvement framework alignment /alignment of architecture
9. Subcontractor mgmt.	21. Service level agreement	33. Technology change mgmt.
10. Issue tracking	22. Service quality assurance	34. Defect prevention
11. Standards setting	23. Integrated service mgmt.	35. Process improvement/ transformation process improvement
12. Organization focus def./transformation focus definition	24. Resource management	36. Data governance
		37. Transformation governance

Fig. 6. Graph showing number of recorded protocols for each KPA by subject.

data that we extracted from the experts was very detailed and rich. Given that all the subjects in our study are experts working for NCQA-recognized facilities, we do not expect the protocols to exhibit high variance. Also, note that our goal was to verify the knowledge of KPAs elicited in the previous step. In that context, using four subjects for protocol analysis appears to be a sound and effective strategy. Altogether, we collected a total of 436 protocols from the four experts. The richness of the protocol data allowed us to verify that all the KPAs identified in the taxonomy, except two, are indeed valid.

In order to analyze the *absence of predicted tasks*, we counted the protocol labels of all four subjects. Fig. 6 presents the data graphically. A comparison reveals similarity among the subjects in their emphasis of using the KPAs. The number of recorded counts differs from subject to subject. However, S1 and S2 have similar patterns as they belong to the same organization. The same is true for S3 and S4. Out of the 37 KPAs, we found that only two KPAs (14 and 28) have not been used by any one of our subjects. KPA 14 is *recovery management*, while KPA 28 is *quantitative process management*. The recovery management KPA entails planning for data failures and disasters. The quantitative process management KPA focuses on developing and collecting key process quality metrics. Although both KPAs are essential for organizations, our subjects may not have dealt with them personally and, therefore, they were not present in the protocols.

4.2.3. Step 3. Create KPA structure

Using the *Methontology* paradigm, we continued with another iteration of the intermediate representation by expanding the KPA structure. This was done by recognizing that a KPA needs to include other components such as *KPA Rationale*, *Key Activities*, *Typical Work Products*, *Goals*, *Recognition Levels*, and *Usefulness notes*.

KPA Rationale. This component describes why such a KPA is essential for practice transformation. Many of the KPAs can be traced back to the extant literature.

Key Activities. We define an activity as a specific task across time and place, with a beginning, an end, and clearly defined inputs and outputs

Typical Work Products. This component lists work products for a specific KPA. They are called "typical work products" because they are useful and effective toward the NCQA recognition level document support requirements. For example, typical work products for the *Scope design and verification* KPA are strategic plan for the organization, PCMH transformation gap analysis, etc.

We have already described the ***Goals*** and ***KPA category*** in Steps 1 and 2. The ***Recognition Level*** component represents NCQA's PCMH Recognition Levels. The ***Usefulness Notes*** component includes experts' comments and views, describing why the KPA is useful for practice transformation. Using the extant literature in software process modeling, health care delivery, data warehousing process, and other areas (see Step 1), we once again extended our list of KPAs by three (practice metadata management, workflow alignment, and transformation tools management). Our final list of KPAs for our current intermediate representation, therefore, includes 40 KPAs. We also developed the rationale and key activities for each of the 40 KPAs.

Knowledge verification. The objective of this step is to get all the KPA components verified by an expert panel. To create an expert

panel of PCMH content experts, we sought help from NCQA in early June 2014. In an email to its PCMH content experts in a southwestern state in US, NCQA said "(the project) would be a great opportunity ... to leverage your skills and learn something you might find helpful in your practice transformation efforts. NCQA would like to see this project succeed and a 'process-oriented' practice transformation model created." Out of the 27 PCMH CCE (Certified Content Experts) in the state in 2014, 16 responded and 12 eventually joined the expert panel in July 2014. The panel included independent PCMH consultants, physicians from FQHCs, registered nurses, and quality managers from hospitals and health care facilities across the state. All the members were PCMH CCE certified by NCQA.

We introduced the project to the panel members by sending them a slide deck and then using it to explain our intentions in a 90-min Webinar. We explained the objective of the project, the notion of building a process model, and the reasons as to why a KPA-based model could help a practice achieve PCMH recognition and sustainability. We randomly assigned a KPA to each panel member to study, evaluate, and add responses in each interaction. Some KPAs were assigned to more than one panel member to check if their responses were consistent. We used a knowledge acquisition survey tool, which described the KPA and provided its definition, rationale, and key activities. The panel members were asked to evaluate and refine them. The survey also included other tasks: (a) verify the usefulness of KPAs for initial practice transformation, or for sustainable transformation, or for both; (b) list typical work products that a KPA produces or needs; (c) relate a KPA with PCMH Goals that it satisfies; (d) relate a KPA with PCMH Recognition levels; and finally, (e) rate a KPA for its usefulness in the practice transformation process.

We communicated with the panel members using emails and phone calls. We exchanged a total of 392 emails with the panel members, beyond the initial emails for setting up the panel. On average, each panel member was responsible for four KPAs – one per iteration. This mode of information acquisition was adopted to reduce the work load of the panel experts, letting them concentrate on a few KPAs. It took a total of three months to get all the KPAs verified and surveys filled. The knowledge acquisition surveys for duplicate KPAs were analyzed and found to conform quite closely to each other. The panel members proposed several modifications to the model during the verification and validation activities.

Several KPA activities were modified. Some changes were editorial in nature. Others, however, were substantial. For example, for the *Scope design and verification* KPA, the panel added an activity that "identifies organization's capacity to undergo practice transformation by looking at leadership engagement, competing change projects and allocated resources (like staffing, timing and funding)". Out of the 249 key activities in the model, the panel extensively edited 84, added 17 new ones, and deleted 3.

As discussed earlier, a KPA can be useful for initial transformation (tagged as "Transformation"), or for sustainability (tagged as "Sustainability"), or for both. In our initial model, we tagged KPAs based on our understanding of the practice transformation process. The panel suggested many changes to those tags. For example, even though our model tagged *Standard Setting* KPA as important for PCMH "Transformation" and "Sustainability," the panel disagreed. It pointed out that the *Standard Setting* KPA is needed initially only for PCMH "Transformation," so we removed "Sustainability" from its tag list in the model. For some other KPAs, "Transformation" tags were inserted. We changed tags for 15 KPAs based on expert panel inputs.

The expert panel added a total of 141 typical work products that are needed or are produced by the KPAs. Examples of typical work products include plans, policies/procedures, reports/documents, tools/surveys, and worksheets like NCQA Record Review worksheet. Finally, the expert panel related all KPAs with PCMH Recognition Levels and with PCMH goals at factor levels. Some KPAs were related to a single recognition level, while others were related to multiple recognition levels. The panel pointed out that about 25% of the KPAs was required to be completed prior to the start of the practice transformation process. Once the iterations were complete, we edited the KPAs based on the suggestions from the panel members. Two examples from the final model are presented in Appendix A. A list of all the KPAs is available in Appendix B (note that the KPA numbers in the appendix are not always the same as those in Fig. 6, because of the fact that three KPAs were added later).

4.2.4. Step 4. Build glossary of terms

In this step, we built a glossary of terms that includes all the relevant terms of the domain (concepts, instances, attributes of the concepts, relations among concepts and constant terms). This glossary also includes synonyms and acronyms as needed. Some example terms for the *Staffing* KPA are shown below (Table 4).

4.2.5. Step 5. Build concept taxonomies

After creating all the terms, concept taxonomies were built to define the concept hierarchy. Following *Methontology*, we used four taxonomic relations: *subclass-of*, *disjoint-decomposition*, *exhaustive-decomposition* and *partition* to build the concept taxonomies. Each of these taxonomic relations is defined in the OKBC Ontology [43].

4.2.6. Step 6. Build binary relation diagrams

Once the taxonomies were built, we proceeded to build binary relation diagrams. Our goal was to establish binary relations between concepts. For example, the KPA concept is related to the *Work Product* concept by a binary relation *needsWP*; it is also related to other concepts such as *RecognitionLevel* and *PCMH Goal*

Table 4
Partial glossary of terms of practice transformation.

Name	Description	Type
KPA (Key Process Area)	A cluster of related key activities that when performed collectively achieve a set of goals	Concept
Key Activity	Each activity is defined as a type of action at a specific place and time based on a KPA (Focus is on "key" activities)	Concept
Staff Final Degree	Education level of Staff who will work for the practice transformation	Instance Attribute
Advisor	Someone who helps steer the practice transformation process. Could be providers, patient representatives, IT/data staff	Concept
Subcontractor	People who will help in the transformation process	Concept
Type	Type of member of the Advisory Board	Instance Attribute
Max number staff	Maximum number of staff that a practice has (we only consider staff who can help in the PCMH project)	Constant
Manages (Team Manager, Staff)	It is the "responsibility relationship" between manager and his/her staff	Relation
Selects (Staff, Subcontractor)	It is a "choice relationship" between staff and subcontractor showing staff choosing subcontractors	Relation

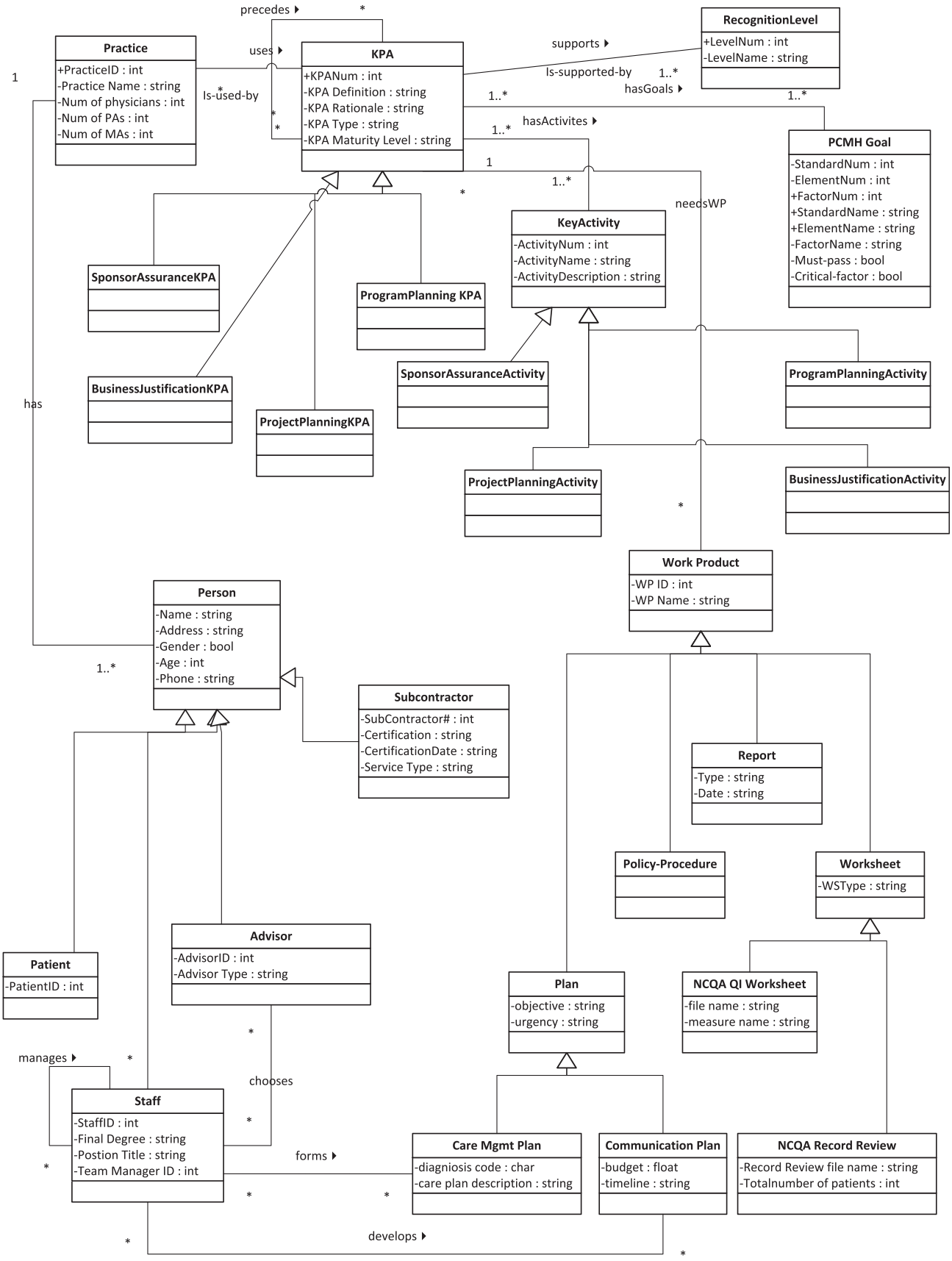


Fig. 7. A UML conceptual class diagram for PTP ontology.

through binary relations such as *supports* and *hasGoals* (see Fig. 7 below). Each of the binary relationships must have correct domains and ranges to delimit precisely the classes that are appropriate.

4.2.7. Step 7. Build concept dictionary

At this stage, we need to specify the properties and relationships among the concepts of the taxonomy presented earlier. We developed a concept dictionary for our practice transformation ontology. The concept dictionary contains all the domain concepts, their relationships, their instances, and the class and instance attributes.

4.2.8. Step 8. Define binary relations

The goal of this step is to describe in detail each of the binary relations used in the ontology. We described each relation in terms of its *name*, *source concept name*, *target concept name*, *cardinality*, and *inverse relation*. Focusing on ad hoc binary relations among concepts, we utilized the concept dictionary and employed the UML diagramming approach to represent relationships among classes in the ontology. Fig. 7 shows the binary relations between the classes in our ontology, *supports*, *uses*, *hasActivities*, etc., along with inverses such as *is-supported-by*, *is-used-by*, *isPartOf*, etc. It also captures the precedence relationship between two KPAs through the unary relation called *precedes*. The cardinalities for the relationships are also specified; for example, a KPA has one or more key activities, while a key activity is part of one KPA. The class diagram shows the concept taxonomies we developed in Step 5; for example, the KPA class has subclasses such as SponsorAssuranceKPA, BusinessJustificationKPA, ProjectPlanningKPA, etc., and the Person taxonomy has subclasses such as Patient, Staff, Advisor, and Subcontractor.

4.2.9. Step 9. Define instance attributes

The aim of this step is to describe in detail all the instance attributes already included in the concept dictionary by means of an instance attribute table. Each row of the table contains detailed description of an instance attribute. Instance attributes are those attributes whose values could be different for each instance of the concept. Each instance attribute is defined by *name*, *the concept it belongs to*, *value type*, *measurement type*, *precision*, *range of values*, and *cardinality*. Examples of instance attributes include KPANum, KPA Definition, KPA Rationale, and KPA Maturity Level within the KPA class, and LevelNum and LevelName within the RecognitionLevel class.

4.2.10. Step 10. Define class attributes

The objective of this task is to describe in detail all the class attributes already included in the concept dictionary by means of a class attribute table. Each row of the table contains a detailed description of the class attribute. We developed the table using *name*, *concept name*, *where it is defined*, *value type*, *value*, *measurement unit*, *value precision*, *cardinality* and *value*. A class attribute describes a concept and realizes its value in the class where it is defined. An example of a class attribute is Type within the Report class, with a value type of "string," cardinality of (1,1), and a value of "Report."

4.2.11. Step 11. Define constants

The aim of this step is to describe in detail each of the constants defined in the glossary of terms. For each constant, we need to specify: *name*, *value type*, *value*, and *measurement unit*.

4.2.12. Step 12. Define formal axioms

The objective of this step is to identify the formal axioms in the ontology and describe them precisely. Using *Methontology* guidelines, we specified the following information for an axiom needed in our practice transformation ontology: *axiom name*, *description*, *expression using first-order logic*, *concepts*, *referred attributes*, *ad hoc relations to which the axiom refers*, and *variables used*. Some example axioms include: *every KPA has at least one Key activity; every Key activity must be related to a KPA; every KPA is linked with one-to-many PCMH goals; each PCMH goal is either a STANDARD, or an ELEMENT, or a FACTOR*. Table 5 describes one formal axiom used in our practice transformation ontology.

4.2.13. Step 13. Define instances

We now define the relevant instances of the concepts described in the concept dictionary. To define each instance, we used the instance name, the name of the concept it belongs to, its attributes, and values. Table 6 presents some instances of KPA and other concepts in the practice transformation domain for a practice.

4.2.14. Step 14. Define rules

Similar to the previous task, we now identify the rules that are needed in the practice transformation ontology. Following the *Methontology* paradigm, we described the rules in a rule table. Using a similar template to that for the axiom table, each rule table includes: *rule name*, *description*, *expression using first-order logic with if-then template*, *concepts*, *referred attributes*, *ad hoc relations to which the rule refers*, and *variables used*.

Table 5
A formal axiom table for practice transformation.

Axiom name	KPA-has-at-least-one-Key activity
Description	Every KPA has at least one activity
Expression	$(\forall x)((\text{KPA}(x) \rightarrow (\exists y)(\text{Activity}(y) \wedge \text{Has}(x, y)))$
Concepts	KPA Activity
Referred attributes	–
Ad hoc binary relations	Has Used-in
Variables	*x*, *y*

Table 6
Instance table of KPA for practice transformation.

Concept name	Instance name	Attributes	Values
Staffing KPA	StaffKPA	KPA#	1
		KPA Definition	The objective is to provide a plan that cultivates sponsorship
		Rationale	Needs for generating awareness targeted to senior leadership
		Type	Transformation, Sustainability
		Associates	Key-Activiity-5a Key-Activiity-5b etc.
Recognition	RecognitionLevel_1	Level Num	1
		Level Name	Level 1
PCMHGoal	PCMHGoal_1A1	StandardNum	1
		StandardName	Enhance Access and Continuity
		ElementNum	A
		ElementName	Patient-Centered Appoint Access
		FactorNum	1
		FactorName	Providing same-day appointments for routine and urgent care
		CriticalFactctor	True
		MustPass	True

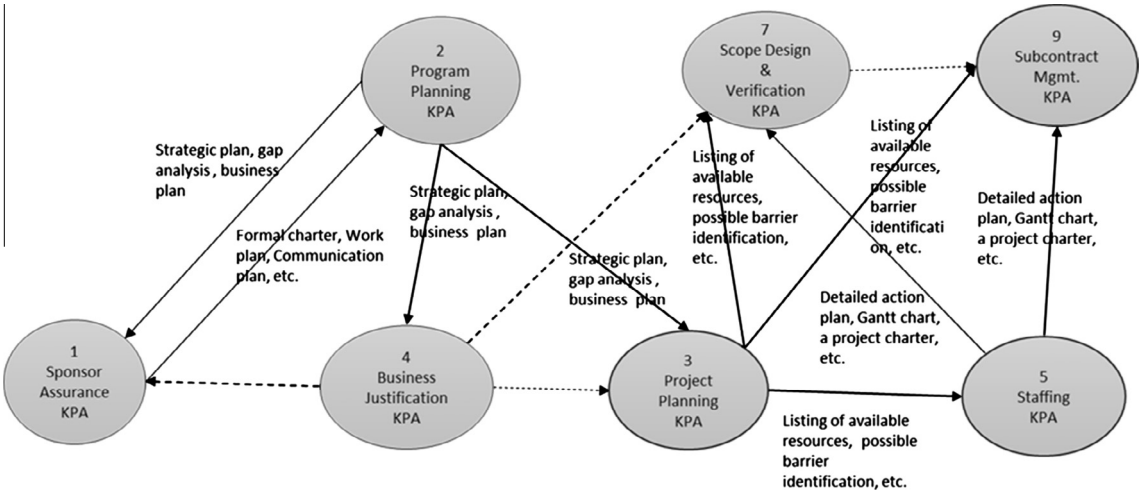


Fig. 8. A precedence diagram for KPAs.

Our ontology includes rules that support precedence relationships among the KPAs (a partial precedence diagram among some KPAs is shown in Fig. 8). The key activities performed by Sponsor Assurance (KPA 1) are to target potential sponsors of the practice transformation for generating awareness and interest in the transformation process. Based on the typical work products, strategic plans for performing transformation, gap analysis and a business plan were created (KPA 2: Program Planning). Stable plans are created for the practice by KPAs 1 and 2 working iteratively. Based on these inputs (shown by a solid arrow between KPAs 2 and 4), Business Justification (KPA 4) identifies the goals and objectives of the practice transformation projects, along with the costs, benefits, and potential sources of funding. The business justification is then used to garner and sustain interest in practice transformation within the organization. KPA 4 has a prerequisite relationship (shown by dashed arrows) with KPAs 1, 3 and 7, implying that KPA 4 needs to be performed before the other KPAs can start.

Note that a precedence relationship between two KPA instances is direct and is denoted by ***directPrec***(x, y). This means that node x directly precedes node y (there is an edge from x to y). If there is a path from node x to node y, it is represented by ***Prec***(x, y). The precedence relationship is transitive. It can simply represent precedence or can represent precedence with information flow. Examples include *Program Planning KPA case instance* ***precedes (with information flow)*** *Project Planning KPA case instance; Program Planning KPA case instance* ***precedes (with information flow)*** *Business Justification KPA case instance; Business Justification KPA case instance* ***precedes*** *Sponsor Assurance KPA* ***case instance***, etc. Table 7 describes a formal rule used in our practice transformation ontology.

Table 7
A rule table for practice transformation.

Rule name	Association between precedence and direct precedence
Description	Path is related to direct precedence between two KPAs x and y
Expression	$(\forall x)(\forall y)((\text{KPA}(x) \wedge \text{KPA}(y) \wedge \text{directPrec}(x, y)) \rightarrow \text{Prec}(x, y))$
Concepts	KPA instance – x KPA instance – y
Referred attributes	–
Ad hoc binary relations	–
Variables	x, y

4.2.15. Step 15: Develop transformation process maturity level – PCMH recognition level grid

As discussed in Sections 1–3, the practice transformation process is complicated and the magnitude and pace of change required to transform a practice into an NCQA-certified medical home can generate "change fatigue." To overcome this problem, we developed a process ontology that provides KPA-based documentation of the practice transformation process. Even though the model describes the PCMH goals in terms of KPAs and their associated activities in the ontology, it is still quite difficult for end users to determine the right KPA-based path for achieving the desired level of NCQA recognition. To address this issue, we could generate a complete precedence diagram among all 40 KPAs by utilizing the precedence relationships among them (see Fig. 8). However, such a precedence diagram will be combinatorially very complex. Also, such a precedence diagram will not explain to the practice which related KPAs need to be implemented to achieve a certain NCQA recognition level.

To resolve this problem, we developed a grid (see Fig. 9 and Table 8) based on NCQA's recognition levels and a new concept called *transformation process maturity*. The grid can be used to categorize the KPAs into smaller groups – each forming a set of KPAs required for a specific maturity level and a specific recognition level. Using a much smaller set of KPAs, the practice can then utilize the precedence order among KPAs for implementation.

We now define the concept of *transformation process maturity*. Process maturity is a concept that is rooted in the field of quality management [58,59]. The concept of maturity implies that a process can get mature by progressing from some *initial state* to a *more advanced state*. The notion of evolution utilizes stages of growth, suggesting that the progress transitions through a number of intermediate states on the way to higher maturity levels. Using Cosby's Quality Management Maturity Grid (QMMG) [59], a capability maturity model (CMM) was proposed [60]. CMM advocates that continuous process improvement is based on small, evolutionary steps and provides a framework for organizing those steps into five maturity levels [60]: *Chaos*, *Repeatable*, *Defined*, *Managed*, and *Optimizing*. Based on other disciplines such as project management [61], open source systems [62], enterprise architectures [63], information quality management [64], data base administration [65,66], IT services [67] and data warehousing [53], we developed our transformation process maturity levels as follows:

Level-1 (Chaos): At this level, there is no strict rule or procedure for practice transformation. In such an immature practice,

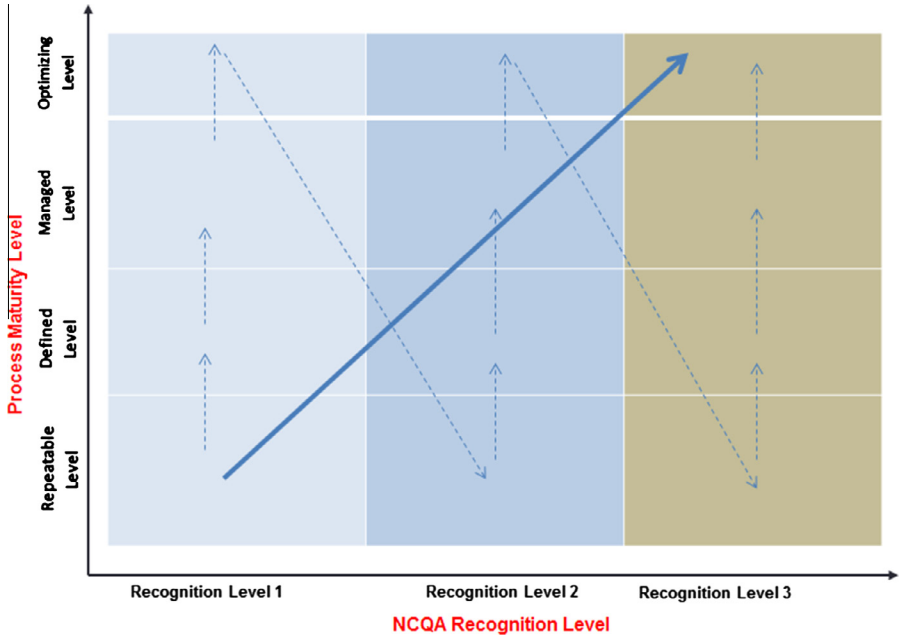


Fig. 9. Relating process maturity levels with NCQA recognition levels.

Table 8
Maturity level – Recognition level grid of KPAs.

	Recognition Level 1	Recognition Level 2	Recognition Level 3
Optimizing	• Data governance • Technology change management	• Data Governance • Technology change management • Process improvement	• Data Governance • Technology change management • Process improvement • Quality improvement framework alignment • Defect prevention
Managed	• Service level management • Data change management • Data quality management	• Service level management • Data change management • Data quality management • Quantitative process management	• Service level management • Data change management • Data quality management • Quantitative process management • Financial service management
Defined	• Practice metadata management • Integrated infrastructure management • Peer review • Service level agreement • Resource management • Transformation governance • Training program • Stakeholder management • Recovery management • Service level agreement	• Practice metadata management • Integrated infrastructure management • Resource management • Transformation governance • Training program • Recovery management • Organization process definition • Stakeholder management • Information delivery management	• Practice metadata management • Integrated infrastructure management • Resource management • Transformation governance • Training program • Recovery management • Configuration management • Organization process definition • Organization process focus • Information delivery management • Data quality assurance • Service quality assurance • Inter-group coordination • Workflow alignment • Integrated service management • Transformation tools management
Repeatable	• Sponsor assurance • Program planning • Project planning • Business justification • Staffing • Requirements management • Scope design • Project tracking • Subcontract management • Issue tracking • Standards setting	• Project planning • Business justification • Staffing • Requirements management • Scope design • Project tracking • Standards setting	• Sponsor assurance • Project planning • Business justification • Staffing • Requirements management • Scope design • Project tracking • Standards setting

practice transformation processes are generally improvised by the staff and physicians during the course of the transformation program. Even if the practice uses consultants and their transformation expertise, it is not rigorously followed or enforced. The immature practice organization is reactionary, and staff is usually focused on solving immediate crises (better

known as fire-fighting). Schedules and budgets are routinely exceeded because they are not based on realistic estimates. In such practices, quality of transformed services is difficult to predict. Activities intended to enhance quality such as care planning, care coordination, team-based care management and performance measurement are often curtailed or eliminated when transformation projects fall behind schedule. The practice transformation at this level tends to be expensive; while some are successful, many others fail badly.

Level-2 (Repeatable): A practice at this level focuses on establishing controls of the transformation projects to track cost, schedule and functionality. The necessary process discipline is in place to repeat earlier successes. Example process areas important at this level include *requirements management*, *project tracking*, *subcontract management*, *issue tracking*, *standards setting* and many others. Some practices at this level may have several transformation project initiatives and associated activities. Some of these initiatives may have robust plans and may track the transformation efforts. Although repeatable processes exist for certain processes, they are followed by certain groups, but not by the entire organization [68].

Level-3 (Defined): A practice at this level has a stated policy of treating medical home as a corporate asset. Best practices for developing, maintaining, and operating the practice transformation are documented and used across the practice. For example, the *practice metadata management* policy becomes a core component of transformation. This policy is enforced and tested to ensure that metadata quality requirements are met. These defined processes are updated when necessary, and improvements are developed through controlled piloting and/or cost benefit analyses. Roles and responsibilities within the defined process are clear throughout the project and across the organization. All projects use an approved and tailored version of the practice transformation process. Usually at this level more transformation projects tend to succeed than fail.

Level-4 (Managed): A practice at this level introduces a managed environment. Detailed measures of the practice transformation process and typical work product quality are collected. Both the process and the products are quantitatively understood. The practice starts conducting audits to measure quality. Measurable process goals are established for each KPA. Quantitative/statistical techniques are used to analyze the collected measurements. Transformation projects are consistently successful and the practice can predict their future performance toward recognition with reasonable accuracy.

Level-5 (Optimizing): A practice at this level uses knowledge learned in earlier levels to continually transform practice toward medical home. The practice now has the means to identify weaknesses and strengthen the transformation process proactively. Very low levels of data, process, and technology redundancy exist; any remaining redundancy is well documented and understood. The practice aligns its processes with its strategic business goals and tries to optimize its investments in practice transformation.

To relate the process maturity levels described above with the recognition levels developed by NCQA, the grid includes the *x*-axis showing the three recognition levels developed by NCQA, and the *y*-axis depicting the process maturity levels, starting with *Repeatable* at the lowest level and going up to *Optimizing* at the highest level.

In the knowledge acquisition surveys obtained from the expert panel members in Step 3, we asked our experts to relate the assigned KPAs to different NCQA recognition levels, in an effort to determine which KPAs need to be performed for a certain recognition level. That information helped us categorize the KPAs along the *x*-axis. Based on the literature of process maturity, we categorized the 40 KPAs into one of the four maturity levels (*Chaos* was not included). KPAs at higher maturity levels assume that KPAs at lower levels have already been completed. With this knowledge, we categorized the KPAs into the grid, starting from the *Repeatable level at Recognition level-1* cell at the lower left to the *Optimizing level at Recognition level-3* cell at the upper right (see Table 8). The grid can now be used as a visual map that a healthcare practice can employ to locate the cell that their organization belongs to with respect to the PTP standards and then find a path to segue to higher levels of PCMH recognition.

We can make the following observations regarding the grid in Table 8:

a. KPAs at each level of process maturity are unique to that level. For example, the *Sponsor Assurance* KPA is only present at the *Repeatable* level, whereas the *Practice Metadata Management* KPA is only present at the *Defined* level.
b. Some KPAs at each level of NCQA recognition are non-unique. For example, *Scope Design* KPA belongs to all levels of the recognition as it is continuously needed for all transformation projects at any level of recognition.
c. Several KPAs at each level of NCQA recognition can also be unique. For example, *Program Planning* KPA is only at NCQA Recognition Level 1. This is due to the fact that complete planning for practice transformation needs to be done at the very start.
d. Practices tend to start from the lowest level of the process maturity targeting NCQA Recognition Level 1. As discussed earlier, practices with mature quality improvement capabilities can achieve recognition much faster. The ultimate cell a practice would aspire to reach is the *Optimizing level at Recognition level-3* cell. But the path to get there is dependent on the practice's quality improvement maturity capabilities.
e. KPAs are also related to other KPAs through *precedence relationships*, which were coded as rules in our ontology prototype. Our ontology could therefore support users by providing them with knowledge of the KPAs that need to be satisfied before a given KPA can be performed. The maturity-recognition grid also shows graphically how a recognition level can be reached.

4.3. Stage 3: Build a prototype of PTP ontology

In the final step of developing the ontology for practice transformation, we implemented the PTP ontology model from the previous stage using the Protégé tool. We used Protégé 3.5 (build 663), which is easy to use and supports building of ontologies in OWL and RDF [68,69].

We started by creating owl:classes (Fig. 10) in Protégé, using concepts from the glossary of terms in the formal model. We operationalized the KPA taxonomy of Fig. 7 by creating a class called *KPA*, along with its subclasses. The *KPA* class has properties such as *RecognitionLevel*, *hasActivities*, *PCMHGoal*, and *WorkProduct*. The class *RecognitionLevel* captures the different NCQA Recognition Levels. The class *KeyActivity* represents the key activities associated with a KPA. The class *Practice* points to the organization whose practice is getting transformed. *PCMHGoal* captures the standards, elements, and factors in the PCMH model. The class *Person* includes all the staff, subcontractors, advisory board members, and others involved in practice transformation. Finally, the class *WorkProduct* represents all the reports, documents, worksheets, plans, etc. that are essential for practice transformation process in the organization. We created class hierarchies for KPA, *Person*, and

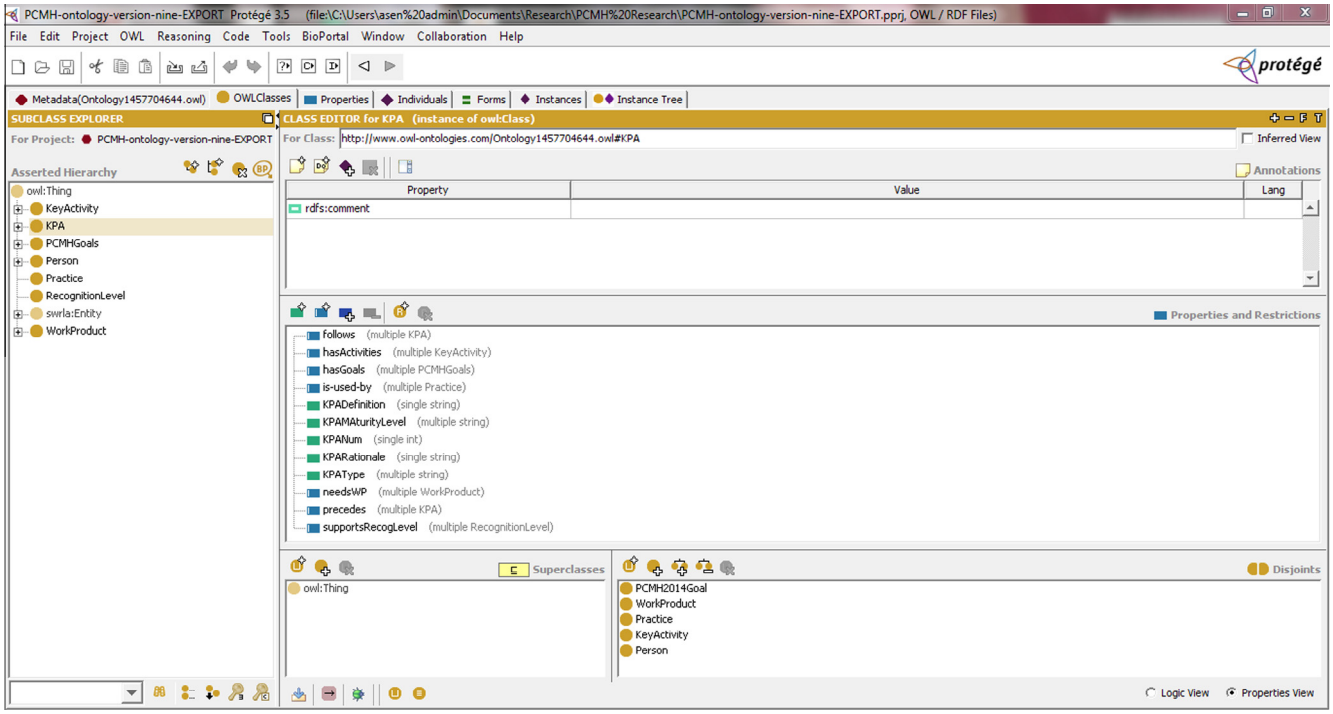


Fig. 10. OWL classes in Protégé.

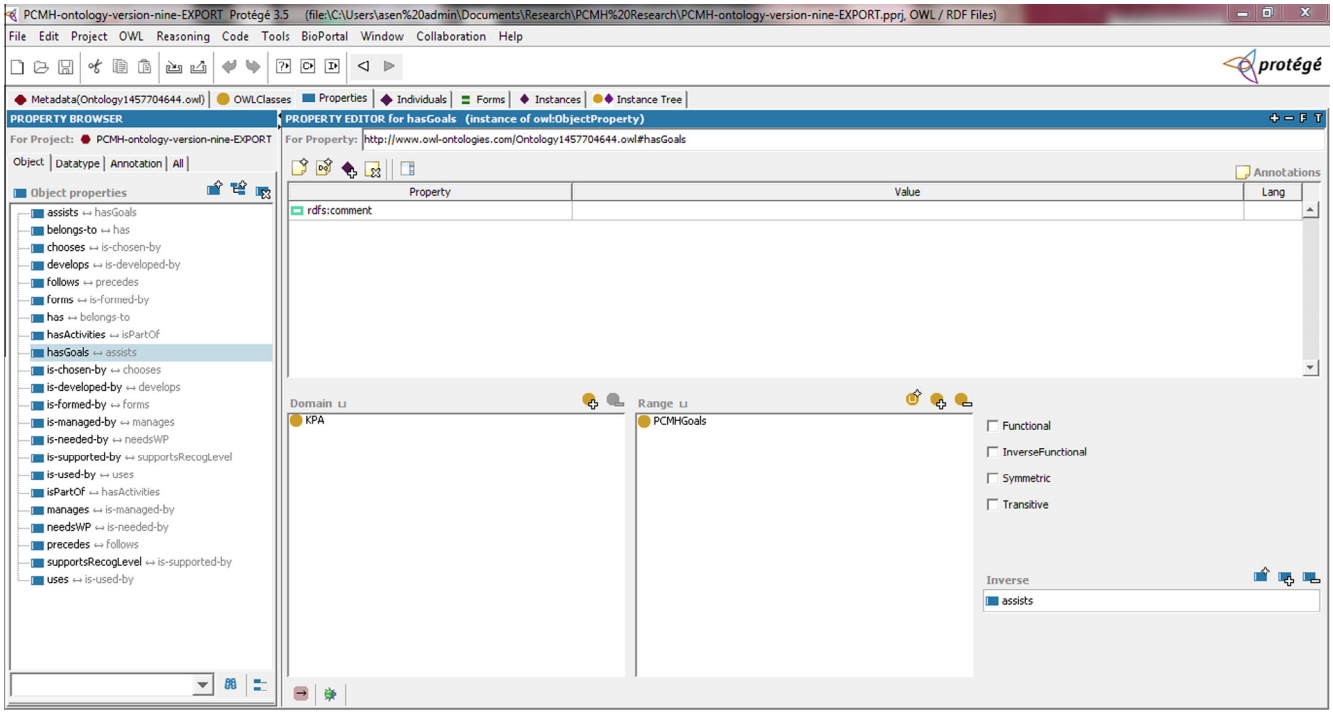


Fig. 11. Binary relations as object properties in Protégé.

WorkProduct, based on the taxonomies identified earlier (see Fig. 7) and asserted the subclasses and disjoint classes.

Fig. 11 shows how the binary relations (discussed in Step 8 of the previous section) were formalized in OWL using the Protégé tool. They were implemented as object properties using Protégé. For example, the binary relation *hasGoals* between KPA (domain) and PCMHGoal (range) is implemented as an object property, which links KPA and PCMHGoal instances (individuals).

The cardinalities between the domain and range were also instantiated. As we wanted to standardize the tasks that are needed to transform a practice, we have 40 KPAs in our practice transformation model. These 40 KPAs (e.g., BusinessJusfificationKPA, ConfigurationMgmtKPA, ChangeMgmtKPA, etc.) are subclasses of the KPA class in our ontology (see Fig. 12). Each of these KPAs has a single instance, representing the actual KPA in our ontology. For example, Fig. 12 shows the BusJustKPA instance, which represents the actual business justification KPA with values for its properties.

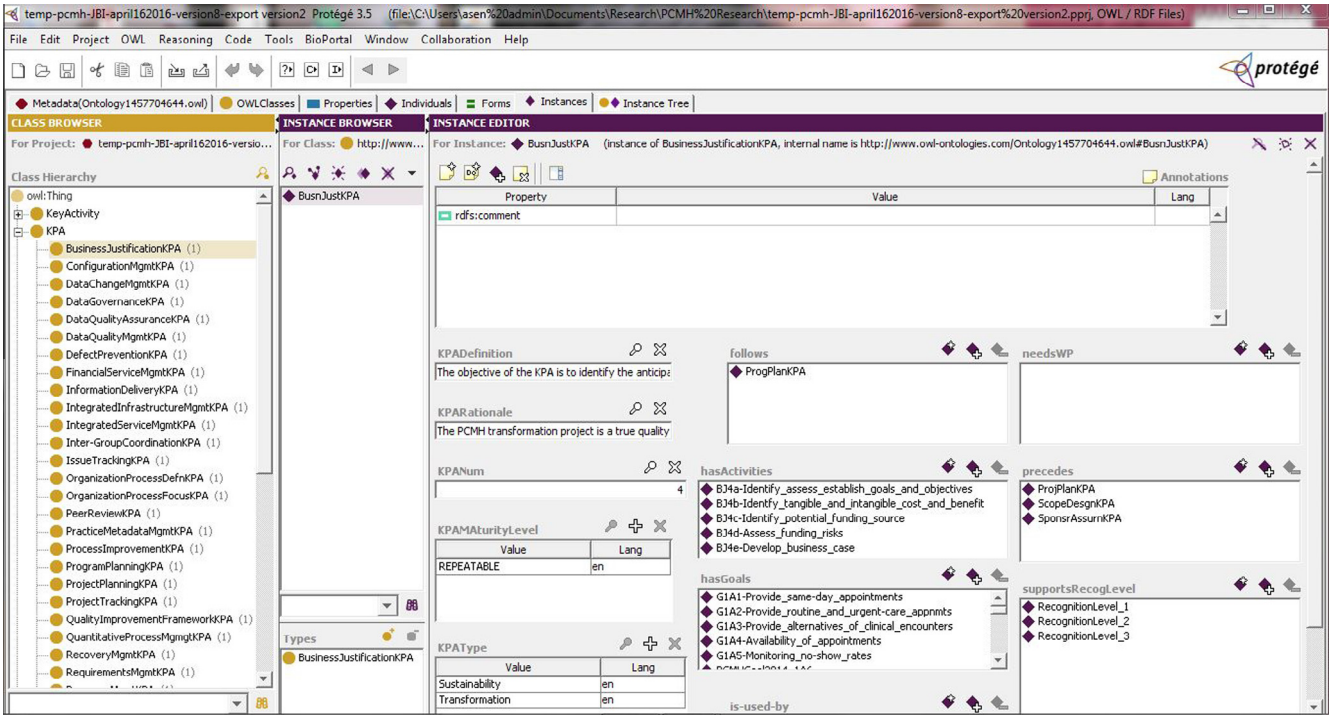


Fig. 12. KPA subclasses and a KPA instance.

Fig. 13 shows the BusinessJustificationKPA class with its properties (e.g., *hasGoals*, *precedes*, *needsWP*, *is-used-by*, *supportsRecogLevel*, *hasActivities*, etc.). Note that while some properties such as *KPADefinition* and *KPARationale* are datatype properties, other properties such as *hasGoals*, *hasActivities*, *precedes*, and *supportsRecogLevel* are object properties, implying that they represent relationships between individuals (instances). For example, BusJustKPA instance is linked to three different RecognitionLevel instances through the *SupportsRecogLevel* property. Also, note that we have placed a universal restriction on the *hasActivities* property for all the KPA subclasses. The figure shows the restriction, (∀ hasActivities only BusinessJustificationActivity), implying that for the business justification KPA instance, all values of *hasActivities* must be instances of BusinessJustification Activity. All the KPA subclasses in our ontology have such a universal restriction on the *hasActivities* property, implying that each KPA consists of a specific set of activities. Fig. 13 also shows how the precedence relationships among different KPAs are implemented. The instance tree in the figure shows that the business justification KPA precedes the project planning and sponsor assurance KPAs.

5. Limitations and future directions

In this paper, we have presented an ontological model of a practice transformation process. The ontology organizes and structures the domain knowledge of PTP standards in terms of KPAs, KPA taxonomy, KPA activities, binary relations, formal axioms, etc. We also developed a grid that links the transformation process maturity levels with NCQA's recognition levels. The grid provides a visual guide to a healthcare practice for assessing its PTP standards and navigating to higher levels of PCMH recognition. But currently it cannot be used as platform for documenting the actual process that the practice adopts for PCMH transformation. The scope of our study was limited to developing an ontological model of PTP, which captures the domain knowledge of PTP standards. How the model could be used in practice for addressing the problem of actual practice transformation is beyond the study's scope.

To address how a healthcare organization could actually employ the ontology to meet the PTP standards, one has to complement the domain knowledge with a method that would enable the organization to achieve the goals of practice transformation. While we employed the UML class diagram for conceptualizing our domain ontology, the UML activity diagram could be useful for capturing the knowledge of the method – including tasks, subtasks, and control flow – needed for practice transformation.

Future efforts could be directed at documenting the actual transformation process within an organization. Also, extensions such as SWRL (semantic web rule language) could be used to encode rules for practice assessment and transformation, thereby providing effective decision support to healthcare users in the organization. For example, SWRL rules could be used by a practice to implement NCQA's scoring mechanism for different levels of PCMH recognition.

The ontology has been implemented as a proof-of-concept prototype using Protégé. As it currently stands, it is far from being fully operationalized in a healthcare environment. Note that the main contribution of our study is in providing an explicit specification of the conceptualization of practice transformation, which was guided by intensive knowledge acquisition and evaluation efforts. Even without implementation, our ontology – with the KPAs and their activities, the concept taxonomy, the UML class diagram, maturity grid, etc. – comprehensively captures PTP domain knowledge and would be very helpful to any organization interested in understanding and assessing its practice transformation process.

In the future, we plan to perform a comprehensive evaluation of the knowledge base for redundancies, inconsistencies, and incompleteness. Two KPAs (recovery management and quantitative process management) were not present in the retrospective protocols we collected; those KPAs need to be verified by other experts. Operationalizing the prototype would also help end users browse the KPA taxonomies and quickly find a PTP standard and its definition; to effectively share and reuse the process transformation knowledge; etc. Most importantly, it would provide a potential platform for leadership in a healthcare organization to effectively and efficiently assess a practice's performance with respect to the PTP standards and pave the way for the practice to reach higher levels of process maturity and PCMH recognition.

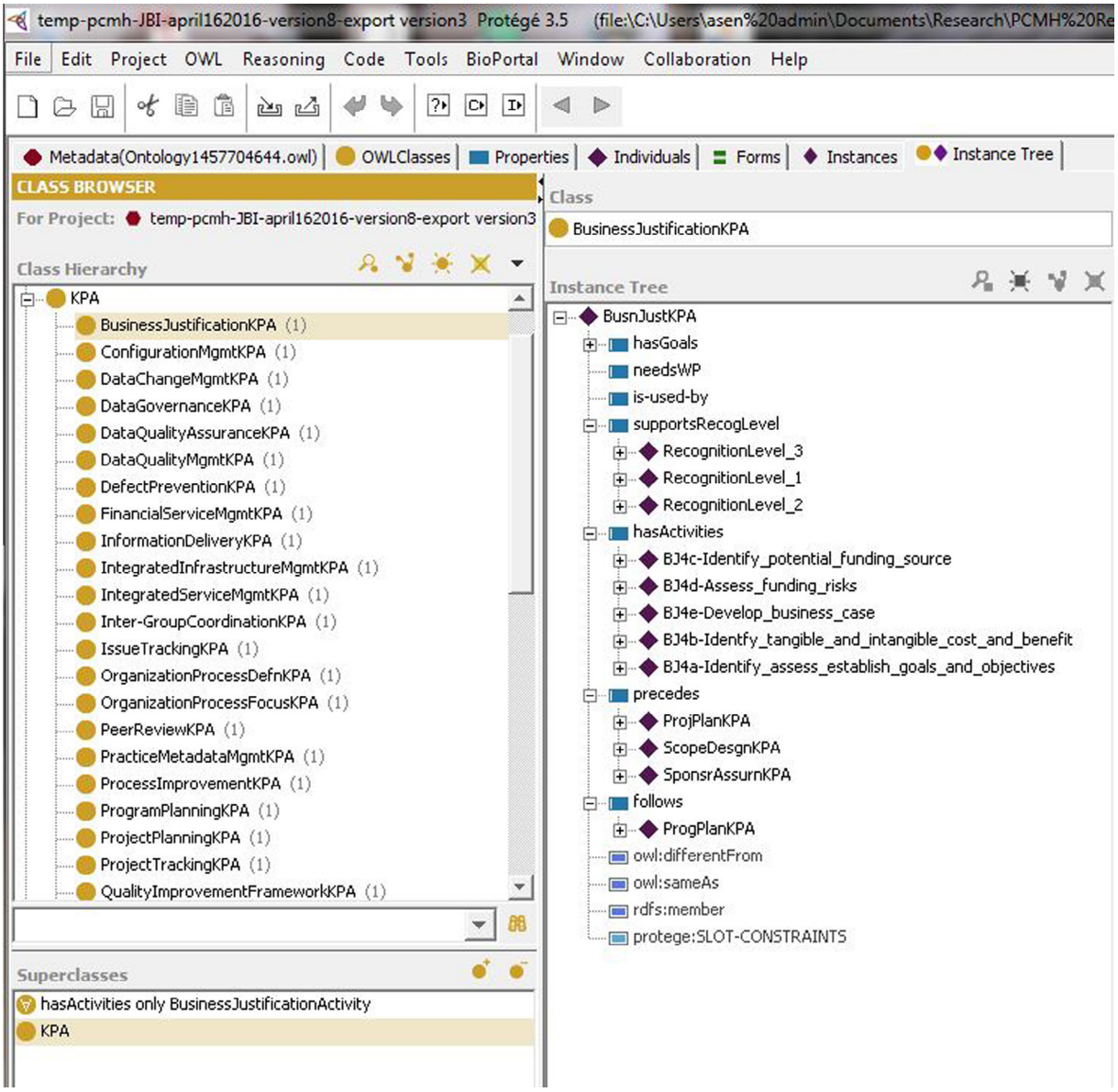


Fig. 13. Business justification KPA instance with property values.

6. Summary and conclusions

As discussed in Section 3, the practice transformation process is complicated because it involves a complete re-engineering of the practice, given the evolving nature of the PCMH model and its requirements. To address this issue, we developed a set of KPAs that can be mapped into the practice transformation process. The objective was to standardize the practice transformation process. Using the process modeling literature, we developed a practice transformation process ontology. The model has been thoroughly vetted by several practice transformation experts.

The main contribution of our study is in developing an ontology of PTP standards. We employed a well-known methodology called *Methontology* to develop the ontology iteratively, using feedback from multiple practice transformation experts for verifying and validating the intermediate representations. The investigation into the standardized formal practice transformation process was supported by evidence from a systematic literature review and multiple expert panel opinions. We also implemented the ontology as a proof-of-concept prototype using Protégé. We believe that our ontology provides an effective platform for sharing and reusing PTP standards in a healthcare organization. A potential benefit of using the ontology is that it could facilitate healthcare practices to achieve and sustain higher levels of PCMH recognition.

Our study has some important implications. First, with this methodology, we related NCQA's PCMH goals with the key activities that are needed to achieve those goals. This enriches the practice transformation model supported by NCQA. Second, we developed a maturity-recognition grid, which positions the KPAs based on process maturity and recognition level, and helps a practice pursue a path toward the desired level of NCQA recognition. Finally, to evaluate the practice transformation process, appraisal methods can be developed in the future. These appraisal methods can range from evaluating if the transformation process KPAs have been institutionalized to self-examination by the practice to see how the KPAs are being implemented in the practice transformation.

Conflict of interest

None.

Acknowledgments

We are indebted to Tom Fluegel and others at NCQA (National Committee for Quality Assurance) for supporting our project. We would like to acknowledge the immense help we received from various expert panels, including hospital leaders, FQHC and for-profit clinic directors, and NCQA's PCMH-certified content experts. We are also very grateful to Kathy Mechler of the Rural and Community Health Institute (RCHI) of Texas A&M Health Sciences Center for her help and support in the project. Finally, we would like to thank the Associate Editor and three anonymous referees for their valuable feedback during the review process.

Appendix A. Examples of KPAs

Scope design and verification KPA – The objective of the KPA is to develop a plan to determine the scope of the practice's transformation project targeting a certain NCQA's PCMH recognition level. This includes understanding the eligibility of the practice, its network of practices, and size of the practice itself. **[Transformation]**

Rationale. The transformation process needs to have a target of a particular level of PCMH recognition. This in turn will determine what is meant by a recognition level and how that influences the scope of the transformation process. Efforts will also be needed to determine how to handle multiple sites.

Key Activities

a. Identify and document all the work that will be involved in creating/delivering practice transformation intervention.
b. Importantly, clearly document what is NOT included in the practice transformation projects.
c. Identify organization's capacity to undergo practice transformation.
    a. Leadership engagement
    b. Competing change projects
    c. Allocated resources (staffing, timing, funding)
d. Define and obtain consensus for the practice transformation project scope (e.g., Work Breakdown Structure – WBS, Statement of Work – SOW, etc.).
e. Define and develop agreement from stakeholder groups on Scope Verification and Scope Change Control approaches.

Work Products

- The KPA is pre-work

Goals (for PCMH 2014)

- Predecessor to start of work

KPA Category

- KPA connected to Supervision

Recognition: All three levels

Usefulness Notes

- Very useful ("Determining scope of project before embarking on this major transformation is key to its success. The leadership fundamentally underestimates the amount of change necessary, woefully under-resources the project and/or believes the changes can be delivered from the management level. Proper understanding of the necessary scope using NCQA resources, a practice transformation coach and a self-assessment tool can allow better planning and more timely PCMH recognition, regardless of the desired level.")

Staffing KPA – The objective of the KPA is to develop a plan to staff the transformation project team with various types of people usually needed in the PCMH transformation process and for its sustainability. **[Transformation, Sustainability]**

Rationale. In seeking NCQA recognition as a PCMH, the practice needs to commit a significant amount of administrative and staff time to a quality improvement project that will require inputs from many different parts of the practice [3]. Identifying and creating a team will be a key to the success of the transformation process. Staffing is also significant in maintaining medical home based care and care coordination for the patients in a sustainable way.

Key Activities

a. Form advisory board by selecting primary care providers, patient representatives, and IT/data staff. Practice community, representatives from the larger health care and QI communities, state and county health departments, etc. are also needed for specific elements of the transformation process and may not be included in the advisory board.
b. Hire consultants or internal project facilitators for practice transformation by looking at the core competencies needed by the consultants/facilitators either from outside or recruit them from the practice.
c. Identify and establish the broad membership composition of the practice transformation teams. It is recommended by the Institute for Healthcare Improvement (IHI) that such team should have *clinical leadership*, *technical expertise*, *day-to-day leadership*, *sponsor* who serves as the link to the team and the practice's senior management.
d. Develop an "organization structure and plan" to identify, assign and document roles, responsibilities and reporting relationships for (each of the proposed) practice transformation projects (e.g., Responsibility Assignment Matrix) along with key deadlines and timelines.
e. Acquire specific staff to fill the (above) identified roles and responsibilities. If necessary (and depending on the criticality and visibility of the practice transformation projects) hand pick the "best and brightest" members/staff (including physicians, physician assistants, office manager, patients, patient families, peer mentors, billing department staff, community representatives, health educators, etc.).
f. Establish the form of relationship and frequency of reporting between each practice transformation project team(s) and their sponsor, associated stakeholder group, IT Function, etc.
g. Plan for setting up schemes for "Team Development" including motivation building, skill training, etc. using AHRQ's TeamSTEPPS program.

Work Products

- Detailed action plan
- Gantt Chart
- A project charter

Goals (for PCMH 2014)

- Need for the practice transformation program (includes all standards)

KPA Category

- KPA connected to Supervision

Recognition

- Levels 1, 2 and 3

Usefulness Notes

- Very useful ("To truly achieve the transformation beyond a yes response to gather the necessary points, a dedicated team with time and resources allocated to the transformation process will be essential. A sufficient amount of time and documentation in the initial stages will pay off in the long run. This KPA will set up a team for success.")

Appendix B. List of KPAs

1	Sponsor Assurance KPA
2	Program planning KPA
3	Project Planning KPA
4	Business Justification KPA
5	Staffing KPA
6	Requirements Management KPA
7	Scope design and verification KPA
8	Project tracking KPA
9	Subcontractor management KPA
10	Issue tracking KPA
11	Standards setting KPA
12	Organizational process definition KPA
13	Organization process focus KPA
14	Practice metadata management KPA
15	Recovery management KPA
16	Stakeholder management KPA
17	Workflow Alignment KPA
18	Integrated infrastructure management KPA
19	Inter-group coordination KPA
20	Data quality assurance KPA
21	Transformation tools management KPA
22	Peer review KPA
23	Information delivery KPA
24	Service level agreement KPA
25	Service quality assurance KPA
26	Integrated service management KPA
27	Resource management KPA
28	Configuration management KPA
29	Training program KPA
30	Data quality management KPA
31	Quantitative process management KPA
32	Data change management KPA
33	Service level management KPA
34	Financial service management KPA
35	Quality improvement framework KPA
36	Technology change management KPA
37	Defect prevention KPA
38	Process improvement KPA
39	Data governance KPA
40	Transformation governance KPA

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