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Review

Knowledge Management In Health Care Organizations

Abstract: This review article analyzes theories, methods, and technologies that can be effective in building a socio-technical environment within a health care organization that is able to facilitate the collaboration between individuals in the management of patient care and in expanding scientific and professional knowledge. The article is organized as follows. In section 2, I discuss the nature of knowledge in general and with a particular attention to medical knowledge. The future of health information systems (HIS) is discussed in section 3, which provides also an overview of theories for designing and developing such systems. Section 4 describes different types of collaboration, and reviews the methods and information and communication technologies (ICT), which can be exploited for knowledge creation and interaction management. The potential of workflow management technology for building innovative components within HIS is analyzed in section 5. Finally, section 6 presents the conclusions.

Introduction

The goal of this article is to provide a review of theories, methods, and technologies that can be applied to knowledge management and to assess their actual or potential contribution to the basic processes of knowledge creation and diffusion within Health Care Organizations (HCOs). The aim is to identify trends and new developments that seem to be significant and to relate them to research in the field of Medical Informatics, rather than to provide a comprehensive review of established research projects or commercially available products.

Knowledge Management (KM) [1] is the name given to the set of systematic and disciplined actions that an organization can take to obtain the greatest value from the knowledge over which it disposes. Knowledge in this context includes both the experience and understanding of the people in the organization and the information about artefacts, such as documents, guidelines, protocols, and reports, available within the organization.

Knowledge has been recognized as the key to success for HCOs [2], and it is simply too valuable a resource that we cannot avoid investigating effective strategies for its management. HCOs must understand precisely what scientific and clinical knowledge will give them the possibility to meet the needs of patients. They must be able to keep this knowledge up to date, deploy it, leverage it in operation, and spread it within and across organizations. Over the last decade it has become widely accepted that HCOs' capacity to learn, innovate, and leverage knowledge-based capabilities are critical to the improvement of their performance [3, 4, 5, 6].

Health care must be delivered by systems that are carefully and consciously designed to operate in a way that is safe [7, 8], effective, patient-centered, timely, efficient, and equitable [2]. Such systems must be designed to serve the needs of patients [9], and this means: to ensure that patients are fully informed, retain control and participate in care delivery whenever possible, and that they receive care that is respectful of their values and preferences [2]. Such systems must facilitate the application of scientific knowledge to practice, and provide clinicians with the tools and support mechanisms necessary to deliver evidence-based medical care consistently and safely [10].

Health care providers should actively interact to ensure that information and knowledge needed for the management of care is appropriately shared. How to bring this about human behaviour within HCOs needs to be carefully analyzed to achieve success. Thus, it is fundamental to develop a general theory of the ontology of social facts and social institutions [11]. Moreover, we need to investigate how human cognition and decision-making is always situated in and affected by a complex socio-cultural environment [12]. Clinical practice is clearly a cognitively complex matter involving a variety of different types of problem-solving in diagnosis and therapy planning, as well as keeping them up-to-date according to the progress in research and in drug development. This complexity is also linked to the clinical division of cognitive labour: no single individual will in general possess the complete knowledge about any given patient [13]. The findings of studies of this cognitive complexity are essential to the formulation of organizational strategies for cultivating communities of medical practice which are able to manage organizational knowledge just as systematically as they manage other critical assets [14].

The explosion in biomedical science and technology creates a paradox. At the very same time that the increasing complexity of knowledge requires greater efforts towards specialization and collaboration, so the half-life of knowledge becomes ever shorter. Considerable effort and resources have been expended internationally on the development of the best clinical practice guidelines that represent state-of-the art management of care delivery to well-defined categories of patients. Yet at the same time one survival analysis estimates that half of the guidelines became obsolete in about five years [14].

If medical communities are not focused on critical areas, they will be unable to keep up with the rapid pace of medical knowledge change. Peter Drucker describes health care professionals as typical *knowledge workers*. They must be responsible for fostering continuous learning and innovation in their work, and they must rely on colleagues and scientific medical societies for assessing the effectiveness of their practice [15]. Cohen and Prusak describe the problems that occur when a doctor has no colleagues in the field with whom she can confer to keep her knowledge up-to-date [16].

The knowledge economy presents an additional challenge to HCOs. They are starting to compete for health market share but also for excellent clinicians and surgeons. Finding and keeping the right people can make a big difference in a HCO's ability to increase its visibility and to gain new customers and stakeholders. In developed countries, recruiting, developing, and retaining talented health professionals and researchers represents a greater challenge than does competing in the health market. Professional relationships and social ties are important reasons to stay with an organization [17, 18]. It has been argued that organizations can *win the war for talent* by offering employees an opportunity to build a sense of community with professional and workplace colleagues [16]. Moreover, employees have good reason to stay when their organizations can offer attractive opportunities to participate in competitive knowledge-based communities.

2. The Nature of Knowledge

KM is the process of creating value from an organization's intangible assets [19]. As such, knowledge management combines various concepts from numerous disciplines, including organizational science, cognitive science, human resources management, artificial intelligence, and information and communication technology (ICT).

Before analysing theories and tools for KM, the nature of knowledge needs to be investigated. There are currently two major views on the nature of knowledge. The *cognitivist perspective* is the most firmly established and well known. It originated during the cognitive revolution in the early 1950s and greatly influenced the development of artificial intelligence [20, 21, 22, 23]. The cognitivists developed formal models of the cognitive system as a machine for information processing and logical reasoning [24]. Knowledge is considered to consist in representations of the world, and the key task of any cognitive system is to represent it as accurately as possible. What is important for the purposes of this paper is that knowledge is considered universal by cognitivists: two cognitive systems should achieve the same representation of the world. To them, knowledge is explicit, capable of being encoded and stored, and easy to transmit to others. This justifies the great emphasis given by the artificial intelligence community on knowledge acquisition, representation, and transfer until the 1980s.

New insights in neurobiology, cognitive science, and philosophy, raised the *constructionist perspective*: cognition is viewed not as an act of representation, but as an act of knowledge construction [25, 26, 27, 28]. To constructionists, because knowledge resides in our bodies and is closely tied to our senses and previous experiences, we will come to construct our knowledge in ways that are unique to ourselves.

Thus, knowledge is not considered universal, and the constructionists do not pay much attention to comparing various representations. Rather, one knows that her cognitive system works when knowledge allows her to act effectively. From the constructionist perspective, some knowledge is explicit, but some is also tacit, highly personal, not easily expressed, and therefore not easy to share with others.

When surgeons operate on a patient, they do not apply only knowledge they have gleaned from books and procedures they have stored in their heads. They also consider the patient's medical history, monitor vital signs, look at tissues, make incisions, draw conclusions, and possibly revise the plan to make sure that the procedure is constantly responsive to the evolving situation. Thus, a significant part of the knowledge of experts derives from an accumulation of experience – a kind of *residue* of their actions, thinking, and conversations – that remains a dynamic part of their ongoing experience [29]. This type of knowledge is much more a living process than a static body of explicit knowledge. It cannot be reduced to a collection of objects. Working within an organization or a team makes it an integral dynamic part of their activities and interactions.

The cognitive and constructivist perspectives have been presented in a very condensed form in this section merely in order to point out the two extremes of proposed views of the nature of knowledge. Contemporary cognitivists are gradually becoming aware of the cultural dependence of knowledge and thus are lessening the strength of their earlier universalistic claims. On the other side, constructivists are reformulating their theory in order to avoid the confusion between *knowledge creation* and *creation of the world* to which this knowledge relates. Barry Smith elaborated a very promising third perspective, which he has called the *ecological theory of knowledge* [30]. He started from the seminal work of the ecological psychologist J. J. Gibson [31], drawing also on the evolutionary theories of Merlin Donald [32], to reconcile the cognitive and constructivist perspectives. Smith claims that the understanding of cognition requires the study of human actions as they exist in the real world environment, but he stresses that this is typically a social environment, which includes records and traces of prior actions in the form of communication systems (languages), knowledge repository systems (libraries), as well as financial, legal and political systems of a range of different sorts.

In HCOs records and traces of health professional actions are represented by patient health records, knowledge repositories, such as medical textbooks, journals, guidelines, protocols and many other sorts of knowledge sources relevant for learning and clinical actions.

Both cognitivist and constructivist perspectives on the nature of knowledge have influenced knowledge management theory and practice. Thus, it is essential to start any evaluation of knowledge management potential from considering that knowledge takes various forms. The fundamental distinction between tacit and explicit knowledge originated from the work of Polanyi [33]. He claimed that tacit knowledge involves physical skills, such as executing a manually complex surgical intervention, as well as perceptual skills, such as interpreting a complex medical chart or X-ray. Tacit knowledge also allows doing something automatically almost without thinking, such as examining the abdomen of a patient by touch. Practice is required to acquire and maintain such a skill. A careful study of the skill-acquisition process shows that a person usually passes through at least five stages of qualitatively different perceptions. Someone at a particular stage of skill acquisition can always imitate the thought processes characteristic of a higher stage but will perform badly when lacking practice and concrete experience. Hubert and Stuart Dreyfus discussthe "*proper balance between calculative reason and intuition*" and provide important insights into the distinction between explicit and tacit knowledge.

Nonaka and Takeuchi claim that tacit knowledge is the key source of innovation in Japanese companies and hence of major importance to sustainable company performance [34]. They analyzed the interaction between tacit and explicit knowledge, concluding that they are complementary. They interact and become transformed into each other in the creative activities of human beings. Explicit knowledge can be more easily documented and represented [35]. Tacit knowledge is difficult to extract and elicit due to the knowledge engineering paradox. The more expert one is, the more tacit the knowledge is, so the harder it is to extract and formalize it in a knowledge repository. Sharing tacit knowledge requires interaction and informal learning processes, such as conversation, coaching and apprenticeship. This is not to say that it is not useful to represent knowledge in whatever manner serves the needs of practitioners. But even explicit knowledge is dependent on tacit knowledge if it is to be applied. Practice is a tangled combination of the tacit and explicit dimensions of knowledge.

Nonaka and Takeuchi formulated a dynamic model of knowledge creation that is based on a critical assumption: human knowledge is created and expanded through a social interaction between tacit and explicit knowledge. This process has been called knowledge conversion. It represents a social process between individuals and is not confined within any single individual.

Four different modes of knowledge conversion have been postulated: socialization, externalization, combination, and internalization.

1. *Externalization* (tacit to explicit) is the process of conversion of tacit into explicit knowledge through some formal or semiformal representation language.
2. *Combination* (explicit to explicit) is the process of recombining or reconfiguring bodies of already existing explicit knowledge that leads to the creation of a new body of explicit knowledge.
3. *Internalization* (explicit to tacit) is the process of individual learning by repetitively executing an activity applying some type of explicit knowledge (e.g., a protocol or a guideline) and absorbing the results thereof as new personal tacit knowledge.
4. *Socialization* (tacit to tacit) is the process of learning by sharing experiences that create tacit knowledge as shared conceptual models and professional skills.

A more detailed description of these knowledge conversion processes in HCOs is available in [36]. A KM framework should properly facilitate and stimulate the knowledge conversion processes described above. Such processes occur continuously during daily medical work. Thus, to build effective KM systems in HCOs one needs to support each conversion process with the most suitable methods [37]: knowledge representation tools for externalization, medical ontologies for combination, knowledge discovery and intelligent data analysis for internalization [38], and process and clinical data management for socialization.

Later on, Cook and Brown extended the constructivist perspective on the nature of knowledge in way that yields a deeper understanding of what it means to speak of *organizational knowledge* [39]. They call the traditional understanding of the nature of knowledge the *epistemology of possession*, since it treats knowledge as something people possess. Yet, this epistemology cannot account for the knowing found in individual and group practice. Moreover, the epistemology of possession tends to privilege explicit over tacit knowledge and knowledge possessed by individuals over that possessed by groups. Organizations are better understood if four distinct and coequal types of knowledge are considered: individual explicit, individual tacit, group explicit, group tacit knowledge.

A view which focuses on knowing as a matter of actions calls for an *epistemology of action*. Thus, the great challenge for organizations is effectively managing the interplay of organizational knowledge and organizational knowing since it can generate new knowledge and new ways of knowing. Supporting what they call the *generative dance* between knowledge and knowing with the most suitable organizational and technological infrastructure requires a fundamental change in modelling organizational working processes and in designing organizational information systems. The latter must support individual and organizational learning in the context of routine practice [40]. The most promising approach seems to be represented by evidence-based careflow management systems (CfMS) [36, 41], as illustrated in section 5 of this paper.

I have already remarked that communication is an essential component of knowledge creation within HCOs. They are usually composed of multiple teams with specialized medical expertise, and lateral organizational forms are usually more important than hierarchical ones in establishing and maintaining effective communication links within the care process. This requires the ability of each team to take continuously the perspective of another cooperating team into account – and this in turn requires an effective communication system. Boland and Tenkasi developed models of language, communication and cognition that can assist in the design of an organizational infrastructure for communication built around the ideas of *perspective making* and *perspective taking* [42]. Perspective making is the process whereby a community of knowing develops and strengthens its own knowledge domain and practices. Perspective taking can be synthetically described as the process in which the overall organizational knowledge emerges out of the exchange, evaluation, and integration of knowledge. Like any other organizational knowledge, it is comprised of the interactions of individuals and not their isolated behaviour. They claimed that the ways in which experiences are *narrated* is a critically important mode of creating knowledge. Narrating patient clinical histories or *illness trajectories* is the most common way to develop a common understanding of patient problems between clinicians. The patient medical record traces the course of the illness, as well as the total teamwork actions over a given period as well as the impact of these actions on the individual caregivers involved. Such narratives always describes past actions in the context of a set of organizational arrangements.

Thus, task-narrative facilities could support a perspective making for those creating the narratives and also support a perspective taking experience for those reading the narratives. The narrative is always incomplete and the reader must *read into* the story in making it sensible. This reading into can become a primary vehicle for opening oneself up to the perspective of another only if the system for managing electronic health records makes available tools for analyzing patient illness trajectories and investigating, if needed, elements within them (findings, decisions, actions, outcomes, etc) supported by suitable medical and organizational knowledge sources. CfMS can provide the right information and knowledge management infrastructure to automatically build the patient clinical history of individual patients in the context of the work done by individual caregivers who collaborate in their management [36].

3. Future Health Information Systems

The International Medical Informatics Association (IMIA) working group on Health Information Systems (HIS) held its fourth working conference in Heidelberg, Germany, in April 2002. The discussion covered topics referring to HIS bottlenecks, strategies to achieve open architectures, patient empowerment, and HIS desired outcomes. Two special issues, of Methods of Information in Medicine [43] and the International Journal of Medical Informatics [44], report the strategic views presented and discussed by the participants at the conference.

One of the most important results of the conference deals with the fundamental claim of the present paper: namely that there is a need to investigate the dominant role of cognitive-organizational factors in adapting systems to users' working practices. The process of providing health care is inherently based on a complex network of socio-organizational interactions among a large number of participants. The path to success will lie in systems that support communication and knowledge creation as key components of the health care process, rather than as incidental by-products [45]. It is now time to identify which of the fundamental human factors essential to success have been ignored by current HIS products.

Meeting this need will require a challenging co-development approach to the HIS design process [46]. Health information systems need to become less technology-centric and more oriented towards the variety of organizational environments within which they will have to operate [47]. HISs will also need to provide tools for outcomes measurement in terms of increased efficiency and flexibility and higher HCO performance [48].

A large body of organization theory literature has focused on examining the interface between the external environment and internal organizational processes, providing theoretical explanations that pinpoint the need for efficiency and flexibility [49, 50, 51]. Indeed, the idea of a trade-off between efficiency and flexibility is perhaps the most enduring idea in organization theory [52]. Two different types of organizational design – called *mechanistic* and *organic* – have been identified, and it has been argued that each is more appropriate to accomplish different tasks in different environmental situations [53]. Mechanistic organizations have been judged most appropriate where the environment is stable. Here, there is no need to attempt to develop new products or services or to introduce new organizational processes, because the environment does not require them. However, where the environment is more dynamic, so that the organization does need to change its products, services, or processes in order to adapt to changing demands, then an organic structure is required.

There is no doubt, now, that HCOs operate in a highly dynamic environment, since medical knowledge is evolving at an increasingly rapid pace and patient demand for medical excellence is steadily growing. Thus, the great challenge for HCOs is that they must find ways to behave as *both* mechanistic structures able to achieve high levels of efficiency in using available resources *and* organic structures able to cope in an environment of quickly expanding medical knowledge which requires high degrees of flexibility to achieve the expected levels of safety, effectiveness, and quality of delivered care.

There are now some few researchers who have suggested that it is possible to be simultaneously both efficient and flexible, or *ambidextrous* [54, 55]. Adler et al. [56] reviewed different approaches to *ambidextrousness* and highlighted four different organizational mechanisms that the literature postulates as being important for achieving simultaneous efficiency and flexibility: meta-routines, job enrichment, switching, and partitioning. Mata-routines are routines to standardize organizational processes that focus on flexibility and innovation. For example, CfMS can be adopted in an attempt to routinize any health care delivery innovation. In terms of job enrichment, the motivating potential of a job or a role is increased by giving its holder increased autonomy and responsibility, in such a way that the person involved can be more innovative and flexible even if the tasks became routine. Switching refers to the division of tasks, so that a person is given time to spend on some non-routine tasks, such as that of being involved in health professionals' communities, but then switches back to doing routine tasks. Partitioning refers to the division of tasks by teams, so that some teams in the organization concentrate more on routine tasks while others concentrate more on the non-routine in ways that are aimed, for example, at expanding individual and organizational medical knowledge.

Newell at al. carefully investigated the problem of balancing efficiency and flexibility in managing organizational processes. They proposed a solution based on simultaneously implementing two management information systems: the Enterprise Resource Planning (ERP) and Knowledge Management (KM) systems [57]. ERP systems have been defined as organization-wide packages that tightly integrate business functions into a single system with a shared database [58]. They have also been characterized as comprehensive software solutions that integrate organizational processes through shared information and data flows [59)]. Thus, ERP systems are marketed as a vehicle for integrating the core business activities of an organization, such as finance, logistics and human resources management, to the legacy systems [60]. KM systems emphasize how organizations can enhance competitive advantage through more effective utilization of their knowledge assets. This is achieved by allowing free flow of knowledge within and across organizations [61]. The idea is that through improved knowledge sharing and creation, flexibility and innovation will be enhanced [62].

Exploring the simultaneous deployment of ERP and KM systems within an organization provided an opportunity to examine the resulting interactions and their impacts. More specifically, Newell at al. examined the combined influence of the two systems on efficiency and flexibility [57]. Through an interpretative case study, the research confirmed that[1]: the two systems *can* be implemented in tandem with positive effects: complementarity between the two systems is possible, although this is not an automatic outcome since it has to be fostered. This could represent a strategic suggestion for HIS designers and developers. Knowledge-based CfMS constructed along these lines, as discussed later on in this paper, could provide the most effective approach to achieve efficiency and flexibility.

The mechanistic and organic organizational structures are implicitly involved in the concept of *double knit knowledge organization* described by Wenger et al. [14], who talk of *communities of practice* [63], that is groups of people who share a concern, a set of problems, or a passion for one topic, and who deepen their knowledge in a specific domain by interacting on an ongoing basis. For a HCO to learn from its own experience and to fully leverage its knowledge, the communities that steward knowledge creation and the care processes where knowledge is applied must be tightly interwoven. Health care professionals themselves, in their dual role as knowledge creators and care providers, help the conversion of tacit into explicit knowledge. This kind of multimembership creates a learning loop. As agents in routine care delivery processes, people are accountable for the performance of certain tasks. When they face familiar problems, they apply and refine their skills; when they encounter new problems, they create new solutions. But the same people are also members of scientific and professional communities and as such they are accountable for developing new practices. They bring their practical experience to their scientific or professional community and receive help with their problems. Communities of practice are essential in medicine for connecting health professionals across organizational and geographical boundaries and for focusing on scientific development rather than merely on the application of their expertise in routine patient management.

4. Computer Supported Collaborative Work

An innovative vision of future HISs is centered on the strategic goal of building collaborative information systems that facilitate communication and collaboration between patients and professional care providers in achieving health care goals. This will require the development of systems supporting patient empowerment [64] and care process management [65]. ITC will not be a barrier since it is developing rapidly: the chief barriers of the future would be, rather, conceptualizations and theories too weak, or too partial, to allow the design, development, and deployment of effective HIS.

A number of theoretical constructs have been used to study and describe Computer Supported Collaborative Work (CSCW) settings and systems, but few explicitly approach the *design* of such systems. The most commonly used methods to support the design process include contextual inquiry [66], participatory design [67], and user centered design [68]. We draw on still another set of theories when we address the underlying computer system's architecture, such as workflow management systems theory [69]. What do we expect from such theories? An interesting analysis has been developed by Christine Halverson, who compared theories on the basis of four main attributes: descriptive, rhetorical, inferential, and application power [70]. She compared two theories relevant for this review: Activity Theory (AT) and Distributed Cognition theory (DCog). Their relative strengths and weaknesses have been explored with reference to theory attributes defined above, and with respect to what theory does for CSCW. The methodological approach she developed can be reused whenever other theories need to be compared.

AT provides a framework for describing collaborative phenomena by focusing on the social organization of the key players in an activity, whether these be stakeholders, communities of users, and organizational roles. An introduction of the fundamental concepts of AT can be found in [71]. The primary concept employed by AT is human activity. An activity is defined by an *object* that can be a material thing, but it can also be less tangible (such as a plan) or totally intangible (such as a common idea) as long as the participants in the activity can share the entity in question for manipulation and transformation. An activity is motivated towards transforming an object into an outcome. Different objects define different activities. A *subject* is an agent that undertakes an activity. In collective activities, a community of agents share an object and work collectively on its transformation.

Central to AT is the concept of mediation. The relationships between subject, object and community are mediated by tools, rules and division of labour. These artefacts are used by a community to achieve a desired outcome through a set of transformations on an object. Artefacts can range from physical tools, like an electronic instrument, to psycho-cognitive ones, like a language, procedures, methods and general experience. A very useful concept is the notion of subject-object subject relation that combines the object-subject and the subject-subject aspects of an activity. The former is referred to as the instrumental aspects of an activity, while the latter is known as the communication or interaction aspects of an activity.

Three different levels of collaboration have been identified in collaborative work processes: coordination, cooperation and co-construction [72].

1. *Coordination* corresponds to the routine, repetitive work performed by a group or organization. Coordinated work follows a pre-planned sequence of activities with actors simply playing their respective organizational roles. It coordinates the participant's actions as if from behind their backs, without question or discussion. The underlying coordination ensures that the result of these independent actions is the achievement of a common result.
2. *Cooperation* involves the interaction of a group of agents. At this level, work is no longer independent. The actions of each agent influence the actions of the others, enabling a synergistic effect. Actors focus on the shared problem, trying to find mutually acceptable ways to conceptualize and solve it.
3. *Co-construction* corresponds to the re-elaboration or re-engineering of work practices. At this level, work itself is the subject of contemplation. New, better ways of doing it are devised. Co-construction can result in the redefinition of the organization and interaction in relation to a shared object.

There is a close interplay between these different levels, since they all represent aspects of what is ultimately a collaborative activity. A pattern of dynamic transformations between these levels can be observed: coordinated interactions can become cooperative and *vice versa*; the result of a co-constructive activity is the redefinition of the interaction itself. In the next section I will argue that current workflow technology can be used to build coordinative systems. Some important innovations are however needed if this technology is to be used for building cooperative systems. Finally, co-construction requires more effective tools to reformulate workflow models according to the experience acquired from work practice.

AT does not consider the cognitive aspects of activities. The investigation of the latter is, rather, the goal of cognitive science. In the last century cognitive scientists focused primarily on the cognition of individuals extracted from their social and cultural context. However, it is only in the last decade that cognition has been more generally acknowledged as distributed rather then as something that is by definition the property of an individual mind [12, 73, 74]. It has been recognized that collections of individuals have cognitive properties that are different from those of individuals taken singly, properties often emergent from their collective behaviour. This factor cannot be overlooked when a HIS has to be designed.

Distributed cognition is not some new form of cognition. Rather all cognition can be fruitfully viewed as occurring in a distributed manner. As a cognitive theory DCog is focused on the organization and operation of cognitive systems; that is, on the mechanisms that make up cognitive processes that result in cognitive accomplishments. It also opens up our conceptualizations of cognitive processes to a much wider variety of mechanisms than the classic symbol manipulation of the physical symbol system hypothesis (PSS) (21) (75). Hutchins argues that PSS works better as "… *a model of the operation of a socio-cultural systems from which the human actor has been removed, rather than a model of an individual's internal cognitive processes* …". DCog capitalizes on this view by refocusing attention on the socio-cultural system – the cognitive system which functions by bringing representational artefacts into coordination with one another.

The utility of AT and DCog for supporting the design of CSCW systems is its theoretical commitment to examining the broader socio-technical system which is necessary for collaboration between individuals of a sort that is mediated by human-made or ICT-based artefacts. What are the main differences between AT and DCog? AT has a much stronger rhetorical power, not because it names things in the world, but because it names conceptual and analytical constructions with which any analyst looking at a collaborative system has had to struggle. In apparent contrast, DCog does not have a special name for the unit of analysis. It frames the problem in terms of examining the cognition of a system in terms of its function. The functional requirements drive the analytical focus, whereby functional operation are decomposed into smaller units of analysis that make sense with respect to the particular function or task within the system. Taking a perspective that does not privilege the individual may mean that configurations exist of collective and individual components, human agents as well as human-made or ITC-based artefacts, and social and cultural structures.

5. Knowledge-based Careflow Management Systems

To describe the architecture of a Careflow Management System (CfMS) it is worthwhile to use the glossary defined by the Workflow Management Coalition [76]. This is a non-profit organization with the objectives of advancing the opportunities for the exploitation of workflow technology through the development of common terminology and standards. It has been recognized that all workflow management products have certain common characteristics, enabling them potentially to achieve a level of interoperability through the use of common standards for various functions.

A CfMS is a system that defines, creates, and manages the execution of careflows (Cfs) through the use of software running on one or more Cfs models engines, which are able to interpret the care process definitions, interact with Cf participants and, where required, invoke the use of ICT-based tools and communication links.

Careflow indicates the automation of a care process, in whole or in part, as a result of which information, documents or tasks are passed from one participant to another for action, according to a process definition. This identifies the various process activities, procedural rules and associated control data used to manage the Cf during process enactment. Many individual process instances may be operational during process enactment, each associated with a specific set of data relevant to the individual process instance. Such systems also typically provide administrative and supervisory functions, for example they support task assignment, audit and management information.

The core activity in designing a CfMS is represented by formulating Cf definitions on which it is based. While clinical practice guidelines describe the activities of a medical team in a comprehensive manner for the purpose of defining best practices, Cfs focus on the organization of medical work with regard the execution of such best practices under the coordination provided by the CfMS.

Cfs are *case-based*, i.e., every piece of work is executed for a specific patient. One can think of a patient care process as a Cf *instance*. The goal of a CfMS is to handle patients by executing medical tasks in a specific order. A Cf process definition specifies which tasks need to be executed and in what order. A task, which needs to be executed for a specific case, is called a *work item*. Most work items are executed by a resource. A work item executed by a resource is called an *activity*. To facilitate the allocation of work items, resources can be grouped into classes. The resource class which results when we conceptualize the HCO's members in terms of their capabilities is called the class of *organizational agents*, both human and non-human. If the classification is based on the structure of the HCO, such a resource class is called *organizational units* (e.g., team, laboratory, clinic, department, etc.). The ontology of granular partitions seems to be very promising for effectively managing the level of details required by the description of the different activities involved in a Cf [77].

The core entity in Cf modeling and AT is the same: the activity. However, there are important differences in the emphasis given to the remaining entities. AT focuses on the subject (i.e., the caregiver), object (i.e., the patient), and outcome (i.e., the clinical outcomes achieved through the care process) of an activity. The resources and context are also taken into consideration under the names of *rules* and *division of labor*. Thus, the viewpoint for AT is that of the individual executing an activity in a given working context. Cf models provide a more detailed description of this context since they require us to define participants' roles, the distribution and routing of tasks, resource availability and utilization, and constraints in executing activities. Thus, the viewpoint is that of an organization managing a care process involving certain activities. The two approaches are complementary since the two views should be supported by a collaborative HIS. While AT, as previously pointed out, is a theory with a great rhetorical power, Cf can be viewed as a theory with a great application power, since it represents a computational representation that a CfMS can use to coordinate activities.

Evidence-based Cf descriptions are knowledge components which represent simultaneously both the best-practice medical knowledge that Cf participants should possess and the organizational knowledge they need to possess for operating within a collaborative care process. Thus, they make available the knowledge for knowing in acting. Since a Cf description represents an ideal care process, any adaptation [78] or exception management action [79, 80, 81] needed during individual patient care delivery is recorded in a database automatically managed by the CfMS. Those are the data sources that should be continuously analyzed to decide when a reformulation of the Cf description is necessary. This represents the result of an organizational learning process from the outcomes of organizational agent actions and corresponds to the co-construction type of collaboration described in the previous section.

The individual health care professionals in a HCO are working in a complex environment. Thus, they may at any time be carrying out a variety of tasks and interacting with other organizational agents to manage patients. Thus, we need more effective methods for the design of interaction between human and computational agents mediated by ICT artefacts. Coiera recently presented an interesting general theory of mediated agent interaction [82]. It is based upon models of the way communities or teams of people interact with each other, mediated by technology, but bounded by scarce cognitive and physical resources. Such a framework is able to model the effects of introducing new technologies, or indeed to design new technologies in such a way as to anticipate their effects on the population of users.

A CfMS may contribute to solving the interaction problem within HCOs since it is able to manage the execution of a large number of tasks and acts of communication among the organizational agents involved in care processes. This is because the common ground is large enough to make synthetic and accurate the communications between Cf participants [83] managing specific types of patients thereby justifying the effort of designing and developing a CfMS.

I strongly believe that CfMSs have a great potential in fostering the move towards integrated care, where care processes are redesigned around patients' needs and are based on scientific medical evidence. However their development is not an easy task and several conceptual and methodological problems still need to be faced.

Berg and Toussaint raise the problem whether a detailed modelling of care processes and data flow is the primary task that needs to be completed before a CfMS can be designed, developed and deployed [84]. I fully agree with their main conclusion: the Cf model on which a CfMS will need to be based should be formulated after both a careful investigation of the socio-organizational characteristics of the work context where the CfMS will operate and an epistemological analysis of the medical knowledge the CfMS will put into use. The *fluidity* of medical knowledge, which is constantly adapting itself to local needs and changing circumstances [85], is one of the major challenges in developing evidence-based Cf representations. Thus, epistemological theories like those presented in section 2 provide a set of fundamental conceptualizations for CfMS designers and builders. It is also essential that we never forget that medical work is based as much on communication and negotiation between health care professionals and patients as on the cognitive thought processes of individual physicians [86]. Thus, in modelling Cfs we must never forget that they, like any kind of model, always provide a necessarily partial representation of the reality beyond. As a consequence, CfMSs based on Cf models need to support communication among Cf participants and to incorporate methods for coping with the flexibility imposed by the fluidity of medical knowledge and the needs of individual patients [36]. Cf models should impose only the *rigidity* justified by those elements of medical knowledge that are recognized by the medical community as constraints on medical practice unavoidable to achieve the best possible outcome and avoid medical errors as much as possible. Such a design strategy will also help our understanding of the effects of medical actions on patient outcomes. We have to design care processes where flexibility is left only for behaviours that are proved not to jeopardize the desired outcomes. For example, Micieli et al. [87] investigated how the degree of compliance to an international guideline for stroke patients' management significantly influences the effectiveness of the provided care.

CfMSs require developing models of HCOs that need to be based on a suitable organizational ontology. The TOVE project developed an interesting organizational ontology, which provides a useful starting point [88]. It allows us to model an organization by defining a set of constraints on the activities performed by organizational resources. In particular, a HCO can be thought as consisting of a set of organizational units (e.g., wards, laboratories, clinical units, rehabilitation units, etc.), a set of organizational agents (members of a organizational units), a set of roles that the agents play in the organization, and a set of organizational goals that they are committed to achieving. An example of a HCO ontology developed in the case of the rehabilitation management of post-stroke patients is described in [36]. A more principled ontology for describing social reality is needed for developing an organizational ontology that is more effective in supporting collaborative work within a HCO. John Searle argues in [11] for a two-level ontology along the following lines. Facts on the lower level, called *brute facts*, can exist independently of human beings and their organizations. Facts on the upper level, called *institutional facts*, depend on human organizations and above all on an associated *collective intentionality*. Barry Smith raised many fundamental points for extending such an idea and a very stimulating debate between the two philosophers is reported in [89].

Research on workflow is presently very active and deserves special attention from the Medical Informatics community in order to improve the processes of design and deployment of CfMSs. A good Cf is not a simple image of a care process but rather an abstraction from it. The current workflow system development approaches lack a built-in development methodology. The WfMC standard only provides a workflow definition language, but it does not provide work process analysis tools and development methodology. Component technology is a way to raise the efficiency and quality of system development. It seems to be very promising to apply the software component concepts and methods to Cf description development [90]. In order to simplify the management and usage of Cf processes and to integrate them into HIS, powerful modelling methods are essential. The coloured Petri net formalism is very powerful since it has a sound mathematical basis as well as analysis and verification algorithms and tools [91]. However, there are some basic research issues to be addressed, such as the description of families of careflow processes and more efficient methods and tools for integrating CfMSs into HIS [92].

Although human cognition and work practice are two inseparable parts of human problem-solving, as I pointed out in previous sections, we need more innovative approaches to model these two parts of care processes to support distributed collaborative teams. The exploitation of the agent concept into the traditional modelling of Cfs to develop an agent-based Cf model seems very promising to me [93].

Moreover, there is an increasing interest in making workflow systems more adaptive and using knowledge-based techniques to provide more flexible process management support than is allowed by current workflow technology [94, 95]. Such a goal is even more important in the health care domain [36]. An equally strategic value will be enjoyed by effective solutions to the problem of intra- and inter-organizational work integration, since these would allow us to design and build ever more complex CfMS [96].

6. Conclusions

ICT available today are so powerful that the lack of new theories and models represents a major obstacle to the design and deployment of more flexible and interoperable HIS able to support knowledge management and collaborative clinical work. Reviewing the available conceptualizations and putting considerable work into expanding and integrating such theories and models is essential for building the next generation of HIS.

Medicine is an extraordinary field where socio-technical issues are central due to the variety of human needs, values and expertise involved. The economical factor is also relevant, given the incredible resources, which are being invested in the delivery of care services. Thus, a close collaboration between health care professionals, medical informatics researchers, and the healthcare IT industry is needed to achieve the expected levels of efficiency and quality of care. Industry has recognized that care providers are demanding more comprehensive HIS covering a larger spectrum of clinical functionality, and some vendors are actually investing in this new functionality [97, 98, 99].

The present role of academic centers is that of gradually replacing self-developed components of HIS by commercial modules and cooperating with vendors in order to design, develop and embed into an open architecture innovative solutions to support added-value aspects of clinical work [100, 101, 102]. National and international research and development projects should foster such a strategic cooperation. Medical Informatics researchers will benefit from the opportunity to evaluate the potential of systems derived from their work in a real work context. They should at the same time continue to develop basic research on fundamental issues such as those reviewed in this paper. The *generative dance* between innovative ideas and systems implementing them will improve the efficiency and effectiveness of the next generation of HIS.

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