Rethinking the Use of Ontologies in Learning

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Abstract. This paper investigates the use of ontologies in processes of collaborative learning and knowledge generation. The creation and use of ontologies is analysed from an activity theoretical perspective in order to understand processes of shared conceptualization as well as the role of ontologies in processes of change and transformation. Scenarios of ontology-based collaborative learning and knowledge-creation are presented. This work is based on the cultural-historical activity theory, providing a theoretical framework (1) for understanding processes of knowledge-creation which take place when generating and using ontologies and (2) to investigate the dynamic relationship (coupling) between individual learning and the transformation of a community.

1 Introduction

A fundamental challenge for modern societies is to organize both work and learning in a way that goes beyond the reproduction and use of preexisting knowledge and contributes to the generation of innovative solutions and knowledge, such as new theories, innovative work flows, and advanced technological products. Here, knowledge generation is a common intention of learning and knowledge management. To address this challenge diverse approaches have been developed in the fields of knowledge management as well as in education. These approaches, which can be subsumed under the so called "knowledge-creation metaphor of learning" [21] conceptualize learning and knowing as a social process where people collectively improve their understanding by generating shared knowledge artefacts. As knowledge creation is directed towards the creation of shared artefacts, the development of a shared understanding about the knowledge domain becomes crucial. Therefore the collaborative creation of ontologies and conceptual models lends itself to this task quite naturally. But, while much effort has been spent on the definition of ontology languages and the automated processing of ontologies, the individual and social processes underlying the creation, use, and evolution of ontologies, as well as the potential of ontologies to foster processes of knowledge creation are not yet being studied to its full extent [11].

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This paper explores how to utilize ontologies to support and trigger processes of knowledge creation. Unlike in present ontology-based learning applications, we are interested in exploring learning processes where learners collectively advance their individual and shared understanding through social interaction. This work is based on the cultural-historical activity theory as a theoretical framework, capable to explain the generation and evolution of ontologies from a social as well as an individual perspective. Section 2 illustrates the usage of ontologies in education and defines the core terminology. Section 3 gives an outline on the *cultural-historical activity theory* and discusses ontologies for learning from an activity theoretical perspective. Section 4 explores ways to use ontologies in education and outlines several educational scenarios. Section 5 sets up directions for further work.

2 The Usage of Ontologies in Learning

The term *ontology* has generated substantial controversy. As one can find many definitions in the current literature, this paper provides some introductory remarks on terminology and presents how ontologies are used in learning. It explores the status of ontologies from an activity theoretical perspective. Even though they are rarely acknowledged as such, ontologies are a cognitive tool in a wide range of settings where learning takes place. Learners often actively deal with ontologies in learning processes. For example, students learn to read geographical maps. In order to read and understand the map, they have to understand the underlying ontology codified in the different shapes, colors and symbols and explained in the legend. In another setting learners use a basic ontology of argumentation as they learn to analyze an argument distinguishing between a fact, a hypotheses, a question, and a conclusion. In order to find a certain book in the library students have to become familiar with some academic ontologies on scientific disciplines. A project team developing a shared filesystem to organize their documents has to agree on a shared ontology. When being asked to describe a certain business process students have to decide and to agree on the concepts relevant to describe such a process. In this work, ontologies are discussed as a concept used in computer science, deliberately excluding other denotations. We refer to the following often used definition: “An ontology is a formal explicit specification of a shared conceptualization for a domain of interest” [14]. An ontology includes a vocabulary of terms, and some specification of their meaning [16]. This includes definitions and an indication of how concepts are related, which imposes a structure on the domain and constrains the interpretations of terms. Ontologies formally define the semantics of concepts and their relations for a specific domain. Ontologies are socially shared artifacts as their generation requires a cooperative process in order to gain a consensual representation of the collective knowledge on the domain [11]. As ontologies arise as a result of cooperation within communities, they are inevitably aligned with a particular perspective on the domain of interest. This perspective defines the *underlying rationale* and *theoretical foundation* of the ontology, irrespective if it is explicitly stated or not. We refer to an ontology as a *conceptual model* and to the underlying theoretical foundation of an ontology as the *meta-model* of the ontology. Ontologies can be represented in diverse

languages. While informal ontologies and conceptual models can be described by graphical modeling languages, formal ontologies and their instantiations are usually expressed in formally defined languages. In the context of the semantic web RDFS or OWL (http://w3.org/TR/owl-guide/ and /rdf-schema/) provide such ontology languages.

3 An Activity Theoretical Perspective on Ontology Development

An ontology by definition is a socially shared artefact. It provides a shared understanding of the semantics of objects and their relationships within a certain domain. As shared mediating artefact it is a prerequisite for communication and collaboration within a community. Even though each member of a community might have its own "private" ontology, these personal conceptual models evolve and are shaped in the context of social interaction. Due to the socially shared nature of ontologies, learning theories that focus on individual learning processes fall short to explain the socially shared development of ontologies. Ontologies are created at the intersection of individual learning and the collective transformation of a community. In the following, the cultural-historical activity theory serves as a theoretical framework to explain ontology development from a social as well as an individual perspective.

3.1 The Cultural-Historical Activity Theory

The following is a fragmentary synopsis of the *cultural-historical activity theory*, stressing those aspects that are relevant with regard to the role of ontologies in work and learning. For a more comprehensive introduction the reader is referred to [26], [18], [10]. The cultural-historical activity theory is originated in the works of Vygotsky [26] and extended by Leontjev [18] and Engeström [10]. The theory provides a framework for describing and analysing collaborative processes. In contrast to psychological theories of human action which focus on cognitive processes of the individual on the one hand and sociological theories describing work and activity as merely social phenomena on the other hand, the cultural-historical activity theory stresses the *dynamic interrelation of individual processes and the social context* they are embedded in. It allows explaining the dynamic relationship between individual learning and the transformation of knowledge within a community.

The essential premises of the cultural-historical activity theory can be summarized as follows. (1) Human activity is object-oriented, i.e. it is directed towards a material or ideal object that is transformed or manipulated by the activity. It is the object and not the goal that allows distinguishing different activities from one another. (2) Activities are mediated by tools and signs, which are constitutive elements of any activity system. They are mediating artefacts ranging from physical tools over less tangible artefacts like plans and spreadsheets to scientific theories and languages. Mediating artefacts capture and preserve the socially shared knowledge developed in a community [18], [24]. (3) Human activity cannot be detached form its social context as every activity draws on artefacts which are the result of cultural-historical development. The meaning of an activity is bound to its interpretation within a social

context. (4) Learning is an ongoing process of mutual-dynamic adaptation of culture and the individual. By means of an activity, the individual successively opens itself to the scope of options provided by the culture. In turn, culture is created by individuals' activities [20]. Learning is directed towards the co-construction of shared mediating artefacts, e.g. the conceptualization of a shared conceptual artefact. (5) Activity theory is interested in processes and practices that differ from expectations and anticipations as well as deviate from routines and taken-for-granted assumptions [9]. Consequently, it foregrounds breakdowns, conflicts, deviations, discoordinations, disturbances, tensions, and unofficial work-arounds that tend to be explained away by other approaches. These are assumed to be signs of deeper contradictions among the elements of activity system or between interacting activity systems [15]. Activity systems are never static but evolve, e.g. when contradictions emerge between the elements within an activity system or between interacting activity systems. The elements within an activity system can not be detached and isolated from each other.

3.2 Activity Theory and Ontologies

Before we explore the role of ontologies within the context of learning, it is important to clarify the concept of ontologies from an activity theoretical perspective. The mediation of activities is not limited to physical tools but encompasses linguistic, conceptual, as well as cognitive artefacts, including theories, models and languages [24]. Therefore, it is argued that an ontology or a conceptual modeling language also constitutes an artefact capable to mediate human activity. Given the understanding of an ontology or conceptual modeling language as a shared mediating artefact (tool) that can be used to modify or transform a certain object several implications impose themselves. An ontology is by no means neutral, neither to the subject nor to the object of the activity, but is part of the activity system. The ontology used in a certain activity system has an impact on both the subject and the object. Accordingly the utility of an ontology is bound to the object and the subject of the activity and cannot be assessed independently. Secondly, an ontology like any other mediating artefact is the result of a cultural-historical development process within a certain community. As mediating artefacts are objectifications of socially shared knowledge and are build on specific premises it is likely that ontologies not only vary in their terminology but also reflect different theoretical foundations [1]. Thirdly, an ontology can become the object of an activity itself and can be modified or transformed. As ontologies provide powerful tools for organizing and assigning meaning and directly relate to the epistemological foundations held within a community, the analysis and development of ontologies is an important and sometimes drastic intervention. The domain of psychiatry provides an example for the dynamic relationship between individual learning and transformation of a community: Kraepelin's ethiology-based classification system, which is based on the underlying rationale that deceases can be classified according to its causes, has been the first systematic classification scheme in psychiatry (~1900). It forms the basis for the first standardized International Classification of Deceases (ICD). Despite continuous specification and modification inconsistencies became obvious in work practice using the ontology. As the ontology did not well support work practice of individuals, the community reconstructed the ontology and its underlying

rationale and now classifies psychological deceases by specifying its syndromes. Changes in the ontology and its theoretical foundation came along with transformation of knowledge in the activity system itself.

3.3 The Role of Ontologies in Knowledge-Creation

The development and use of conceptual models in learning has been a research topic of the learning sciences for many years. While the earlier works focussed on the individual learner, the collaborative use of conceptual models has become a research field in its own later on [19]. Despite the ongoing interest in the use of conceptual models for learning, there is a lack of theoretical as well as empirical work regarding the role of ontologies in collaborative learning and knowledge creation. The following is an attempt to chart uses of ontologies for learning and to sketch respective challenges from a learning sciences point of view. Ontologies (whether explicit or not) provide a common ground for a community. Participation within any kind of community requires familiarity with its (explicitly and implicitly stated) ontologies. Accordingly knowing and applying domain specific ontologies is an integral part of vocational training, e.g. the classification of diseases for a nurse. To become familiar with an ontology does not only mean to recall the concepts and their relations correctly but also to use them as a tool when carrying out an activity. Using an ontology is a challenging tasks for a learner: There is not a single ontology as communities often create and use multiple ontologies which do not necessarily map to each other. Accordingly, the learner has to be familiar with multiple ontologies, be able to mediate between them and to know when to use which one. The competent use of an ontology requires to understand the underlying rationale on which it is built, its theoretical foundation, as well as its historical evolution. In order to grasp the provisional character of ontologies the learner must have developed a sophisticated set of epistemological beliefs himself [5].

Shared conceptual models are never static but are constantly transformed as the activity system evolves. Therefore, it is crucial to treat ontologies as the object of an activity itself. New communities have to construct their ontologies from scratch or have to change existing ontologies due to changing practices. Changing work practices often enforce transforming ontologies. The shared conceptualization of an ontology provides a genuine opportunity for learning for the individual (individual learning) as well as the community itself (knowledge generation and transformation of the community, e.g. organizational and societal learning). The shared conceptualization of an ontology has the capability to provoke cognitive conflicts and helps to unravel prevalent misunderstandings: Processes that can trigger significant learning [22].

3.4 Meta-Models as the Object of Activity

Not only an ontology but also its meta-model and underlying theoretical foundation can become an object of activity. The change of a meta-model and the corresponding underlying rationale and theoretical foundation is associated with transformation and change within an organisation and a community. Knowledge generation takes place in

making conflicts and contradictions explicit. Ontologies which are based on conflicting meta-models and underlying rationales can and must not simply be mapped, merged and integrated automatically as they provide the opportunity to generate innovative knowledge as well as organizational and collective learning. This is based on a central principle of activity theory: Conflicts, tensions, and contradictions are assumed to be signs of deeper contradictions among the elements of an activity system (or between interacting activity systems) [15]. The following example demonstrates this: [7] describes the results of an analysis of the formal and informal structure of a huge petroleum organization, depicted by an organigram and a sociogram respectively. Both models are essential to define the problem, to gain insight, to understand the problem, and to propose a solution as each model provides a unique perspective onto the organization. Regarding the use of ontologies this means that learning not necessarily requires mapping and integrating ontologies, but that crucial insights become apparent when incommensurable ontologies based on different meta-models are contrasted. The analysis of meta-models opens up perspectives that go beyond those provided by using a single ontology. The work on meta-models is seen as a profoundly reflective activity tackling the theoretical foundation of a community. Change occurs when a community gives up a certain meta-model and introduces a new one. The comparison of different meta-models allows questioning the theoretical foundation. As the refinement of conceptual models can be seen as a process of successive optimization, changes in the meta-model come along with qualitative changes in the activity system itself. Both, ontologies and meta-models are a means of learning. In this sense the work on meta-models parallels the idea of double-loop learning as proposed by [2].

4 Using Ontologies to Foster Learning

This section explores ways to use ontologies in educational settings. Due to the fact that ontologies provide a socially shared conceptualization we focus on collaborative learning and knowledge creation. Scenarios are presented to exemplify collaborative practises to support ontology-based knowledge creation in education.

4.1 Existing Approaches

Besides one reference [8], a literature review on using ontologies in learning ended without any noteworthy results. Nevertheless there are at least two areas of research on the use of ontology development to foster learning. Even though they are either not explicitly focusing on ontologies (e.g. concept mapping) or do not lend themselves to learning as in the sense of collaborative construction of ontologies, they provide a valuable base to reveal methods for ontology development as a learning method.

Concept Mapping. There are many commonalities between ontology development and concept mapping in terms of learning. Concept maps are used in educational settings e.g. as a technique for teaching conceptual thinking and for externalizing learner conceptualization of a domain [6]. [4] proposes using conceptual models as

advance organizers in instructional design. Concept maps can be developed by individual learners to externalize and organize thoughts, providing a means for reflection and for extending the capability to recall things. Concept mapping techniques have also been applied in evaluating students' learning. [6] proposes concept mapping to capture a student's understanding of the ontology of a domain, as well as to infer his/her misconceptions. Concept mapping is used in scenarios of collaborative learning. [12] describes a scenario where individual students have to develop concept maps for a specific domain of interest and link them to associated materials. Peers then assess these maps, modify and enhance them, and provide alternative versions. While many of the tools and methods developed for concept mapping might also be applied in the context of ontology development, there are limitations of current approaches. Based on the examples found in literature concept mapping often is performed as an isolated task, solely focusing on the explication and negotiation of concepts without being embedded within a purposeful activity. This might hinder learners to see the mediating and dynamic nature of ontologies.

Collaborative Construction of Ontologies. As the potential of constructing ontologies as a means to foster knowledge creation has hardly been recognized in education, there is a lack of respective models. Several methods to facilitate ontology construction processes have been developed in knowledge engineering [13]. Ontologies are usually designed by expert knowledge engineers, who are often not aware of the conflicting views of the specific target domain in question (medicine, process management, etc.) and the respective conceptual models held within a specific domain [3]. To overcome this problem proposals for organizing the cooperative construction of ontologies in (distributed) groups of human actors have been made. [3] proposes a three-phased ontology construction procedure consisting of a generation phase (joint brainstorming on relevant concepts), an explication phase (a joint taxonomy is worked out), and finally the integration phase (the proposals are negotiated into a shared conceptualization supported by a human mediator). [17] presents the Human-Centered Ontology Engineering Methodology (HCOME) for the development of dynamic ontologies, which are seen as a means to explicate conceptualizations that are constructed by humans during practice. The approach aims to empower knowledge workers to manage their formal conceptualization in daily tasks through a continuous process. Methods for the collaborative construction of ontologies provide valuable input to the use of ontologies in education. However, the strategies described above fall short with regard to knowledge creation and learning as they do not provide means to foster reflection on the value and role of the ontology.

4.2 Scenarios of Ontology-Based Collaborative Knowledge Creation

The following scenarios present practices to support ontology-based knowledge creation within communities. In the first and second scenario ontologies are used as tools. In the third scenario, the ontology is the object of the activity. The fourth scenario deals with the use of multiple ontologies and their respective meta-models.

Using Existing Ontologies to Carry out an Activity. To become familiar with the ontologies, classification schemas, and conceptual models used in a certain domain or

professional community is an important learning objective in many training programs. In order to train the competent use of existing ontologies learners can be assigned tasks that require the use of the ontology to carry out an activity. Students in a course on biology have to classify the plants they found on an excursion. Using an ontology not only requires to know the ontology itself, but also to understand the underlying logic. The task becomes even more challenging when there are different and competing ontologies available.

Using Ontologies to Organize or Annotate Shared Artefacts. Both in project- and problem-based learning students often have to deal with a plethora of artefacts that have to be organized, stored and retrieved during the learning process. Ontologies can be used to sort and classify artefacts relevant to the problem. Students assigned to carry out an empirical investigation conduct a literature review and organize the results according to a shared conceptual model. The need to use ontologies for this purpose grows in relation to the amount of shared documents and the duration of the project. While students might have access to existing reference ontologies, it might also be useful that the students develop an ontology on their own.

Collaborative Ontology Development as Part of an Overarching Task. In this scenario a group of students develops a shared ontology to make sense of concepts and relations relevant to their task at hand. As ontologies are not just externalizations of mental models but have to proof their utility in practice, the process of ontology creation should not be an end in itself but an integral part of a more overarching task. Developing a shared ontology requires a lot of collaborative effort in order to gain an improved comprehension of the domain and how it might be conceptualized. Learners produce networks of linked ontologies and associated resources. The process can become very complex, particularly in long-term advancement of shared knowledge artefacts, a process typical to project- or inquiry-based learning.

Collaborative Inquiry Based on Multiple Ontologies. In this scenario students use multiple ontologies in parallel to solve a problem. Each student develops his/her own conceptual model. Then the students compare their models. A group is encouraged to describe the problem from different points of view using multiple ontologies. A group of students in computer science is asked to conceptualize a problem from a technical as well as a social perspective. In contrast to the development of a shared ontology, the goal is not to merge or map the different perspectives, but to use them to shed light on a problem from different angles.

A prevailing characteristic of this learning scenario is the use of multiple ontologies in parallel. The issue of dynamic and multiple classification, hardly addressed by current conceptual modeling techniques, becomes apparent when multiple domain-ontologies are used to describe a common set of resources. According to [23] the concurrent use of multiple domain-ontologies requires an explicit distinction of contexts. In order to allow for dynamic modeling [25] recommends introducing the concept of *roles* into object-oriented modeling. This approach distinguishes *natural-types* (class-types) and *role-types*. Instances of natural-types can fill and leave a role without losing their identity. An instance of a natural-type can fill different roles in different contexts. According to [1] the *role-*

based modeling approach allows describing coherent and theoretically founded conceptual frameworks and activity systems while at the same time allows semantic interoperability by defining attributes of natural-types.

Ontologies as Meta-Cognitive Tools. The use of ontologies in learning, focusing on the concepts of a specific knowledge domain (typically the nodes in a node-arc-node diagram) often sticks to learning facts. It lacks to support the development of meta-cognitive skills, such as the competence to carry out research, comprising argumentation, inquiry, and knowledge generation. Meta-cognitive tools comprise e.g. an ontology of argumentation and an ontology of progressive inquiry. Ontologies which specify different types of knowledge are integrated in tools like Belvedere and the Future Learning Environment (FLE3), but are not explicitly stated as such. The use of an argumentation ontology is depicted in figure 1.

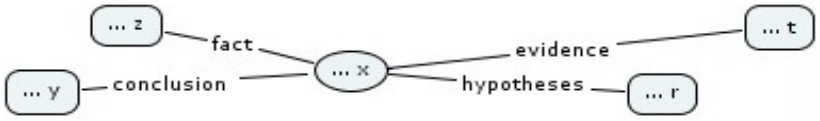

Fig. 1. An argumentation ontology which helps to develop meta-cognitive skills.

5 Discussion and Further Work

Ontology development as learning method is mentioned in [8] with a conclusion that "a good suite of tools, integrating both learning environments and ontology development tools, are required in such a learning process". The rationale for using formal languages to represent conceptual models developed by learners is that formal languages will enable many kinds of applications that are based on automatic or semi-automatic processing of the formal models. It makes sense to re-use and build on existing tools developed for ontology engineering. Present ontology-based learning applications do not embrace learning processes where learners collectively advance their individual and shared understanding through social interaction. Ontologies may have a significant role in learning when studied from an activity theoretical perspective, in which an ontology can be seen as an artefact that is capable to mediate human activity. Further work may develop methods and techniques to foster knowledge creation e.g. when ontologies can not be mapped and merged automatically, for reflecting the underlying theoretical foundation of ontologies within activity systems. Learning oriented tools include technologies to support the collaborative ontology development embedded within a purposeful activity, evaluation and evolution of ontologies.

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