Towards an assessment methodology for pre-service teacher thinking in an online problem-based learning environment

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Abstract

Pre-service teachers often start learning about the educational psychology domain as if it is a great toolbox. “Let’s use transfer, discourse, knowledge construction, etc,” are ideas that often appear in student-generated artifacts and discourse and inform us about their ontological understanding. An ontological analysis provides information about whether students have learned about the nature of concepts and how to appropriately apply concepts in a problem-solving task. In this study, we conducted an ontological analysis of pre-service teachers’ ideas generated during an online problem-based learning activity using the STEP system (Derry & the STEP research group, 2002). We found that student understanding seems to develop from a state of objectification (in which concepts are all treated as tools) to a state in which students learn how to differentiate amongst the different ontological categories within the domain. A more developed state of learning may also coincide with a view of the domain as a complex system. Appropriate understanding of the domain ontology may help establish a common agreement for ideas and relations being discussed which is an important factor in social knowledge construction.
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Recent debates in educational research have raised the need for research that accounts for the processes of learning, rather than only its outcomes, and for the complex ecology of the learning environment (Cobb et al., 2003). Research on complex learning ecologies require analytical methodologies that can capture the dialectical interaction of the various components of the learning environment - knowledge, task, social discourse, explicit and implicit norms, and other situated artifacts (Cobb et al, 2003).

This study proposes an analytical methodology that captures the dynamic aspect of learning, or, more specifically, the application of knowledge in a complex learning ecology – the STEP system (Derry, Gance, Gance, & Schlager, 2000; Derry & the STEP research group, 2002). The STEP system is an online problem-based learning (pbl) system designed to support teacher professional training. The site presents video cases of real-life instruction that offer opportunities for pre-service teachers to redesign the instruction. Through the STEP system pre-service teachers can collaborate online while working through a problem-based learning activity. The STEP system is a complex learning ecology because learning happens through a diverse, interdependent, constantly evolving, and largely self-regulating process of knowledge construction and application.

We present a case study that examines the discourse and artifacts generated during an online pbl activity using the STEP system. Our main goal is to explore the development of pre-service teachers’ conceptual understanding of the learning sciences domain.
Theoretical perspective

Problem-based learning might result in several cognitive outcomes: knowledge integration, development of problem-solving skills and critical thinking, and development of self-directed learning skills (Blumenfeld et al., 1991; Kagan, 1993; Barrows, 1996; Hmelo, 1998; Hmelo, 2000; Blumberg, 2000). In pbl, students learn through solving ill-structured problems and reflecting on their experiences. This requires students to gather knowledge from multiple sources and negotiate about its meaning and relevancy for solving the problem. As any collective enterprise, pbl involves a complex ecology in which students, facilitators, knowledge, and artifacts interact with each other to foster learning. Learning is a dynamic and ongoing process. Because of pbl's characteristics, assessing learning in pbl becomes challenging, as it should account not only for relevant and coherent applications of knowledge but also for sophisticated levels of understanding. But how can we know whether students have reached sophisticated levels of understanding?

From the perspective of the Hierarchical Schema Theory (Derry, 1996; Siegel et al., 2001), deeper understanding might be characterized by student’s successful completion of the three increasing phases of conceptual attainment – activation of course concepts, activation of relevant concepts, and integration of the activated concepts into a coherent theoretical interpretation of the situation. In a nutshell, deep understanding involves the mastery of concepts and their situated use. Yet, the next challenge is how to know whether students have mastered more sophisticated levels of understanding.

We found ontological analysis to be a fruitful methodology for investigating depth of understanding in complex environments. An ontological analysis of student
learning accounts for the dynamic aspect of learning in complex learning environments such as pbl. It informs us whether students have properly understood the definition of a concept and its situated uses.

Much of the literature on ontology and its applications have come from philosophy, sociology, and, lately, from artificial intelligence. Ontological analysis is often applied with the purposes of specifying conceptualizations and relationships within a domain and developing general criteria for segmentation and organization of objects in the world (Gruber, 1993; Eriksson, Puerta and Musen 1994; Poli, 2001a; Poli, 2002). Particularly, defining the ontological grounds of a domain provides a common language in which terms and relationships are agreed upon ahead of time. This in turn enables knowledge sharing and reuse (Musen, 1992).

Poli (2001a) clarifies distinction between epistemology and ontology by explaining that the first is concerned with definitions and uses of knowledge, while the latter is concerned with the nature of the knowledge itself and its place in the world. As for the learning sciences domain, an epistemological account of the concept of motivation, for example, would say that motivation is the knowledge of why people do what they do. An ontological account would say that motivation is a feeling, a state, a situated attribute of the individual.

It is then logical to infer that unlike an epistemological account, an ontological account views knowledge from a macro perspective. Back to our previous example, one needs first to know that motivation is a feeling, a state in order to understand what the knowledge about motivation is useful for. As a consequence, if the understanding of a concept’s ontology is not properly attained, the understanding of its epistemology will
certainly be diminished. The way learners ontologically categorize certain concepts
determines how they will apply such concepts as Chi and colleague (Chi, Slotta, &
DeLeeuw, 1994; Slotta, Chi, & Joram, 1995) demonstrated in the physics domain.

Chi and her colleagues (1994) found that learners categorize new concepts into
the ontological category that seems initially the most appropriate for them. In science,
concepts can belong to three ontological categories: matter, process, and mental states.
Meanings and applications of concepts will depend on the ontological categories to which
they were assigned. So, for example, if a student says that a “movement is heavy”, he is
giving movement, which is a process, a predicate - "heavy" - that is not appropriate for a
process ontology. Heaviness is a property of matters, not processes. In this case, the
student seemed to have categorized movement into a matter ontology rather than a
process ontology. Therefore, looking at concepts and their surrounding words informs
about ontological understandings. It also provides windows into the nature of some
misconceptions in science, which in turn helps to support conceptual change (Chi et al.,
1994; Slotta et al., 1995).

This sort of analysis has largely been conducted in well-structured domains such
as physics but has not been used for ill-structured domains, such as applied learning
sciences. In this paper, we apply an ontological approach to analyze pre-service teacher
thinking in a complex learning ecology.
Developing an ontology for the Educational Psychology domain

The initial challenge in applying ontological analysis to investigate learning in complex environments is the very construction of a domain ontology. In constructing a domain ontology, levels of reality and categories need to be identified first (Poli, 2001b). Levels of reality are ontologies of the domain. Each level of reality (or ontology) needs to be distinguishable by a unique dynamic and causal nature. Once a level of reality is identified, categories are then assigned to subordinate levels as a way to represent distinctive features of higher levels (see Figure 1).

*Figure 1: Constructing a domain ontology.*

In the learning sciences domain, as in the majority of social science domains, major ontologies (or levels of reality) may consist of tools, states, and processes (see Figure 2). Concepts falling under a *tool ontology* are distinguishable by being controllable, tangible, and instrumental. Two possible categories for this ontology are *static versus dynamic tools*. *Static tools* are those that do not require interaction to be brought about, whereas dynamic tools require it. Concepts falling under the *state ontology* are distinguishable by situated attributes that reside in the subject. Finally, a *process ontology* is distinguishable by concepts that represent emergent, ongoing, and
unbounded processes. Two possible categories for the process ontology are mediating versus metamorphic processes. Mediating processes are processes that are not directly associated with changes in individual psychological states and in knowledge and belief structures. Alternatively, metamorphic processes are directly associated to changes in individuals’ psychological states and in knowledge and belief structures. For example, although social knowledge construction may lead individuals to confront their knowledge gaps and engage in conceptual change, it is only through conceptual change (and this is the reason why this concept belongs to a metamorphic-process ontology) that change in individual knowledge structure happens. Social knowledge construction only mediates another process (i.e., conceptual change).

Figure 2: Levels of reality and categories for the Educational Psychology domain

After an ontological structure is established, the next challenge is to categorize and agree upon the concepts that should be assigned to each ontology. This is a sample of concepts that students learn about during their study of the learning sciences. The choice of topics for this analysis is based on the concepts that students discussed. For this study, we conducted several group discussions with domain experts in order to categorize learning sciences concepts in their appropriate ontology. The purpose was the development of an ontological taxonomy for the domain.
Concepts assigned to the static subcategory of the tool ontology were instructional objects in general. Concepts assigned to the dynamic subcategory were teaching techniques and learning strategies such as direct instruction, reciprocal teaching, problem-based learning (pbl), assessment, scaffolding, and rehearsal among others. Concepts assigned to the state ontology involved intrinsically situated attributes such as motivation, zone of proximal development (ZPD), schemas, skills, knowledge, and cognitive flexibility. Concepts assigned to the mediating category of the process ontology involved transfer, discourse, and social knowledge construction (SKC). Finally, concepts assigned to the metamorphic category of the process ontology were conceptual change, development, and learning itself (see Figure 3).

Figure 3: Categorizing concepts in the appropriate ontology

With an ontological taxonomy established, the next step is the definition of a scoring rubric for students’ level of ontological understanding of the concepts. In order to score students’ level of ontological understanding, concepts need to be analyzed within an ontological context. An ontological context is as a sentence or a set of sentences that
make the situated use of a particular concept visible. The situated use of a concept involves the concept itself and its surrounding words. It is the situated use of a concept that informs us about whether its ontology was appropriately understood. For example, a sentence in which a student writes, “transfer will also be used by the students when they make predictions...”, is considered an ontological context for two reasons. First, the student is not simply defining the concept of "transfer" in an inert, declarative fashion, but applying it to a context. In other words, we are observing a situated use of transfer. Second, the words that surround the concept of transfer (i.e., “students” and “be used”) help inform us about ontological understanding. In this particular case, transfer – which is a mediating process – was erroneously treated as a tool rather than a process. Tools can be "used ", processes (such as transfer) cannot. Processes cannot be "used" because they are intangible and uncontrollable. Therefore, in this case, the student's ontological understanding of the concept of transfer should be scored as inappropriate.

In summary, an ontological analysis informs us whether students have learned the nature of the concepts in the learning sciences domain and relationships that concepts bear with each other. It also tells us whether students have acquired an understanding of the learning sciences domain as a complex system rather than simply as a toolbox. This study focuses on the following three research questions:

1. How does pre-service teacher ontological understanding develop during a pbl activity?

2. How do different levels of ontological understanding affect learning?

3. Which concepts in the learning sciences domain are difficult to understand and why?
Finally, it is important to bear in mind that the ontological taxonomy we are proposing in this study is in no way definitive. On the contrary, we hope other learning sciences experts will join us in the task of refining this taxonomy. The process of building up such taxonomy will help establish a common language for concepts' meanings and applications, which is a fundamental step toward strengthening knowledge sharing within our scientific community.

Method

Participants and data source

Eleven participants were pre-service teachers enrolled in an Educational Psychology course taught in a pbl format. They worked in two groups. The data source for this study is the students' artifacts generated during one of the problems of the course that was taught utilizing the STEP system (Derry & the STEP team, 2002).

Instruction

The STEP system is an online pbl system designed for pre-service teacher training. The system contains three parts: an online pbl environment, a hypermedia textbook, known as Knowledge Web, and a library of video-cases for student analysis. The video-cases present examples of real-life instructions that afford several opportunities for improvements and changes. As students follow the steps of the system, they watch a video-case, research about concepts relevant for that particular case, collaboratively discuss about ways to improve the featured instruction, and offer suggestions to re-design the instruction. The site allows students to collaborate online while working through all the steps of each pbl activity. Some steps were designed for individual work and some for group work.
Students participated in a seven-week long pbl activity. The final goal of the activity was to have students redesign a lesson. To accomplish this goal, students were organized in small groups and asked to follow certain steps that helped scaffold them through the problem-solving process. A facilitator was assigned to each group to help students maintain their agenda and to push them to think deeply and be reflective. The entire activity occurred asynchronously with using the STEP system (http://www.wcer.wisc.edu/step).

The students initially studied a video-case individually, recording their observations. They collaboratively constructed a conceptual analysis while exploring relevant learning sciences concepts. Finally, they designed a piece of instruction that they might use in their own classroom and then reflected on the whole experience. We constructed case studies of two groups that used the online STEP system to support their activity. The analyzed data source includes the students’ individual artifacts during the pbl activity.

Coding and analysis

We scanned the corpus of written artifacts generated during the pbl activity to find exemplars of concept uses and define the ontological contexts for the concepts students dealt with. Ontological contexts, as stated before, represented our major unit of analysis within which concepts were analyzed and coded for ontological accuracy. In order to be considered appropriate, the application of a tool ontology should include the description of an agent (or a more than one) responsible for materializing, employing and controlling a particular tool. Moreover, tools should never be applied as ends but only as means of a broader process. As an example of an appropriate use of a tool ontology we
have a sentence in which a student wrote “the teacher will employ a pbl activity to help students to understand how to apply their knowledge.” This sentence demonstrates an appropriate application of a tool ontology because “pbl activity” is a tool (i.e., something controllable, instrumental, and tangible) that requires an agent to employ and control it (in this case, the teacher). This sentence demonstrates an appropriate ontological understanding because both the concept and its surrounding words are being applied in a manner consistent with the ontology to which that concept is assigned. Alternatively, a sentence such as “rehearsal needs motivation” reveals an inappropriate ontological understanding because “rehearsal” is a tool and, as such, it cannot be motivated. As motivation is a state, only living beings, not tools, can feel it. In this case, both the concept (i.e., rehearsal) and its surrounding words (i.e., “needs”, “motivation”) were applied in a manner inconsistent with the ontology to which that concept is assigned.

As for a state ontology, an appropriate application was attained if students provided a clear depiction of the circumstances provoking the given state. Additionally, states should be referred to as situated attributes residing within a living being. An example of an inappropriate use of a state ontology was given above where a student wrote a sentence in which motivation (which is a concept that belongs to a state ontology) was attributed to a tool (rehearsal), which is a non-living being. An example of an appropriate use of a state ontology is a sentence "by understanding the relevancy of the topic in the outside world, students will feel more intrinsically motivated to participate in the activity.” In this example, the student stated the circumstances that further motivation (i.e., “understanding the relevancy of the topic in the outside world”) and attributed that state to living beings (i.e., “students”).
Finally, an appropriate application of a process-ontology concept would require the understanding of the concept as an emergent schema (i.e., as an ongoing, affected by multiple causes, and unbounded process). Concepts belonging to a mediating category were considered appropriately categorized if students clearly described the variables that the process mediated. A sentence that says, 

“through social knowledge construction, students will confront their level of knowledge with that of more capable peers. In turn, this will help students to recognize knowledge gaps and engage in conceptual change.”

is an example of an appropriate ontological understanding because social knowledge construction (which is a mediating process) is being described as mediating (i.e., by allowing student to “confront their level of knowledge and recognize knowledge gaps”) another process - conceptual change. An inappropriate ontological use of social knowledge construction (SKC) would happen if a student had linked SKC directly to conceptual change, without explaining the mediating mechanisms that lead to change. In other words, SKC (as any other mediating process) cannot be linked directly to changes of knowledge and belief structures. Something needs to happen in between. Likewise, a sentence that tells, “the teacher needs to employ social knowledge construction” is also an example of inappropriate ontological understanding because SKC is being applied as a tangible, instrumental tool and not as an emergent process.

As for the concepts belonging to a metamorphic ontology, appropriate categorization happened when students clearly described the processes or states that the metamorphic process changed or transformed. For example, in the sentence, “by engaging in conceptual change, students will revise and transform their current
schemas”, a student demonstrated an appropriate understanding of conceptual change as a metamorphic process since the sentence clearly describes what will be transformed - in this case, students' current schemas.

Results and discussion

Students used concepts that fit into each ontological category equally often (see Figure 4), but student understanding of each of these ontological categories varied remarkably. Overall, students did not attain appropriate level of understanding of concepts associated with the process ontology. In the 25 ontological contexts in which process-ontology concepts were analyzed, concepts were applied appropriately only 32% of the time (see Figure 5).

Figure 4: Percentage of time that students used concepts that fit into each ontological category.

Figure 5: Percentage of appropriate and inappropriate ontological categorization for the concepts that students used.
Discourse and transfer were the two process-ontology concepts that students had the hardest time understanding. Amongst the 18 ontological contexts in which those two concepts were analyzed, inappropriate application occurred 72% of the time. In the majority of inappropriate applications, transfer and discourse were treated as tools (see Figure 6).

Figure 6: Student ontological categorization of concepts that belong to the process ontology (highlighted in gray). The Figure shows that students largely treated process-ontology concepts as tools.

The state ontology was the second most difficult ontology for students to grasp. In the 27 ontological contexts in which state-ontology concepts were analyzed, concepts were applied appropriately 56% of the time (see Figure 5). Prior knowledge and metacognition were particularly difficult for students to understand. They failed to recognize those concepts as belonging to a state ontology 54% of the time. Instead, they treated those concepts as tools (see Figure 7). Finally, students demonstrated no difficulty to understand tool-ontology concepts. In the 26 ontological contexts in which tool-
ontology concepts were analyzed, concepts were applied appropriately 100% of the time (see Figures 5 and 8).

**Figure 7:** Student ontological categorization of concepts that belong to the state ontology (highlighted in gray). The Figure shows that inappropriate ontological categorization involved to treat the concept as a tool.

**Figure 8:** Student ontological categorization of concepts that belong to the tool ontology (highlighted in gray). The Figure shows that students’ ontological use of these concepts was always appropriate.

From these results, it is apparent that ontological misunderstandings of states and processes involved treating these types of concepts as tools. “Teacher should use
transfer, social knowledge construction, discourse, etc...” or “students should use attention, motivation, transfer, etc” are some of the examples of state and process ontology being used as tools. This instrumental stage of knowledge development, in which concepts are seen as tools, may indicate that students hold naïve views of learning as a great toolbox - a fixed and controllable environment. If this is the case, the students have not understood the learning sciences domain as a complex system.

This naïve view of the learning environment overestimates the role of the teacher and underestimates the role of situational variables in learning. Causality is mainly attributed to the teacher's dispositional factors. In the social psychology literature this is often referred to as the “fundamental attribution error” (Ross, 1977). Naïve ontologies may also be distinguishable by excessive material causal attributions (Slotta et al., 1995).

As an example, students who think that it is the teacher who completely controls the discourse in a classroom have clearly a naïve understanding of this concept. They do not understand discourse as socially situated phenomenon. Rather, they assume that discourse is just one more tool out of the teacher's toolbox. As a consequence, it is likely that students with a naïve conceptual ontology might solve educational psychology problems by giving teachers much more power and control than they actually have.

On the other hand, as ontological understanding deepens, appropriate application of state- and process-ontology concepts may indicate that students have understood the learning environment as a complex system. They understand the situational dimensions of state and process-ontology concepts. This is considered a more developed understanding because the student is placing a concept in a much broader systemic, dialectical framework.
An important question that follows from this analysis is how to design tasks that allow for both ontological differentiation and understanding of learning as a complex phenomenon rather than simply a toolbox. Certainly the answer should involve students' dealing with knowledge application. Complex learning environments such as pbl may afford deeper ontological understandings because they emphasize use of knowledge. This is a hypothesis that will be tested in further investigations.

Another important question is how to design assessment that captures the level of ontological understanding. Such assessment needs to create situations in which ontological contexts become salient for analysis. Again, this will only be possible if students engage with knowledge application. Assessments focused on dictionary-like and static knowledge may be biased towards tool ontology, which were shown to be much easier for students to understand. This may give a false sense that students have mastered the content while actually they have never fully apprehended the systemic and socially situated complexity of the domain.

Conclusion

Our conclusions are threefold. First, we found that pre-service teacher ontological understanding seems to unfold from an instrumental and objectified account of the educational psychology domain that views it as a toolbox. “Let’s use transfer, discourse, knowledge construction, etc,” are common examples of inappropriate ontological understanding that reveal an instrumental and simplistic view of the domain.

Second, we found that different levels of ontological understanding affect not only how students define concepts but also, and more importantly, how they apply concepts to solve problems. Simplistic and instrumental accounts of the educational
psychology domain lead students to overestimate the role of the teacher in promoting learning. The role of the teacher is overestimated because students see learning simply as a function of how teachers employ and control tools. As a consequence, the social complexities of the learning ecology are not only overlooked but also mostly reduced to the teacher's dispositions. In contrast, as ontological understanding deepens, the appropriate differentiation of concepts within their ontologies might equip students with more complex accounts of the learning process and the socially situated mechanisms that it entails.

Finally, the ease with which students had to grasp tool-ontology concepts and the difficulty they had with process-ontology concepts might be due to differences in the schemas associated with both types of ontology. In order to understand tool-ontology concepts, a causal schema is often required, while to understand process-ontology concepts an emergent schema is required (Chi et al., 1994). A causal schema is easier than an emergent schema because it has a simpler causality (often controllable) and a clearer beginning and end. In contrast, an emergent schema has multiple, non-controllable, and ill-defined causality and it is often ongoing and unbounded. As students are often much more familiar with experiencing causal schemas than emergent schemas, it might explain the ease with which they come to understand tool-ontology concepts.

The advantages of applying an ontological analysis for investigating student learning are threefold. First, it focuses on how well students are able to differentiate among concepts that are (1) part of teacher's toolbox, (2) intrinsically situated, and (3) emergent. The first type of concepts belongs to a tool ontology, the second type belongs to a state ontology, and the third type belongs to a process ontology. Another advantage
of ontological analysis is that it is consistent with some well-established theories in the field such as the Hierarchical Schema Theory (Derry, 1996). We suggest that more developed ontological understanding may be associated with higher phases of conceptual attainment. Finally, an ontological analysis provides a dynamic account of the development of student conceptual understanding of ill-structured domains by picturing the various ways students categorize and apply concepts. Such dynamic account is particularly relevant in complex learning ecologies where learning evolves briskly as students continuously confront their current level of knowledge against the affordances and constraints of the environment in which they are embedded (Pea, 1993).

An ontological analysis makes the challenges of designing instructional activities that might promote qualitative improvements in students’ ontological understanding salient. Further investigations should address the impact of different instructional methods in either hindering or promoting deeper ontological understanding. It is also the work of the future to design assessments that capture such ontological understandings.
References


