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Conceptual Maps vs Ontologies: A Comparison on the Utility of Computational Tools for Discovering Misconceptions in Educational Environments*

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Abstract

This paper presents a preliminary comparison between different tools for modeling domain knowledge in educational settings: concept maps, as described by Novak and Cañas [1] (a tool traditionally used in schools), and computational ontologies (formal systems for conceptual modeling, widely employed in artificial intelligence systems for their capacity for "automated reasoning". Specifically, the paper reports on the results of a field experiment conducted at the "Guido Parodi" Scientific High School in Acqui Terme with 128 students, in which different student classes compared the use of concept maps and ontologies in solving a "misconception" problem (i.e., issues of incorrect conceptualization). The problem was induced by providing students with notes and educational materials containing deliberately contradictory information (simulating a situation where a student may take incorrect notes for various reasons). The main finding highlights the role that ontologies and semantic technologies can play in education by identifying potential conceptualization errors (misconceptions). In contrast, the mere use of concept maps (whether created by hand or using tools like C-Maps) does not enable students to realize they have acquired incorrect conceptualizations within a given knowledge domain.

Keywords

ontologies, conceptual maps, misconceptions, symbolic reasoning, AI in education

1. Introduction

Conceptual maps have been an influential tool in the field of education aiming at improving the learning capabilities of students. This work stems from the aim to investigate and compare this traditional educational tool with that of computational ontology [2]. In a study involving 128 high school students of philosophy classes the two different tools are analyzed and compared. In the first section, conceptual maps and ontologies are briefly examined, then we present presents an experiment conducted in schools with groups of students of different classes, comparing the use of concept maps and ontologies in solving a misconception problem. Finally we show how this preliminary evaluation suggests that the tool of ontology can be successfully employed as a solution to the problem of misconception in the education field.

2. Conceptual Maps and Ontologies

A conceptual map is a graphical representation of a specific topic, an attempt to depict the relationships between concepts, or a way to explicitly display the implicit structure of knowledge to have a better overall picture (and a better understanding) of a given learning phenomenon. Designing a concept map is

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a complex task that involves not only knowledge of the subject but also metacognition and the theoretical foundations of such tools are rooted in constructivist psychology [3] Scholars in education and concept mapping, starting with Joseph Novak, consistently emphasize the importance of constructing one's own concept maps in order to promote meaningful learning allowing students to move beyond a mechanical-mnemonic learning style. Computational ontologies, on the other hand, are referred to as "an engineering artifact, constituted by a specific vocabulary used to describe a certain reality, plus a set of explicit assumptions regarding the intended meaning of the vocabulary words" [4] The main building blocks of ontological models are, therefore, concepts (or classes), roles (or properties), and individuals describing a given domain. In other words: ontologies provide an explicit reference domain model to perform simple forms of automatic reasoning like model checking, instance categorization, classification, subsumpion etc. (for a complete account we refer to [5]).

3. Experiment

A field experiment was conducted at the "Guido Parodi" Scientific High School in Acqui Terme, where groups of students compared the use of concept maps and ontologies in addressing two problems of "misconception" (or erroneous conceptualization). One misconception was induced by providing notes and educational materials containing deliberately contradictory information (a situation that could correspond to a student, for some reason, taking incorrect notes). In order to compare the educational implications of concept maps and ontologies the involved students were invited to undertake a modeling task using both a concept map and an ontology, allowing for a comparison of the two tools. Based on teaching experience and knowledge of typical student errors, a relatively simple and focused topic was chosen from the fields of philosophy (to facilitate modeling), which nonetheless frequently generate misconceptions.

The topic chosen for philosophy involved placing certain philosophers within the context of the 17th- and 18th-century debate between empiricists and rationalists. Students were provided with educational material, based on which they were tasked with creating either a concept map or formulating the basic assertions that would later be used for building an ontology. Deliberately, an error was introduced into this material, incorrectly attributing the belief in innate ideas to the philosopher Locke. This intentional error mirrors a common mistake made by fourth-year students, who often struggle to identify the key concepts that define a philosopher as either an empiricist or a rationalist. It is quite common during oral exams to hear contradictory statements such as "Locke is an empiricist and believes in the existence of innate ideas" or, conversely, "Descartes is a rationalist and does not believe in the existence of innate ideas," without recognizing the contradiction, as the assertion "does not believe in the existence of innate ideas" is a defining characteristic of empiricism.

Errors of this nature can arise from inattentiveness while taking notes or retrieving information, or from relying solely on rote memorization, without any meaningful learning that would allow contradictions to surface.

4. Results

The students tasked with converting the provided material into a concept map correctly identified the two main categories, rationalism and empiricism, and subdivided these into their respective theses and associated philosophers. They accurately included the key shared thesis among rationalist philosophers and among empiricist philosophers, including the correctly attributed proposition "innate ideas do not exist."

The students then proceeded to insert the individual characteristics of each philosopher, having correctly placed Descartes, Spinoza, and Leibniz under rationalism, and Locke, Hume, and Berkeley under empiricism. When listing Locke's characteristics, they accurately indicated specific theses such as "ideas derive from experience," "the idea of substance arises from the combination of several simple ideas," and "criticizes the idea of substance." These propositions are entirely consistent with the broader

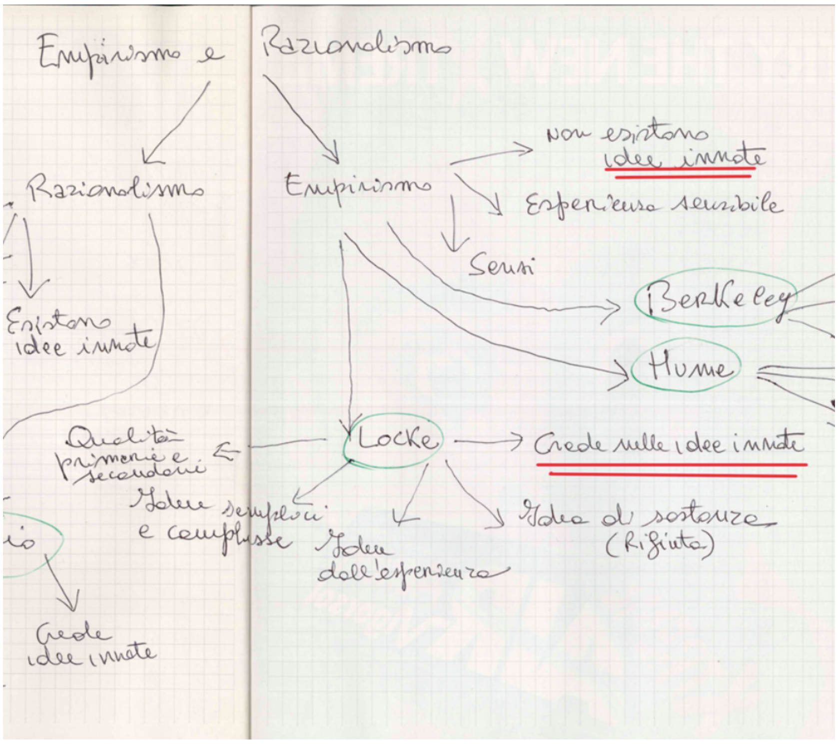

Figure 1: A paper-based example of a conceptual map created by students from a fourth-year class at a science high school on the topic of Empiricism and Rationalism. The map correctly identifies the main theses of Empiricism but highlights the contradiction of attributing to Locke a belief in innate ideas, despite the earlier assertion that empiricists do not acknowledge the existence of innate ideas.

statements attributed to all empiricists, such as "there is nothing in the intellect that was not first in the senses" and "knowledge begins with sensory experience." However, due to the manipulated material, the students also included the proposition "believes in innate ideas," which directly contradicts the statement "innate ideas do not exist."

This is a typical categorization error, where an individual is incorrectly assigned to a category. A highly attentive student might notice this error while constructing the concept map, but since the map is relatively large and possibly created over multiple sessions, the error can remain "in plain sight" without being detected.

In the following, an example of the completed model is shown (first drafted by hand and then recreated using CmapTools for clarity) by the group of students, who did not notice (none of them) the contradiction highlighted in red. By the time the students identified the propositions characterizing each philosopher's thinking, they had "forgotten" the general propositions of empiricism and rationalism and did not verify their coherence and consistency. The process of creating a concept map too often becomes a mechanical task, similar to summarizing, which undermines the educational purpose of the map. In both cases, the maps correctly identifies the main theses of Empiricism but introduce a misconception by attributing to Locke the belief in innate ideas, despite the fact that it was previously stated that empiricists reject the existence of innate ideas.

In a second phase, for the same modeling task assigned, the students—assisted by a researcher—created an ontology (visible below) capable of detecting conceptual errors [1]. Specifically, if the individual Locke is placed within the ontological class 'Empiricism' and, due to a conceptual misunderstanding, an attempt is made to assign Locke the property 'believes in innate ideas,' the software highlights the inconsistency within the ontological base. Since Locke is classified as an 'Empiricist,' he can only believe in 'ideas based on experience.' Thanks to the ontological reasoner, when the user attempts to assign the

[1] All the described activities have been done outside the standard lessons time. They were delivered as laboratories in afternoon sessions. This was possibile because one of the authors, i.e. Rebuffo, was an actual teacher in the school.

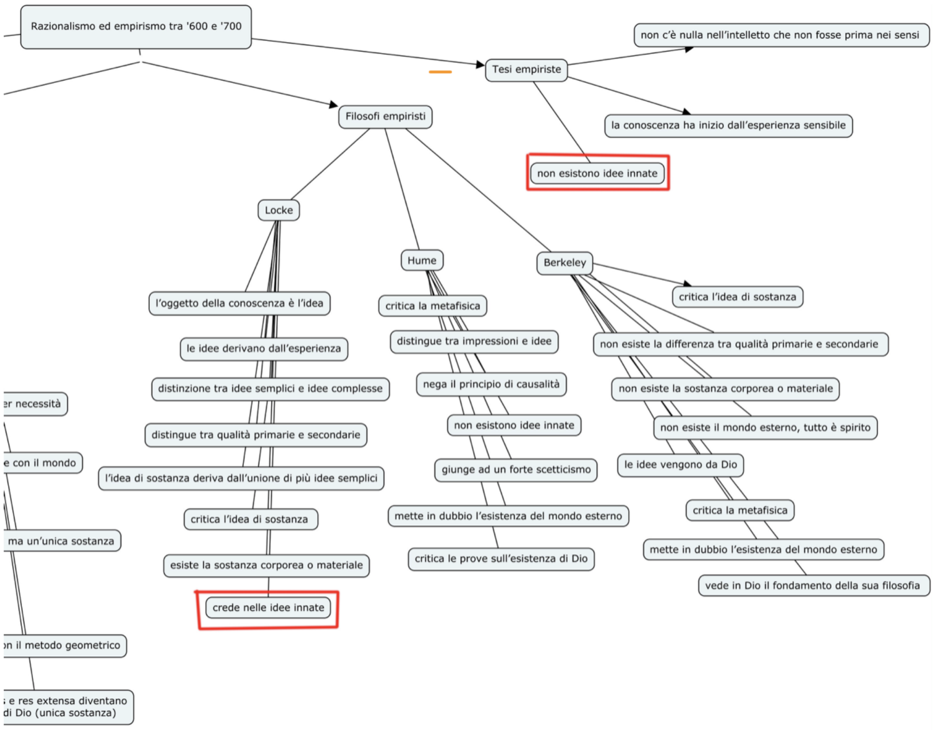

Figure 2: Conceptual map reporting the previously paper-based representation. The impossibility of attributing a semantics to the link used to connect concepts and their relationships allows the possibility of drawing contradictory elements.

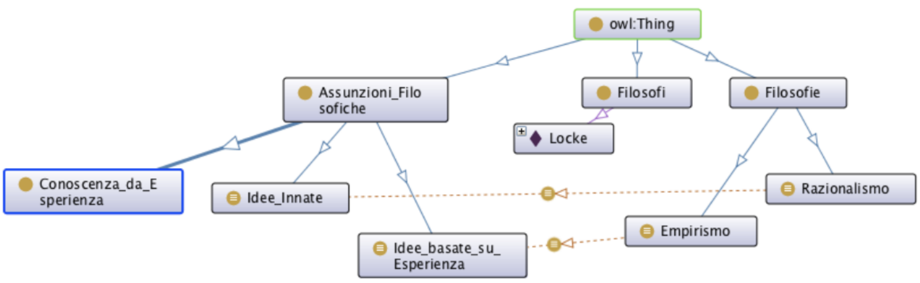

Figure 3: The corresponding domain ontology modelled by the students using OWL (Ontology Web Language) specifying classes, definite classes, properties and instances of the domain of interest.

contradictory information to the instance 'Locke,' the inconsistency immediately surfaces (unlike in the conceptual map), and the reason for this inconsistency is explained to the students (as shown in the figure below).

5. Conclusions

In the modeling of an ontology, a deeper understanding of concepts is required, along with their classification and categorization in order to define classes, subclasses, individuals, and relationships. This

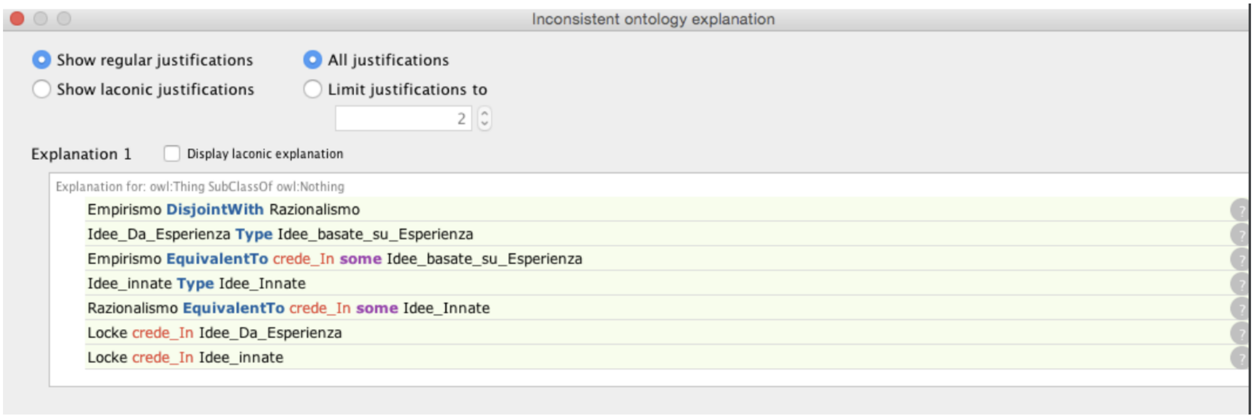

Figure 4: The laconic explanation interface of the reasoner Pellet within the software Protegé allowing the students to know the cause of the generated inconsistency in their model.

is a time-consuming activity, but one that engages a much deeper cognitive and conceptual reflection. While a conceptual map can serve as a tool to facilitate meaningful learning if well-constructed, it often promotes mere memorization. In contrast, an ontology forces a deeper exploration of the core of concepts to ensure its own construction. The ontology tool highlights internal contradictions in conceptualization and forces real-time corrections, requiring solutions to categorization problems and reducing the constant need for the teacher to intervene and correct the maps.

Too often, errors in conceptual maps become apparent too late, sometimes only during the final evaluation, which does not provide a true learning opportunity but instead serves as a penalty for the student. In some cases, the misconception persists in the student, indicating a complete failure of the formative purpose of the final assessment. In ontology modeling, every conceptual error emerges in real-time, forcing a rapid reconsideration of the inadequate knowledge paradigm for the task at hand (i.e., the modeling itself). One of the major educational challenges is managing misconceptions—handling students' false beliefs, which frequently generate incorrect foundational beliefs that negatively affect future learning. It is very difficult for a teacher to dismantle these beliefs, whereas the ontology tool can be highly effective because it confronts the student with the objective inconsistency of their conceptual foundation, demonstrating how those foundations inevitably lead to contradiction.

Despite the complexity and time investment required for its modeling, ontology, unlike conceptual maps, guide students toward meaningful learning, never merely toward rote memorization of knowledge.

An extension of this work will involve the introduction of hybrid knowledge representation systems, capable of distinguishing between different types of conceptualization (e.g., "prototypical," classical, etc.; see [6, 7] on this topic). The use of this extended framework will allow for the testing of hybrid artificial systems integrating ontological and common-sense reasoning components (as in the case of systems like [8]). Such integration would allow to model and analyze in more detail not only how and when different types of misconceptions occur but also to explore different strategies of "conceptual change" aiming and modifying specific pieces of knowledge components that eventually revealed to be the more difficult ones to learn. Being able to detail and analyze such issues can be crucial for the development of theory-driven serious games activities (e.g. see [9] as well as to design specialized versions of such games (like in [10] targeting different types of errors and cognitive vulnerabilities in the educational setting.

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