Computers in Human Behavior 27 (2011) 1389–1398

Contents lists available at ScienceDirect

Computers in Human Behavior

journal homepage: www.elsevier.com/locate/comphumbeh

Modeling instructional-design theories with ontologies: Using methods to check, generate and search learning designs

Miguel-Ángel Sicilia [a,*], Miltiadis D. Lytras [b,1], Salvador Sánchez-Alonso [a], Elena García-Barriocanal [a], Miguel Zapata-Ros [c]

[a] Information Engineering Research Unit, Computer Science Dept., University of Alcalá, Ctra. Barcelona km. 33.6, 28871 Alcalá de Henares, Madrid, Spain
[b] The American College of Greece, 6 Gravias Street GR-153 42, Aghia Paraskevi, Athens, Greece
[c] Instituto de Ciencias de la Educación, Edif. Luis Vives, Campus de Espinardo, University of Murcia, 30100 Murcia, Spain

ARTICLE INFO

Article history:
Available online 22 September 2010

Keywords:
Instructional design
Ontologies
Learning objects
IMS LD
OWL
SWRL

ABSTRACT

Instructional theories have been defined as practice-oriented theories offering explicit guidance on how to help people learn that offer situation-specific methods. The descriptions of many instructional theories include recommendations or rules that can be subject to modeling in formal knowledge representation languages. Further, recent work in the application of ontologies to learning technology has made openly available formal representation schemas for activity sequences and learning resource descriptions, based on evolving standards. Combining these with the representation of instructional-design theories provides a framework for developing rule-based, instructional theory-aware support tools for different practical purposes. These purposes include (partially) checking the compatibility of learning designs with instructional theories in authoring tools, using methods as query criteria in learning resource repositories, and the generation of tentative learning activities for some given instructional design methods. This paper addresses the main epistemological issues and the representation of the main elements of instructional models using the formal ontology language OWL, which can be used in conjunction with the SWRL rule language for the purposes described. Following existing conceptualizations, methods and conditions are modeled in a generic way able of capturing a plurality of views.

1. Introduction

According to Reigeluth (1999), *instructional theories* are practice-oriented theories offering explicit guidance on how to help people learn. Such theories offer situation-specific methods, i.e., collections of rules or guidelines that can be used when facing decision making in practical situations requiring the design and development of learning activities or resources. These methods are known to be effective to some extent in facilitating learning under some conditions, and they organize in components or sets of methods. Instructional theories and their underlying models conform an existing and growing body of practical design knowledge ready for application in the arrangement of learning experiences of a diverse kind – see, for example, Reigeluth (1999) or Gagné, Briggs, and Wager (1992). Even though some authors consider learning design as a superset of instructional design (McLean and Scott, 2007), in this paper we will use the term "learning design" only to refer to the final artifacts of the design process, i.e., the plans, resources or arrangements of activities and tools. Then, the term "instructional design" will be used to refer to the process itself, which is informed by instructional theories (or "instructional-design theories").

It is noteworthy that some instructional theories are at least partially inconsistent with others in some situations and that they can be contrasted (Gropper, 1983). There are even cases in which different theories may have similar effects (Harskamp & Suhre, 2006). Actually, instructional theories are elaborated on the basis of research studies attempting to find and explain learning-related patterns that contrast carefully delineated hypotheses. Since learning conditions and contexts are so diverse, theories evolve with the course of advance of new research studies, and the result of the work in the field is more similar to an array of different and sometimes competing theories than a single, unified body of integrated knowledge ready to be applied deterministically. An important consequence of this state of affairs is that documenting design theories or representing them (to some extent) in computer-based languages should allow for a separate and independent representation of different theories and the possibility of selecting only some

* Corresponding author. Tel.: +34 916249104; fax: +34 916249103.
E-mail addresses: msicilia@uah.es (Miguel-Ángel Sicilia), mlytras@acg.edu (M.D. Lytras), salvador.sanchez@uah.es (S. Sánchez-Alonso), elena.garciab@uah.es (E. García-Barriocanal), mzapata@um.es (M. Zapata-Ros).
[1] Tel.: +30 210 600 9800.

0747-5632/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.chb.2010.07.040

of them for use in a particular situation. In addition, design theories are not always stated in an expression that is ready for unambiguous, direct application by "knowledge users" or designers (Snelbecker, 1974), but they provide some general guidelines and rules that must be considered critically.

In general, only a small part of instructional theories can be effectively formalized. For example, a method component expressed as "hold *interesting* and lively discussions about each book" in reading-based affective education cannot be fully represented a priori since "interesting" is a category that escapes a computationally-significant formal representation. Another example is the method "select only topics that can be *reasonably* connected to some *powerful* themes" (Gardner, 1999). In this case, the identification of "powerful" themes and "reasonable" connections are out of what can be formalized with simple rules. However, as discussed below, formalized heuristics or interpretations of parts of the theories can cover some of their interesting points, thus enabling a degree of computer support for the activities of instructional designers.

In any case, the application of the practical guidance contained in such models results in some *design artifacts*, be them contents, exercises, problems, simulations, activity plans, guides or any other kind of resource or their combinations. In the context of e-learning and instructional technology (Ely, 2008), those artifacts include digital contents and digital representations of activity sequences, prepared for some degree of transportability and automation by means of compliance to learning technology specifications as ADL SCORM or IMS LD (Friesen, 2005). These digital elements can be packaged and described through common languages as prescribed by these specifications and standards (McGreal, 2004) to achieve that degree of interoperability and reusability (Sicilia & García-Barriocanal, 2003). The blurring of distinctions between online and distance education (Irlbeck, Kays, Jones, & Sims, 2006) and the emergence of the Internet as a global medium for sharing knowledge is pushing more instructors and teachers to represent their resources and activity designs in computerized form that follow the mentioned specifications. This is becoming even more important in the context of sharing open educational resources, which has become a major strategy in many higher education institutions worldwide (Downes, 2007).

The paradigm of reusable learning objects is considered an important component in the evolution of development methods for digital learning resources (Boot, van Merrienboer, & Theunissen, 2008). The IEEE LOM standard is probably the most widely used model for annotating learning objects according to a specific metadata scheme. These records present information elements divided into nine metadata categories, including technical, educational and relationships between the learning resources being described. Some account of learning objects as components is underlying the majority of the abovementioned learning technology standards and specifications. Current metadata for such standardized *learning resources* describe the structure, objectives and flow of learning activities and contents in detail, and some of them address the specificities of concrete types of learning resources. As an example, the IMS QTI[2] specification addresses a flexible representation of educational tests.

Consequently, bridging instructional-design theories and technologies for learning objects would bring an increased integration of digital resource development practices with sound instructional criteria. The literature on combining the learning object paradigm with instructional-design theories has grown significantly in recent years (Baruque & Melo, 2003; Cheal & Rajagopalan, 2007; Wiley et al., 2004), however there are few reports on the representation of the instructional theories themselves in a computer-understandable form that realizes a part of the methods and guidelines in actionable form. To this day there is not a way to describe in computer-understandable format the instructional model used to devise and develop those digital resources. Or in looser terms, the instructional guidelines and rationale used to devise them. Languages like IMS learning design (IMS LD) allow the expression of the outcomes of the instructional design process in terms of activities (Allert, 2004), but not the rules, guidelines and methods that led to a concrete learning design. Some possibilities for doing so have been proposed elsewhere (Sicilia, 2006). But the languages to express instructional models are still not available in a form that can be used to check or enforce constraints on actual designs. However, the potential benefits of the practice of recording instructional design information are worth the effort of developing such languages. For example, authoring tools for educational materials can benefit from instructional-design theories and techniques to achieve higher levels of support for the design process (O'Neil, 2008). This can be done by providing the author with wizards or assistants for the creation of new learning designs. These wizards, which could be personalized according to user preferences, would not only guide the designers but also would provide suggestions, design patterns and materials suitable for the instructional theory loaded. They could also be used to check the ongoing design process not permitting actions "against" the theoretical foundations of the model.

This paper provides a starting point for the development of a *language for expressing instructional models* in a form that can be used to contrast digitally-represented learning designs (be them targeted to online, hybrid or face-to-face education). The use of formal ontology languages provides the proposal with precise description-logics based semantics (Baader, Calvanese, McGuinness, Nardi, & Patel-Schneider, 2003) and enables sharing and exploiting such models by means of advanced technologies and tools. Here the main representational issues will be discussed and examples will be used to demonstrate the kind of functionality they enable. However, methods and guidelines in instructional-design theories do not follow a single unified style in their formulation, so that ontology-based models are applied flexibly to cover different kind of design theory statements. The main contribution of the paper is that of describing the directions in which actionable representations of instructional theories that can be used to assemble a collection of ontologies describing the numerous theories reported in the literature.

The rest of this paper is structured as follows. Section 2 provides background material and an insight in the so-called Semantic Web technologies and languages. An understanding on the benefits they provide is essential to understanding the rest of the paper. Section 3 describes the core concepts used to describe what is included in an instructional model, first explaining the most abstract ones, and later unveiling the possibilities that the new models presented provide to software applications in terms of improving the analysis and search of learning designs. Section 4 provides concrete examples to show the potential of instructional design languages. Finally, conclusions and outlook are provided in Section 5.

2. Background

As mentioned in the preceding section, the main objective of this paper is to describe the foundations of a flexible language for the expression of instructional models. It is essential that such language is specifically targeted to provide instructional models with computational semantics if we want to reach a satisfactory degree of interoperability and automated support. As this is not common ground for instructional designers, we will further explain what we mean by computational semantics, and what the benefits we foresee from its use are.

Providing representations of instructional models with computational semantics means to describe those models for software applications to "understand" them (i.e., to be capable to

[2] http://www.imsglobal.org/question/.