Development of a Framework for Quality Instructional Design Ontologies

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Abstract. This paper proposes a framework for evaluating of quality, and guidance in an Instructional Design (ID) ontology development. A systematic search of the e-learning ontologies literature revealed key characteristics and issues relating to the intended purposes of ID ontologies. A synthesis of it contributed to identifying the four crucial elements of Reusability, Personalisation, Quality Assurance and Applicability which was identified as relevant to the modelling, validation and execution processes of the ontology development. The use of this framework would first, inform the development of a quality ID ontology that would meet the needs of both learners and ID authors and second, serve as a guide in evaluating different ID ontologies.

1. Introduction

According to Aroyo and Dicheva (2004), specifying reusable chunks of learning content and defining an abstract way of describing designs for different units of learning (for example, courses and lessons) are two of the most current research issues in the eLearning community, which have been considered as the major barriers to improving eLearning. This study focuses on issues relating to the representation of designs for different units of learning using ontology, that is, instructional design (ID) ontology.

It is well known that developing an ID ontology is quite a complex issue, because there have always been different opinions regarding the concepts which should be included in an instructional design model (Devedžić, 2006). Nevertheless, ID ontology is one of the essential elements which contributes to the delivery of a quality web-based learning experience (Paquette, 2003). ID ontology not only supports the creation of instructional designs that are shareable and reusable between different eLearning systems, but it also enables and facilitates the computational reasoning in them so that the automatic construction of personalised eLearning experience can be achieved (Lama et al., 2005; Amorim et al., 2006).

While ID ontologies have being continuously improved and developed over recent years, researchers have expressed various concerns in their own studies regarding the challenges in developing an ID ontology that makes it possible to fulfil its intended function or purpose. However, none of the studies reported about each ID ontology have referenced other research, or have explicitly built upon the findings of those who have

published previously; thus the findings have not been brought together or compared. Furthermore, none of the researchers have drawn together the issues discussed in the many studies to develop a set of key attributes of ID ontologies which could help solve current eLearning problems. Therefore, this study aims to identify the crucial attributes or elements across all published ID ontology studies and develop a framework based on these elements which could be used for evaluating the *quality* of an ID ontology.

'Quality' is a term that is not usually formally defined (Kim, Fox & Gruninger, 1995). However, it is necessary to define quality in this study for two reasons: first, the definition of the term quality provides a benchmark for the identification of the crucial elements associated with the ID ontology, since these elements contribute to achieve the quality requirements defined for an ID ontology; second, the definition of the term quality provides the measurement for what is accounted to be a quality ID ontology. According to the ISO 9126[1] of the International Organisation for Standardisation, quality is defined as "the totality of characteristics of an entity that bears on its ability to satisfy stated and implied needs" (ISO, 2001, p. 31). This definition is adopted for this study. That is to say, for an ID ontology to be of high quality, it must possess certain characteristics that satisfy its intended function or purpose. The intended purposes of an ID ontology include, but not be limited to: 1) being able to increase the expressiveness of the instructional design and facilitate computational reasoning (Lama, et al., 2005; Amorim at al., 2006); 2) enabling instructional designs to be more easily searched, shared and reused (Knight, Gašević & Richards, 2005); 3) being able to support automatic construction of personalized eLearning experience (Van Marcke, 1992); 4) being able to support the creation of pedagogically sound instructional designs (Mizoguchi & Bourdeau, 2000).

2. Literature Review

In our review of literature, we have looked at the general benefits ontology bring to eLearning, as well as what ID ontology could contribute to solve major eLearning issues. We have identified that the use of ontology contributes to the development of instructional design, though the current literature indicates that an ID ontology is difficult to develop. Nevertheless, while Mizoguchi and Bourdeau (2000) are proposing to identify the minimal agreement for the design of an ID ontology, by examining the purposes of ID ontologies, we have found that researchers have expressed various views regarding the crucial challenges facing development of an ID ontology. These key issues include:

1. whether or not to use concepts hierarchy to improve the reusability of instructional designs;
2. selecting the appropriate language for developing an ID ontology;
3. the need to develop an ID ontology with learning standards in mind;
4. whether ID ontology needs to be related to learning styles;
5. whether ID ontology needs to be related to domain knowledge;
6. the challenges of applying instructional theories in an ID ontology;
7. the need to use axioms in ID ontology;
8. the availability of authoring tools (based on the ontology).

[1] ISO 9126 is the software product evaluation standard from the International Organization for Standardization (ISO, 2001).

None of the researchers have considered these issues in an integrative way to evaluate the developed ID ontologies. The issues identified in our review have also been used to construct the framework that could inform the development of an ID ontology.

3. Methodology

This study was framed by the meta-ethnography method, an interpretive approach for synthesising the findings of ethnographic research conducted in the field of education (Noblit and Hare, 1988). The seven phases suggested within the meta-ethnography method are used to identify the steps of the research design, to synthesize the crucial elements associated with the quality of ID ontology.

Among these steps, to determine the research question we have contacted experts and carried out extensive analysis of a wide range of studies about ID ontology. After that, we identified similar key concepts and features between studies and the elements from that which were considered as crucial by the ID ontology developers. We have summarised it and noted the context of the relevant research in a standard form suitable for the later comparison step. This task was not finished until the end of the synthesis effort, since the list of the crucial elements was developed throughout the research and not complete until the end of the research period.

4. The framework

Through a synthesis of the crucial elements considered in different ID ontologies, a framework was formed for evaluating the quality of ID ontologies. The framework is depicted in Figure 1. The four main categories of Reusability, Personalisation, Quality assurance, and Applicability are shown in relation to the eight crucial elements. The elements and the categories are also depicted in relationship to stages in the development process for an ID ontology. These stages, Modelling, Validation and Execution are considered necessary by Sanchez et al. (2008) for creating an ID ontology.

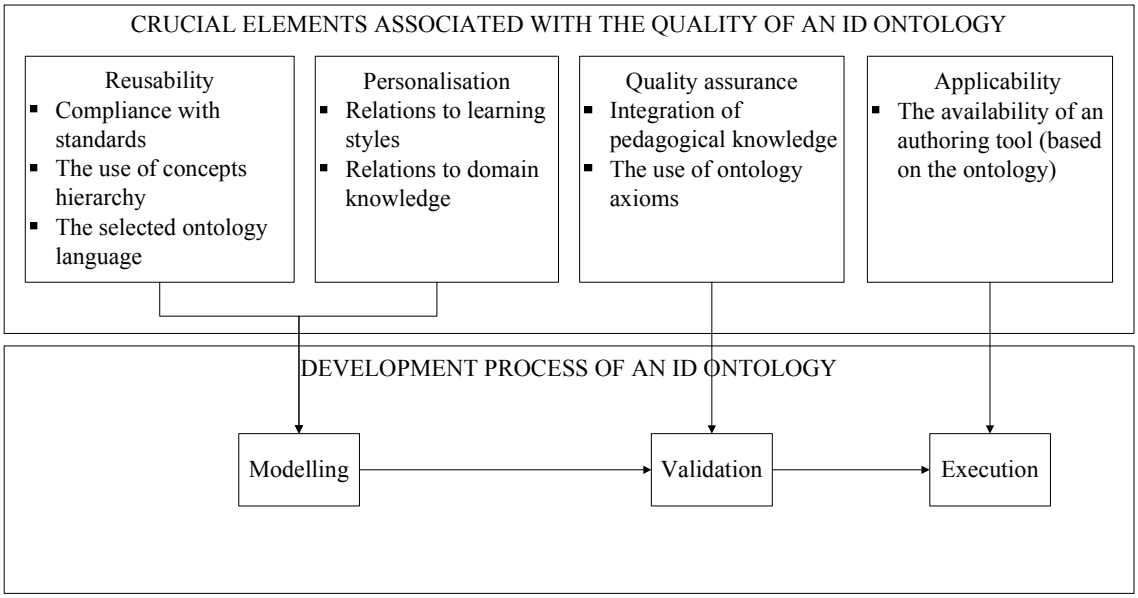

Figure 1. The framework for evaluating the quality of an ID ontology

As shown in Figure 1, Reusability and Personalisation of instructional designs should be taken into account in the Modelling stage of the development of an ID ontology. Reusability involves the consideration of using concepts hierarchy, selecting an appropriate ontology language, and compliance with standards. Personalisation involves consideration of relating the ID ontology to both learning style and domain knowledge. In the Validation stage of the development of an ID ontology, the mechanisms for assuring the quality of the developed instructional design model are considered. This involves the integration of pedagogical knowledge such as educational theories, and the use of ontology axioms to detect the logical consistency between concepts. Lastly, the Execution stage concerns the applicability of the ID ontology, which could be proved (demonstrated) through an authoring tool based on such ontology.

4.1. Selection of the Elements

The elements considered as crucial for developing a quality ID ontology were selected based on consideration of the intended purposes and functions that a quality ID ontology should satisfy. This selection was based on the definition of 'quality' given in study, that is, a high quality ID ontology is required to have certain characteristics that satisfy its intended purposes.

The elements were identified from an examination of four ID ontologies. Brief details of the selected ID ontologies are listed in Table 1.

Table 1. Development Background Details of the Four ID Ontologies

Development Background	ID Ontology			
	IMS-LD ontology	LOCO	ID ontology_Arapi et al.[2]	OMNIBUS
The ontology developers	Lama, Sanchez, Amorim, Vila	Knight, Gašević, Richards	Arapi, Moumoutzis, Mylonakis	Mizoguchi, Hayashi, Bourdeau
Year developed	2005	2005	2007	2007
Construction tool	Protégé	Protégé	Unknown	HOZO
The time the ontology had been in development	< 1 year	< 1 year	Unknown	7 years
The person-years spent in developing the ontology	5	3	5	3

The crucial elements included in the framework were compared across the four ID ontologies, the details of which are shown in Table 2.

Table 2. Comparison Matrix Crucial Elements

[2] *Note*. ID ontology_Arapi et al. is the name given in this research to distinguish the ID ontology of Arapi et al. from the other ID ontologies

Crucial elements	ID ontology			
	IMS-LD ontology	LOCO	ID ontology_Arapi et al.	OMNIBUS
Does the ontology include any concepts hierarchy?	Yes, including the reference class *Item* to learning object, the class *Execution Entity*, and the *Completion Unit*	Yes, including the reference class *Resource Description* to learning object, *the class Abstract Activity* and the *Completion Requirement*	Not available	Yes, many
What modelling language has been used for the ontology?	OWL, F-Logic, SWRL (planned)	OWL	OWL	HOZO, OWL
Was the ontology developed based on learning standards?	IMS-LD	IMS-LD	IMS-LD, LOM	IMS-LD
Is the ontology related to learning style?	No	No	Yes	Yes
Is the ontology related to domain knowledge?	No	No	Yes	Currently no but planned to do
Does the ontology integrate any pedagogical knowledge?	No	No	No	Yes, educational theories
Does the ontology have axioms?	Yes, expressed in F-Logic (design and runtime related)	No	No	Yes, expressed in HOZO (theory related)
Have the ontology got any authoring tool available? Is it user-friendly?	WebLD, the usability is currently being improved.	Not available, but as the authors suggested, they planned to develop (LOCO-Analyst project, 2009)	Learning Design Editor in LOGOS; usability is to be tested	SMARTIES; usability is to be tested

4.1.1 Categorisation of the Elements

The crucial elements in the framework are grouped into four categories, which are Reusability, Personalisation, Quality assurance, and Applicability (see Figure 1). The rationale for this categorisation is elaborated below.

Reusability

While instructional design knowledge is considered to be necessary to any eLearning system, it is important to enable this kind of knowledge to be reused and shared between different systems (Knight, Gašević & Richards, 2006). Increasing the reusability of an instructional design model is considered as one of the intended purposes of any ID ontology (Knight et al., 2005). The first three crucial elements discussed earlier, namely: the concepts hierarchy, the selected ontology language, and compliance with standards make particular contributions to the reusability of instructional designs.

The three elements are all concerned with the reusability of instructional designs. The element ‘the use of concepts hierarchy’ is about the use of abstract class concept for

an ID ontology. Abstract classes help organise a set of specific instructional design knowledge to be reused.

The element 'the selected ontology language' is concerned with the selection of an appropriate ontology language for developing an ID ontology that could be easily adopted in any eLearning system. Based on the evidence found in the four ID ontologies, OWL is considered as a potential modelling language for developing ID ontology since it facilitates the reusability of any ontology between different systems.

The element 'compliance with learning standards' is also concerned with the reusability of instructional design models in different eLearning systems. The IMS-LD specification, as the de facto learning design standard, assures the design model is widely accepted by the other eLearning systems. Therefore, any ID ontologies that are compliant with the IMS-LD are guaranteed to produce reusable instructional design models.

Personalisation

Learning personalisation is another issue which has gained a lot attention in the last few years in the eLearning community (Devedžić, 2006). There is a need to overcome the one-size-fits-all approach, because each learner is unique, that is to say, they have different background knowledge, learning goals, preferences and pace, thus they require a personalised learning environment that can cater for their unique learning needs so that their learning experience become more effective. The settings for this kind of personalisation are fairly restricted in the traditional learning environment (Mizoguchi & Bourdeau, 2000), whereas it is considered to be very achievable in the eLearning environment. Generally speaking, learning personalisation includes tailoring instruction based on learners' requirements and delivering the learning contents that suit their individual learning activities (Devedžić, 2006). Learner Model Ontology which describes learners with respect to learning background, preferences, goals and so on. To achieve true personalisation of instruction, ID ontology needs to interact with the Learner Model Ontology to retrieve the personal information about a particular learner.

In order to be able to produce instructional design models that cater well for each individual learner's needs, the relations to both learning style and domain knowledge are the crucial elements in a quality ID ontology. They are both concerned with the ability to personalise instruction based on the Learner Model Ontology. The element 'relations to learning style' is about relating each instructional design to learning style so that an appropriate instructional design can be selected for learners according to their preferred learning style. The element 'relations to domain knowledge' is about relating each instructional design and their learning activities to the subject domain they belong so the developed instructional design model can be selected according to the domain information specified in the learner's profile. Since both elements are concerned with the personalisation aspect of instruction, they are grouped under the category named Personalisation.

Quality Assurance

A valid instructional design model usually requires inclusion of certain concepts that are necessary for describing any teaching and learning actions. For example, a valid IMS-

LD model needs to include the core concepts *Learning Objective, Method, Learning Object, Learning Design, Activity* and *Role* (Koper & Olivier, 2004). In relation to developing pedagogically sound instruction, Mizoguchi and Bourdeau (2000) point out the necessity of integrating educational theories into instructional design models since this would assure the quality (effectiveness) of these. However, the question is how to ensure that an instructional design model is both concept-valid as well as theory-valid. Traditionally (before the development of instructional design models using ontology), software programmers usually had to understand the description of the model, and then write its logic and concept constraints into the programme code. Although validation could be done in this way, the flexibility in terms of applying and updating different instructional design models would be lost if they were not understood by the system but only the programmers themselves, since these instructional design models are usually required to be updated frequently. The current way to detect logical consistency using ontology is by the application of ontology axioms (Lama, et al., 2005; Amorim et al., 2006; Mizoguchi, Hayashi, & Bourdeau, 2007). Axioms are used for representing knowledge which has to be accepted without proof (Mizoguchi, 1998) and provide semantic constraints among concepts along with rigorous definition of concepts (Mizoguchi & Bourdeau, 2000).

'The use of ontology axioms' and 'integration of pedagogical knowledge' are both focused on assurance of the quality of developed instructional design models. The element 'the use of ontology axioms' is included in this category because it concerns the use of axioms to detect the logical consistency in an instructional design model. For example, the axioms can be used to ensure an instructional design model is IMS-LD compliant by configuring the IMS-LD related concepts. This would ensure the relationships between IMS-LD concepts are appropriately expressed in the developed instructional design model. The element 'integration of pedagogical knowledge' relates to the use of pedagogical knowledge such as educational theories to improve or assure the effectiveness of any instruction. It helps develop pedagogically sound instructional design models as well as their overall quality. Thus, it was also considered as one of the quality assurance elements.

Applicability

It is important to consider whether an ID ontology could be easily applied in any authoring system. The various authoring tools help execute (interpret) an ID ontology for producing valid instructional design models. Depending on the complexity of a particular ID ontology, a specific authoring tool is usually developed for its implementation. It would be advantageous if an ID ontology is *standardised* so that it can be executed in any authoring tool, which implies its wider applicability. Alternatively, an ID ontology should have a fully compatible authoring tool to ensure its successful implementation if it cannot be implemented in the other authoring tools. The crucial element 'the availability of an authoring tool based on the ontology', is concerned with the application of ID ontologies, thus it is grouped in the category named Applicability.

Expert Feedback on the Framework

The developed framework was sent to two experts for validation to ensure its credibility. In particular, one of the experts suggested deleting the Usability category as well as the element included in the initial framework – 'inclusion of context information'. He considered information about context is more relevant and important for personalisation of instructional design, since it indicates in which circumstance a particular instructional design was or was not useful for a particular student. The researcher thus decided to place the element 'inclusion of context information' into the personalisation category. However, it was found that this element created duplication with the other elements in the category, 'relations to learning style' and 'relations to domain knowledge', because context information also includes the information about learning styles and domain knowledge. For this reason, the element 'inclusion of context information' was completely removed from the framework.

5. Conclusion and future work

The aim of this study was to identify the elements considered as crucial for a quality Instructional Design (ID) ontology. Based on consideration of these crucial elements, this study also formulated a framework for evaluating the quality of ID ontologies by synthesising the identified crucial elements. It was expected that such a framework would provide a guideline for practitioners to develop and evaluate any ID ontology, since the framework describes the crucial elements for an ID ontology as well as the steps suggested for considering these in relation to the development process.

Through an examination of four ID ontologies, this study identified eight elements as crucial to helping meet the intended purposes of an ID ontology were grouped into four categories, which are Reusability, Personalisation, Quality assurance, and Applicability. In considering quality in relation to the development stages of an ID ontology, the elements included in both of the reusability and personalisation categories are of relevance in the modelling stage, whereas the elements in quality assurance category are important at the validation stage, those under applicability category are relevant to execution stage.

The quality framework described was validated by two experts after it was developed. The feedback received from the experts mainly related to potential ambiguity in some terms used in the framework as well as the moving of one element to a different category, though this subsequently removed all together.

5.1 Limitations

The limitations of this study relate first, to the method of analysis and the problem of gaining a full understanding of the context thus a potential failure of identifying key framework categories. This was mitigated by applying analyst triangulation. Second, the reliance on publicly-available information on ID ontologies could have limited the study. However by downloading each of the ontologies and on-going communication with the developers, this problem was minimised. Third, the potential for researcher bias was identified, so the reproducibility of the synthesis is suggested for future research. Finally, the meta-ethnography approach has only recently been used and some processes may be ill-defined.

5.2 Implications and Future Work

This research has presented a framework, based on categories and their crucial elements considered necessary for a quality ID ontology. The research findings could be replicated (and updated with newly-developed ID ontologies). In this way the reliability and validity of the quality framework would be further validated. This study noted that the current ID ontologies have mostly involved developers of advanced technology groups. The majority of them have not involved educational practitioners. Since the purpose of ID ontology is to solve problems for teachers and course designers, future research projects could include the practitioners. In this way the ID ontology is more likely to prove useful and meets the needs of the educationalists, thus better responding to teaching and learning needs. The evaluation framework developed in this research for assessing the quality of an ID ontology could be implemented in future ID ontologies.

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References

Amorim, R., Lama, M., Sánchez, E., Riera, A. y Vila, X. A. (2006). A Learning Design Ontology based on the IMS Specification. Educational Technology & Society, 9(1):38–57.

Aroyo, L., & Dicheva, D. (2004). The new challenges for e-learning: The educational semantic web. *Educational Technology & Society, 7*(4), 59-69.

Atkins, S., Lewin, S., Smith, H., Engel, M., Fretheim, A., & Volmink, J. (2008). Conducting a meta-ethnography of qualitative literature: Lessons learnt. *BMC medical research methodology, 8*(1), 21.

Devedžić, V. (2006). *Semantic web and education*. New York: Springer.

Hayashi, Y., Bourdeau, J., & Mizoguchi, R. (2008, Nov. 27-31). *Toward Accumulation of Learning/Instructional Design Knowledge for Authoring Systems.* Paper presented at the Proceedings of 16th International Conference of Computers in Education (ICCE'08), Taipei, Taiwan.

ISO (2001). *International Standard ISO/IEC 9126-1: Information technology - Software product evaluation - Quality characteristics and guidelines for their use*. Geneva: International Organization for Standardization, International Electrotechnical Commission

Kim, H. M., Fox, M. S., & Gruninger, M. (1995). *An ontology of quality for enterprise modelling.* Paper presented at the Proceedings of the Fourth Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises, Berkeley Springs, WV, USA.

Knight, C., Gašević, D., & Richards, G. (2005). Ontologies to integrate learning design and learning content. *Journal on Interactive Media in Education, 2005*(07).

Knight, C., Gašević, D., & Richards, G. (2006). An Ontology-Based Framework for Bridging Learning Design and Learning Content. *Educational Technology & Society, 9*(1), 23-37.

Koper, R., & Olivier, B. (2004). Representing the learning design of units of learning. *Educational Technology & Society, 7*, 97-111.

Lama, M., Sanchez, E., Amorim, R. R., & Vila, X. A. (2005). *Semantic description of the IMS learning design specification.* Paper presented at the Proceedings of The International Workshop on Applications of Semantic Web Technologies for E-Learning.

LOCO-Analyst project (2009). Learning Object Context Ontologies - The LOCO Framework Retrieved March 22, 2009, from http://iis.fon.bg.ac.yu/LOCO-Analyst/loco.html

Mizoguchi, R. (1998). Towards Ontology Engineering. *Journal of Japan Society for Artificial intelligence, 13*(1), 9-10.

Mizoguchi, R., & Bourdeau, J. (2000). Using Ontological Engineering to Overcome Common AI-ED Problems. *IJAIED, 11*(2), 107-121.

Mizoguchi, R., Hayashi, Y., & Bourdeau, J. (2007, July 9). *Inside Theory-Aware and Standards-Compliant Authoring System.* Paper presented at the Proceedings of The Fifth International Workshop on Ontologies and Semantic Web for E-Learning (SWEL'07), Marina del Rey, CA, USA.

Noblit, G. W., & Hare, R. D. (1988). *Meta-Ethnography: Synthesizing Qualitative studies*. Newbury Park, CA: Sage.

Paquette, G. (2003). *Instructional Engineering for Network-Based Learning*. San Francisco: Pfeiffer/Wiley Publishing Co.

Pawlowski, J. M., & Bick, M. (2006). Managing & re-using didactical expertise: the didactical object model. *Educational Technology & Society, 8*(1), 84-96.

Sanchez, E., Lama, M., Amorim, R. R., Vidal, J. C., & Novegil, A. (2008). On the use of an IMS LD ontology for creating and executing Units of Learning: Application to the Astronomy case study. *Journal of Interactive Media in Education*.

Van Marcke, K. (1992). *Instructional Expertise.* Paper presented at the Proceedings of the Second International Conference on Intelligent Tutoring Systems, Montreal, Canada.