UNIVERSIDAD DE LA REPÚBLICA
FACULTAD DE INGENIERÍA

Una Ontología para el Diseño Universal del Aprendizaje

Autor: María Viola Deambrosis

Trabajo de Tesis para la obtención del
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Director de Tesis: Regina Motz

Centro de Posgrados y Actualización Profesional en Informática,

Instituto de Computación, Facultad de Ingeniería,

Universidad de la República

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A Regina, quien supo rescatarme y devolverme el gusto por el aprendizaje continuo, sumando su calidez humana y generosidad en compartir su *expertise*.

Resumen

El Diseño Universal para el Aprendizaje (DUA) son recomendaciones que tienen como objetivo garantizar el acceso a los contenidos para todos los estudiantes. El DUA establece principios para el desarrollo y uso pedagógico de los recursos educativos que respetan las diferencias individuales en la forma de aprender. Sin embargo, los profesores generalmente tienen dificultades para encontrar o adaptar los recursos educativos a todos los estudiantes. Una ontología de dominio en DUA es una herramienta adecuada para ayudar a identificar las adaptaciones necesarias que se deben realizar en los recursos educativos para satisfacer a todos los estudiantes. Esta tesis presenta, a partir de una investigación bibliográfica sistemática sobre ontologías de educación accesible, el diseño de UDLOntology, una ontología en el dominio de DUA. La UDLOntology es desarrollada en OWL, utilizando el editor Protégé, y se describe su utilidad para inferir los recursos educativos que mejor se adaptan a habilidades de aprendizaje específicas, de acuerdo con las recomendaciones del DUA.

Palabras claves

Ontología, Diseño Universal para el Aprendizaje, Habilidades en el aprendizaje, Educación equitativa.

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An Ontology for

Universal Design for Learning

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ABSTRACT

The Universal Design for Learning (UDL) are recommendations that aim to guarantee access to content for all students. The UDL establishes principles for the development and pedagogical use of educational resources that respect individual differences in the way of learning. However, teachers generally have difficulties to find or adapt educational resources to suit all students. A domain ontology in UDL is a suitable tool to help in identifying the necessary adaptations that must be made in educational resources to satisfy all students. This thesis presents, based on a systematic bibliographic investigation on accessible education ontologies, the design of UDLOntology, an ontology in the domain of UDL. The UDLOntology is developed in OWL, using the Protégé editor, and its usefulness is described to infer the educational resources that are best adapted to specific learning skills, according to the UDL recommendations.

Keywords

Ontology, Universal Design for Learning, Learning Abilities, Equity Education

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Abbreviations

EFA: United Nation’s Education for All

ICT: Information and Communication Technology

UDL: Universal Design for Learning

SDG4: Sustainable Development Goal 4

IMS AfA: IMS Access For All

PNP IMS: Personal Need & Preferences

DRD IMS: Digital Resource Description

1. Introduction

Education is a basic human right enshrined in the 1948 Universal Declaration of Human Rights. It is the foundation for a more just society and a basis for people's freedom and full contribution to society. Throughout the last two decades, the international community has been working hard to encourage equality of opportunity and universal access to education. Particularly, within Global Education 2030 Agenda based on the United Nations' Sustainable Development Goal 4 on education, the Education For All movement is working to "ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" (UNESCO, 2015).

However, one in five people is still excluded from education. According to UNESCO (UNESCO, 2015), "more than 262 million children and youth are out of school, six out of ten are not acquiring basic literacy and numeracy after several years in school, and 750 million adults are illiterate", mainly due to disabilities, social, cultural, and economic factors.

Adding to this context, the outbreak of the COVID-19 pandemic has further exposed and deepened inequalities and the fragility of the education systems. This pandemic led most governments to adopt various measures to mitigate the risk of contagion. One of the first adopted measures was the suspension of face-to-face classes, which challenged teachers to reconfigure the planning of their classes to virtual platforms, marking undoubtedly a turning point in the integration of ICT in education. Moreover, this "new reality" is further exacerbating educational exclusion, mainly due to the digital divide and critical social contexts. Teachers, students, curricula, institutions, are barely prepared for immediate implementation of virtual classes, even less for digital pedagogies. ICT now is, even more, deeply linked to almost every aspect of daily life, and education is not an exception. Today's virtual education scarcely acknowledges a quality, universal, and equal access education, where educational resources must be accessible and understandable by all people.

Universal Design for Learning (UDL) combined with ICT is a way to mitigate the problem of education exclusion. UDL is a framework that aims to guarantee access to content for all students. Thinking and believing in the universality of education and betting on individual learning skills and strengths rather than disabilities, implies a paradigm shift and therefore a great challenge. This shift allows for talking of "education in the diversity" rather than "inclusive education" and incorporates as well important advantages for learners and educators. From the learner's side, one advantage is to highlight and work on positive aspects by identifying learners with characteristics that empower the human being like skills and strengths. Another advantage is preserving the students' privacy by avoiding the need to ask them to select their disabilities to determine their learning profile. The educators´ side allows for a curricula's universal design by focusing on aspects of learning and teaching, instead of disabilities. As mentioned by Maden (2011) addressing individuals by their strengths and skills has shown a positive impact on students' commitment, hope, and academic performance.

Universal Design for Learning (UDL) establishes some principles for the development of learning environments that respect individual differences in the way of learning. Among them, the multiple means of representation to provide alternatives in the presentation of educational resources. In this context, digital resources have contributed and facilitated the creation of educational content with different forms of representation (texts, images with alternative texts, audios, etc.). However, teachers generally have difficulties finding or adapting educational resources to fulfill all learners, often due to a lack of knowledge on accessibility guidelines. Our main goal is to develop tools that assist teachers in this task.

Ontologies, as part of W3C, are being used in the domain of education for over 20 years. They "are a set of concepts and categories in a domain that shows properties and the relations between them" (Guarino, 1998). Ontologies are suitable to be used with reasoning engines and recommenders and to assist teachers to identify the necessary adaptations to be made in education resources aimed at inclusion. Following this approach, this thesis design and develops an ontology in the domain of Universal Design for Learning: UDLOntology.

UDLOntology can assist to infer educational resources that best suits specific learning abilities and skills, based on UDL recommendations. This proposal intended to be a teacher reference for inclusive curriculum design, content design, and assessment, based on learning abilities instead of disabilities.

As depicted in Figure 1, an inclusive educational framework is then a user centric framework, where both, the learner and the teacher, are the main actors. The learner defines its learning abilities, and the UDL Graphic Organizer Component presents educational material from the repository based on UDLOntology inferences. The teacher, at the time of curricula, and/or evaluation design, is assisted by the UDL Graphic Organizer Component providing UDL Guidelines Recommendations for specific learning abilities based on UDLOntology inference. UDLOntology is thought to be of assistance for teachers for designing curricula, and/or assessments, as well for students to interact with educational resources that best suit their learning skills and abilities.

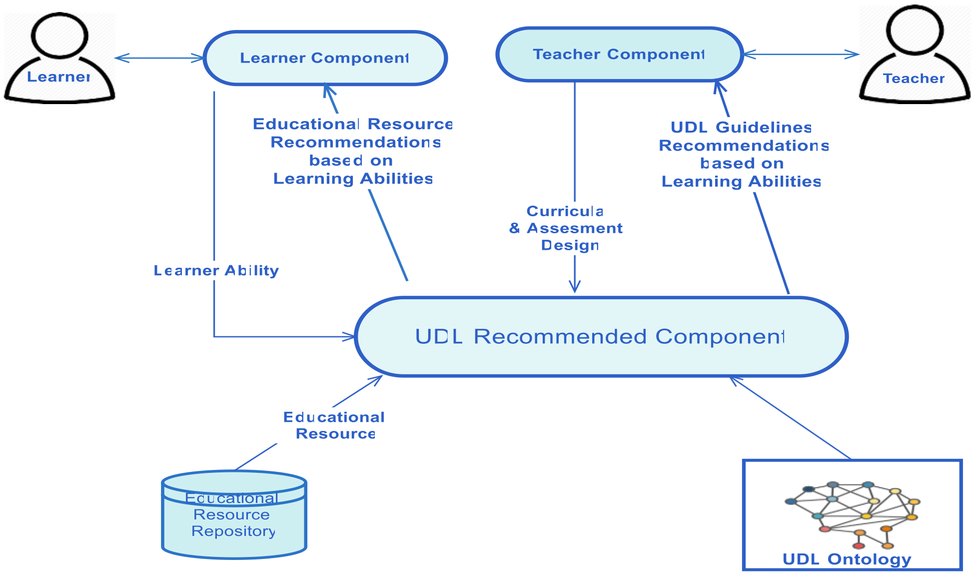


Figure 1 User centric inclusive educational framework.

The contribution of this thesis is twofold: first, we carry out a systematic bibliographic mapping on the use of ontologies for inclusive education, where we conclude that there is no ontology in the UDL domain, nor an ontology for intellectual disability in learning. Second, we designed and developed an ontology for the first phase of the UDL guidelines specialized for Down syndrome.

Published results of this thesis are:

- M. V. Deambrosi, R. Motz and M. A. Eliseo, "Why the Universal Design Learning needs an Ontology?," *2020 15th Iberian Conference on Information Systems and Technologies (CISTI)*, Sevilla, Spain, 2020, pp. 1-6, doi: 10.23919/CISTI49556.2020.9141109.
- M. V. Deambrosi, R. Motz and M. A. Eliseo, "UDLOntology: An ontology for education in the diversity", 2021 In: International Conference on Information Technology & Systems, to be held in Península de Santa Elena, Ecuador, 10 - 12 February 2021 (to be published).

The rest of this document is organized as follows. Chapter 2 presents background concepts of Universal Design for Learning and how it can be used to learners with intellectual learning disabilities. Chapter 3 is an introduction to ontologies, and a literature review of ontologies in the domain of education and disabilities. The result of this review shows that most of the works are restricted to model accessibility to educational content in relation to the use of assistive devices and according to the W3C web accessibility recommendations (WCAG 2.0 , 2020) and (WAI- ARIA , 2020) for hearing, visual and motor disabilities. Chapter 4 presents the design process for UDLOntology. First, it is introduced the UDL framework, and a detail description of its guideline recommendations and checkpoints. Then, there is a description of the learning abilities and strengths to be used to verify the adequacy of the ontology in the inference of specific educational materials for these skills. Finally, Chapter 5 gives some conclusions on how UDL addresses learning abilities and presents some possible future works.

2. Background

This chapter presents the main inputs to design the UDLOntology. It is organized in three sections as follows: the first one presents the UDL framework and describes how is it is used. The second section introduces learning abilities common to people with intellectual disabilities, and the third section suggests how UDL can address the learning abilities identified in the second section.

2.1. Universal Design for Learning (UDL)

UDL has its origin in the Universal Design (UD) movement of architects and designers in the 1990's. In 1988 the architect Ronald Mace defined UD as "the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design" (ACCESS, 2011). The UD philosophy was an important "turning point" in the field of education. Elementary school teachers and university professors alike adopted UD concept "as a conceptual and philosophical foundation on which to build a model of teaching and learning that is inclusive, equitable, and guides the creation of accessible course materials" (ACCESS, 2011) .

The Center for Applied Special Technology (CAST) was created in 1984 by Anne Meyer. It became a reference on applying the principles of UD for education through UDL. UDL is a set of principles for designing curriculum that provides all individuals with equal opportunities to learn regardless of ability, disability, age, gender, or cultural and linguistic background. It is based on foundational research within the neurosciences, developmental psychology, and learning differences (Rose & Gravel, 2010). UDL is based on the neuroscience research which has identified three primary neurological networks that have a successful impact on the learning: the affective network that impacts the why of learning, the recognition network that impacts the what of learning and the strategic network that impacts on the how of learning. Successful teaching and learning consider teaching and learning through all three networks simultaneously (T. E. Hall, Meyer, & Rose, 2012). The UDL framework is grounded on the following three principles: engagement, representation, and action and expression, that are expanded into more detailed guidelines and checkpoints. Checkpoints supports teachers on the implementation of UDL, by providing detail samples that extends beyond the guideline's definitions.

Engagement presents ways to increase relevance, foster persistence, and build self-regulation skills. According to Meyer et al. (2014) "Affect represents a crucial element to learning, and learners differ markedly in the ways in which they can be engaged or motivated to learn. There are a variety of sources that can influence individual variation in affect including neurology, culture, personal relevance, subjectivity, and background knowledge, along with a variety of other factor". Representation addresses the provision of information in varied modalities and an attention to the background information and prerequisite knowledge and skills that students need for comprehension. Action and expression address the use of tools, media, and technologies for expression and demonstration of knowledge.

In 2018 CAST released an updated version of the UDL guidelines that leads “ to develop “expert learners” who are, each in their own way, resourceful and knowledgeable, strategic and goal-directed, purposeful and motivated’ (UDL, 2020), as shown in Figure 2.

Figure 2 UDL Graphic Organizer (Cast,2020).

UDL guidelines recommendations promote presenting the information in multiple ways to ensure accessibility and inclusion. However, it is not enough to present different ways to access and understand the information. There is the need to offer students with alternatives to express what they have learnt, show their accomplishments, and interact with other students. Motivation for learning cannot be forgotten either. The lack of engagement and commitment is another important aspect of exclusion and school dropouts. There is the need to offer students participation and encouraging them to manage their own learning.

Based on the updated UDL principles described above, Marquez (2020) defined ‘Rueda DUA 2020’ (2020 UDL Wheel), a Technology Resources Wheel organized around the three principles of UDL. It is a facilitator for teachers when designing educational material, and for students when learning. The UDL Wheel, as seen in Figure 3, is graphically represented as a circle divided into three equals parts, where each part is associated with one of the UDL principles: Engagement, Representation, and Action & Expression. In turn, each third is divided into three equal parts, where each part is associated with one of the three strategies to apply in each principle: from access, from building the knowledge, and from the internalization of the knowledge. In the third of Engagement, there is Recruiting Interest from the access aspect, Sustaining Effort & Persistence from the building aspect, and Self-Regulation from the internalization aspect. In the third of Representation, there is Perception from the access aspect, Language & Symbols from the building aspect, and Comprehension from the internalization aspect. In the third of Action & Expression, there is Physical Action from the access aspect, Expression & Communication from the building aspect, and Executive Function from the internalization aspect. Within the nine partitions, a variety of applications and resources are listed as possible tools to be used in each of the strategies of the principles. The resources presented Engagement respond to the why for learning. They are valuable tools for teachers to use to motivate students to keep learning in different ways, and for students to use to maintain their interest and motivation. As per Representation, they are applications that allow access to information from multiple routes. It supports what to teach. They are intended to be used for teachers. And lastly, the applications in Action &

Expression respond to the how-to learn, thought to be used for students to express their learning in an alternative format.

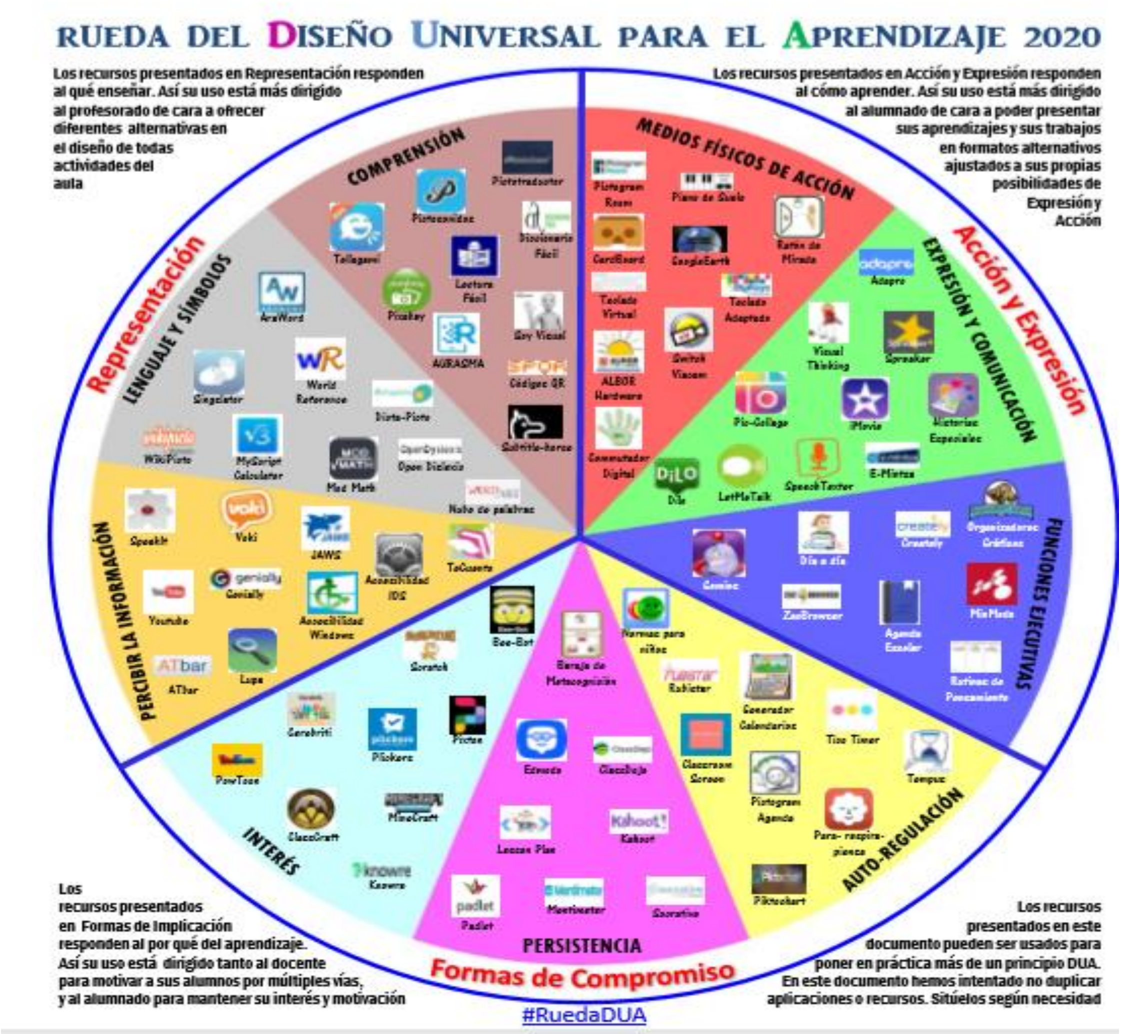


Figure 3 RUEDA DUA 2020 - DUA Wheel (Marquez, 2020).

2.2. Learning abilities and strengths within people with intellectual

disabilities

This section discusses learning abilities and strengths modelled in UDLOntology. It presents those characteristics shared in varying degrees by individuals with intellectual disabilities working towards an equity education. Intellectual disabilities are closely related to difficulties in cognitive functions, necessary functions to process information from the environment, with the aim of organizing behavior and communicating with other people.

In this work, we focus on the learning abilities of people with Down syndrome. Besides having their own individual talents and aptitudes, they share some areas of strength and cognitive characteristics as depicted in Table 1. Some of their areas of strength are strong visual awareness and visual learning skills, ability to learn and use sign, gesture and visual support, ability to learn and use the written word, ability to learn from pictorial, concrete and practical materials, and routine (Down Syndrome International, 2020). As for cognitive learning aspects perception, attention, memory, and reading are the ones we mentioned in this work. From the perception aspect, they have a better ability to capture information through visual perception. Consequently, it is recommended to provide alternative visual options such as images, videos, and pictures for better comprehension. From an attentional perspective, they have difficulty fixing attention and focusing it. They also are easily distracted interfering with the learning process. Some of the learning recommendations are to keep the working framework and digital resources simple and to avoid as many distracting stimuli as possible. Another important recommendation is to provide clear and precise instructions, that require short attention time. As mentioned in perception, it is important to rely on alternative input channels to improve memory.

Regarding literacy, clear and concrete instructions empower their abilities to work with a high degree of rigor and detail in a specific activity. They literally understand what they read, allowing the use of precise information to work abstraction and conceptualization. The DUA Wheel is proposed as a useful and easy-to-use toolbox to identify which resources are available and appropriate to recommend for perception strategies when designing educational resources. The following communications resources are recommended: Easy Read stands out, as a tool for reading comprehension that facilitates access to information, Pictograms and Augmentative and Alternative Communication Systems (AAC) to facilitate the understanding of texts and environments. W3C and WAI recently presented standards and recommendations on cognitive web accessibility (WEBAIM 2020; WAI-AIRA 2020).

Table 1 Guidelines for Learning Abilities to people with Down Syndrome.

Learning Abilities	Guidelines
Attention	Schedule exercises to increase attention span. Use motivating, varied and enjoyable activities. Eliminate distracting stimuli. Present the elements one by one. Avoid sending different messages and stimuli at the same time. Give time to respond (possible delay to respond).
Memory	Train memory expressly. Provide strategies as subvocalize, repeat, associate, group by category. Give help (graphics, lists, photographs). Practice daily.
Perception	Present information in a multisensory way. Use visual references: images, drawings, graphics. Employ observation or vicarious learning. Model what it has wanted them to be learnt. Use short expressions and simple words.
Cognition	Send clear, concise, direct and non-double-meaning messages. Explain even the simplest. Have planned the generalization and maintenance of learning. Instructions, messages and orders must be brief, simple and specific.

2.3. How UDL addresses learning abilities

To identify which UDL guidelines can better address people with Down Syndrome abilities we consider the following questions:

1) For perception perspective: What are the senses through which the learners in study can better process or perceive the information?
2) For attentional perspective: How is the context that better stimulates their attention at the time of learning?
3) For memory perspective: Which techniques are better suited to improve memory?
4) For literacy perspective: What are the characteristics of the contents for a better abstraction and conceptualization of concepts and ideas for learners in study?

To answer the above questions, we refer to the UDL Organizer presented in Figure 2 and Down syndrome learning characteristics, abilities, and strengths presented in Table 1. To answer the first question, *What are the sense through which the learners in study can better process or perceive the information*?, as depicted in Table 1, their strength is on capturing the information through visual perception. As stated by Meyer et al. (2014), “to ensure access to learning it is important that key information is equally perceptible to all learners by providing the same information through different modalities”. Such multiple representations ensure that information is easier to access and comprehend for many ways of perceptions. Reviewing *Appendix B*, as per the learners in study, they have better ability to capture information through visual perception as mentioned before. Therefore, alternative options such as images, videos, and pictures are recommended for a better comprehension as recommended checkpoint 1.2 (see list of checkpoints in Table 2 and Appendix B). To answer the second question *How is the context that better stimulates their attention at the time of learning?* visual alternatives for sound is recommended. For this scenario, checkpoint 1.2 is also the adequate recommendation. For the third question, W*hich techniques better suit to improve memory*?, information transmitted solely through sound is not recommended for learners who need more time to process information, or who have memory difficulties. So as per the first question, it is also recommended to provide visual alternatives whenever feasible. Lastly, to answer question, W*hat are the characteristics of the contents for a better abstraction and conceptualization of concepts and ideas?*, educators can address it by applying UDL Guideline (Figure 2) more specifically the recommendation: "Clarify syntax, instructions and vocabulary, and Illustrate through multiple media". Checkpoint 2.1, 2.2 and 2.5 are adequate alternatives. Table 2 presents an overview of these relations.

Table 2 Relation between Down syndrome learning abilities and UDL Guidelines

Learning aspects	Strength & Abilities	Learning abilities	UDL Guideline	UDL checkpoint recommendation
Perception	They have better ability to capture information through visual perception	Visual Multimedia media ilustrations	1: Perception Offer visual means of representation to sound and voice.	1.2: Share information in more ways than sound and voice alone
Attention	They better work within simple framework and minimum stimuli. They are strong at clear and consice instructions	EasyRead Pictogram AAC	1: same as perception 2: Language & Symbols Clarify vocabulary and symbols	1.2: same as perception 2.1 : Construct meaning from words, symbols, and numbers using different representations
Memory	They have better ability to capture information through visual perception	Visual Multimedia media ilustrations	1: Same as perception	1.2 same as perception
Literacy	Provide alternative representations that clarify the syntactic or structural relationships between elements of meaning. Recommended communications resources : Easy Read and AAC	Clear syntax instructions and vocabulary	2: Language & Symbols Clarify syntax and structure Ilustrate through multiple medias	2.1 : Same as memory 2.2 : Make the patterns and properties of systems like grammar, musical notation, taxonomies, and equations explicit. 2.5 : Make learning come alive with simulations, graphics, activities, and videos

3. What are ontologies?

The term "ontology" in computer sciences (CS) is borrowed from philosophy, where ontology is defined as the study of being or existence. According to Gruber (1993) ontologies from a philosophical point of view do not depend on a specific language. Gruber introduced the term ontology as "*an explicit specification of a conceptualization" (*Gruber, 1995*)* where conceptualization refers to the objects, concepts, and other entities that are assumed to exist within some domain of interest and the relationships that hold among those entities. By way of an alternative, Nicola Guarino proposes another definition. An ontology is an engineering artifact constituted by a specific vocabulary to describe a particular reality (Guarino, 1998). He states ontology as "a formal, explicit specification of a shared conceptualization processable by a computer program". In *What Is an Ontology,* Guarino (2004) expands these concepts. He identifies conceptualization as an abstract model of any phenomenon by identifying the relevant concepts of that phenomenon, while he associates formal to the fact that the ontology should be machine readable, excluding natural language. Explicit states that concepts may be clearly and in detail expressed. In addition, the concept of shared expresses that the modelled knowledge is accepted by a group. This is very important for standardization, a key requirement for achieving system interoperability. Ontologies contribute on the communication and understanding among people, organizations, and applications since they provide a common understanding of a domain. Ontologies also allow to share the knowledge of a domain, overcoming differences in terminologies. They also contribute to the organization and access to information through specific query languages and reasoning engines that produce knowledge inferences. For constructing ontologies, it is necessary to represent the knowledge of a domain in such a way that it is readable by computers, consensual and reusable in different contexts (Guarino, 2009). Ontologies allow to share the knowledge of a domain, overcoming differences in terminologies. It also contributes to the organization and access to information through specific query languages and reasoning engines that produce knowledge inferences.

Typically, an ontology consists a finite list of terms and relationships between them. Terms denote domain concepts and are organized into classes of objects, which in turn have a hierarchy. In addition to relationship between classes, the ontology includes information on *properties, rules,* and *individuals. Properties* of the classes describe the relationships between the individuals of those classes, and *datatype properties*, describe the relationships between an individual of that class and a value. *Rules* define limitations of the properties and *individuals* are the instances of classes (Feilmayr & Wöß, 2018).

3.1. Domain ontologies

There are numerous areas where the use of ontologies proves to be useful. One scenario is to allow Web tools to gather information that has more clearly defined meaning and, in this way, match the users' needs more closely. They have also been widely used in disciplines such as business, finance, health, and industry. Moreover, ontologies are highly suitable for supporting educational-technology systems (Sampson et al., 2004), (Aroyo et al., 2002). For more than 15 years they are being used to model the use of assistive devices for web accessibility, and to assist teachers to identify the necessary adaptations to be made in education resources. However, they are barely used to model educational content accessibility and even less the UDL.

We perform a systematic literature review searching for domain ontologies in education and accessibility presented in Annex A, that produces results as depicted in Figure 4, disjunction sets of ontologies for Learning and ontologies for Disabilities. From this search we produce the analysis presented in the following sections.

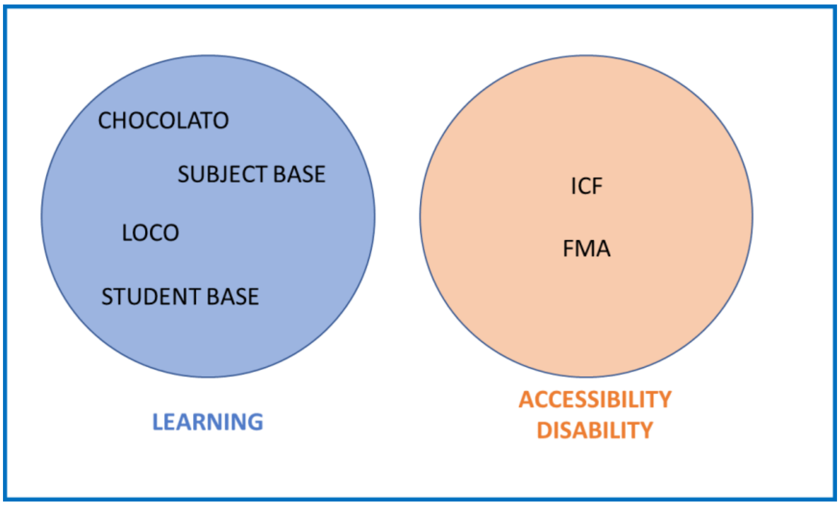


Figure 4 Ontologies in the domain of Learning and Accessibility for Disability

3.1.1 Accessibility and Disability Ontologies

Ontologies in accessibility and disability were developed for different purposes. There are ontologies that focus on standard accessibility for disabilities guidelines, others define mappings of user preferences to assistive devices, and others are concerned with web content reformatting. Reference ICF (2020) and FMA (2020) are two ontologies used for defining and describing disabilities. They contain body functions and disabilities from a medical perspective. These ontologies can be used to describe different types of disabilities and to specify user capabilities and needs. International Classification of Functioning, Disability and Health (ICF) (ICF, 2020) was created specifically to model user accessibility and assistive technologies as described below. It models a unified and standardized language as per the World Health Organization (WHO) (WHO, 2020) standards, into the interaction between humans and devices within the context of the information society (Billi, 2006).

3.1.2 Education Ontologies

Ontologies in education were developed and used for different purposes as well. They play an important role providing metadata for key concepts and entities in the learning domain, allowing for a richer description and retrieval of learning content, facilitating exchange, and sharing of learning content, personalizing and recommending learning content, designing curricula, and assessment of learning (Kizilkaya et al., 2007). Many ontologies are constructed for the education domain like EduOnto (Qin & Hernández, 2004) an ontology for Educational Resources, or OntoEdu (Guangzuo et al., 2004) an ontology based on education grid system for e-learning. Mostly of the ontologies constructed in education domain are used for E-learning system.

Ontologies have an important role in instructional design and the development of course content as well. They can be used to represent knowledge about content, supporting instructors in creating content or learners in accessing content in a knowledge-guided way (Boyce & Pahl, 2007).

Ontologies present important benefits for learners and teachers. When referring to ontologies for the education domain, we mention their benefit towards the organization of educational materials around semantically annotated learning objects (Nejdl, 2001). In addition, learning objects can be easily organized into personalized courses and being accessible for students according to their ontology-based profile and needs as well. According to Wilson (2002) there are important benefits of using ontologies in the education domain for both learners and teachers. When thinking on learners, ontologies can provide students searching support for relevant material on the Web, by directed intelligently towards resources of relevance especially when their understanding of a topic is low. In addition, ontologies can be used as part of a broader system to intelligently guide learners from one topic to another, suggesting related subjects along the way, and by helping them to visualize and comprehend the relationships between concepts in a domain, as understood by more experienced practitioners. This can trigger "associative ways of processing, reflecting and analyzing information" (Aroyo et al., 2002). As per teachers, the information can be shared across educational applications, providing frameworks to reuse learning objects and pedagogical curricula, and resources syntactically different but semantically similar can more easily be located and recommended (Motz et al., 2004). Another important benefit for teachers is for designing, assessing, and reviewing curriculum. They are also useful for modelling specific learning subjects. Ontologies are also of great assistance allowing to personalized courses considering needs, preferences, and context. From the wide variety of works that use ontologies in the domain of education, we present below the contributions from some of these works that we find relevant according to the scope of this thesis.

In (Guangzuo et al.,2004), the authors present OntoEdu, an ontology in the domain of Education for e-learning. This ontology is divided in two parts: activity ontology that describes the activities and operations of education and relations and material ontology that describes the educational content organization. Furthermore, OntoEdu describes educational terms and their relations.

CHOCOLATO (Isotani et al., 2013) is an ontology for the domain of pedagogies. Its name comes from Concrete and Helpful Ontology-aware Collaborative Learning Authoring Tool. It describes learning theories to facilitate the effective design and analysis of collaborative learning activities. It focuses on the domain of different pedagogies to support different levels of guidance such as group formation, designing of collaborative activities, recommendation of learning materials, analysis of individual and group outcomes and proposing new collaborative sessions.

LOCO is a framework that integrates a number of learning-related ontologies "to ease the exchange of data among multiple educational services" (Siadaty et al., 2008). The central component of the framework is the Learning Context ontology, that models the characteristics of educational material. The other ontologies of the frameworks are the User model ontology, which models students and teachers, and the Learning Ontology for modeling user's preferences and performance.

There are also ontologies in the education domain that describe learners' characteristics with the intention of adapting content or activities that best suit the student when interacting with learning environments. The user profile allows the characterization of users based on their identified needs, capabilities, and limitations. They can be implemented through ontologies in order to make inferences and deduce information. Knowing more about the learners is a benefit by improving the quality of their interactions with the learning environment. The works of Clemente et al. (2011), Paneva et al., (2006) and Panagiotopoulos et al. (2012) show the student ontology that aims to describe student characteristics, such as behavior, objective learning preferences, level of knowledge, among others. The work of Clemente et al. (2011) aims to infer whether the learning objectives have been achieved and what the student's state of knowledge is. The work presented by Paneva et al., (2006) is based on general student information and performance in the learning domain, like learning goals, cognitive aptitudes, and student's performance. And the ontology proposed by Panagiotopoulos et al. (2012) describes, in addition to the students' characteristics, the learning style and the academic performance.

3.1.3 Accessible Education Ontologies

In this section we analyze ontologies where their domain is both education and accessibility for inclusive education (Figure 5).

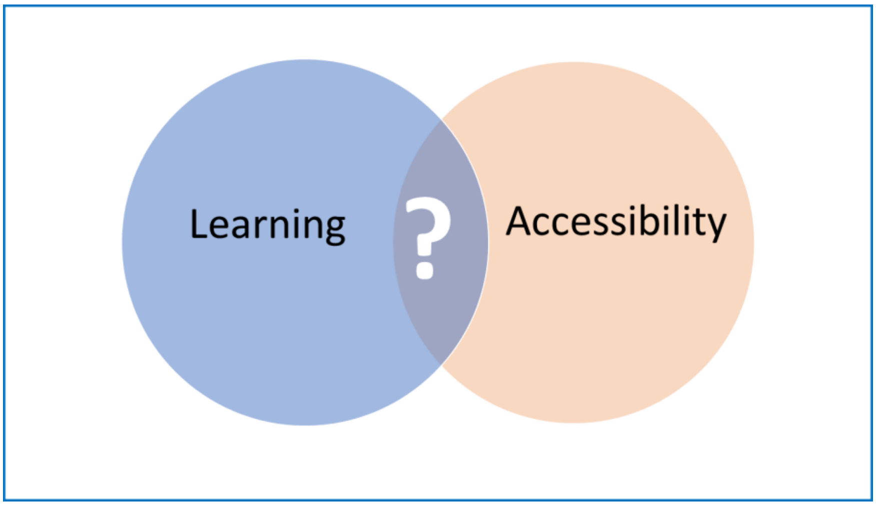


Figure 5 Learning & Accessibility Ontologies intersection

There are some projects that have been used to model users in the accessibility and inclusion domain such as Affinito, EGONTO, ADOLENA, ASK-IT, SUS-IT, AEGIS and ACCESSIBLE.

Affinto (Cearreta et al., 2001) is used to represent a model for the affective on interactions person-system interaction. It focuses on environmental factors like noise and light and personal properties like emotion and mood.

EGONTO (Gamecho et al., 2015) is an ontology used to store, update, and maintain models of user skills, characteristics of the access devices and the interface adaptations. It models the following aspects: users´ physical, cognitive, sensory, and emotional capacities, assistive technologies, and customized support based on user needs.

The Abilities and Disabilities OntoLogy for ENhancing Accessibility (**ADOLENA**) (Nganji et al., 2012) is an ontology of skills and disabilities to improve accessibility. It was designed to demonstrate the proof-of-concept of Ontology Based Data Access (OBDA) with a real database, using the database of the web National Accessibility Portal of South Africa. It is based on ADOOLES (Keet et al., 2008), an ontology that represents knowledge in the domain of e-learning and disabilities. However, the number and types of disabilities covered by ADOOLES are very limited and given as a simple class hierarchy without any properties and further linking.

The project "Ambient Intelligence System of Agents for Knowledge-based and Integrated Services for Mobility Impaired users'' develops its own ontology called **ASK-IT** (Kehagias & Tzovaras, 2010). ASK-IT models reduced mobility users, travel agents and services. It describes the needs of users with reduced mobility, and defines services to support planning trips, moving from one city to another or executing home control activities during a trip.

The project of ''Accessibility Assessment Simulation Environment for New Applications Design and Development'' (AEGIS, 2012) develops its own ontology named ACCESSIBLE. It is a general-purpose, open-source ontology for the domain of accessibility. It describes the characteristics for disabled user based on ICF (ICF, 2020) standards, descriptions of assistive devices and software applications, web accessibility standards and guidelines.

The project of ''Open Accessibility Everywhere: Groundwork, Infrastructure, Standards'' (**AEGIS**) (AEGIS, 2012) has its own ontology. It provides support for the formal and unambiguous definition of accessibility domains, and for possible semantic interactions between its concepts. It models the following aspects: users´ disabilities, impairments, and functional limitations; technical aspects for assistive devices and mobile, web and desktop applications; and users' actions and interactions with the applications.

ACCESIBILITIC (Mariño et al., 2018) is an ontology that models the main characteristics of ICTs users, including their capabilities, disabilities, the state of their physiological and psychological functions, and the technology characteristics related to accessibility and assistive devices. It infers support suitable assistance to facilitate overall accessibility.

AccessibleOCW (Elias et al., 2018) ontology was designed for accessible OpenCourseWare and built on the accessibility concepts of IMS Learning Global Consortium and the vocabulary structure of the ACCESSIBLE ontology. It was developed with the purpose to access the information for recommendations and adaptations in e-learning contexts for learners with disabilities.

AccessOnto (Masuwa & Rungano, 2008) is an ontology modelled to describe accessible guidelines and user characteristics, providing a framework to integrate accessibility guidelines into requirements specification documents. Semantic relationships have been included to involve the activities and user profiles to assist developers in the task of choosing the right technology for each activity and how to operate it.

OntoSAW (Sánchez-Figueroa, 2011) represents the structural elements, attributes, and relationships between web page components, considering accessibility properties of the WAI guidelines. It has been developed for the SAW tool, which uses the ontology to edit web pages code to make them more accessible.

3.2. Accessible Education Ontologies Conclusions

From the previous analysis performed on the list of Accessible Education Ontologies retrieved by the application of the systematic bibliography mapping (showed in Appendix A), we can conclude that only AccessibleOCW ontology maps students to educational resources according to their preferences and disabilities. The rest of the ontologies focus on the use and characteristics of assistive devices, and on WEB accessibility. However, at the time of this thesis no work considers accessibility for intellectual disabilities in education, neither the concept of working with learning skills and abilities within the framework of UDL.

4. UDL Ontology design

This section presents the process followed to design and construct UDLOntology. According to Bravo et al. (2019) ontology design is an incremental and iterative methodology and defines the following ordered series of phases to use in the engineering of an ontology as shown in Figure 6: requirement, design, construction, and evaluation.

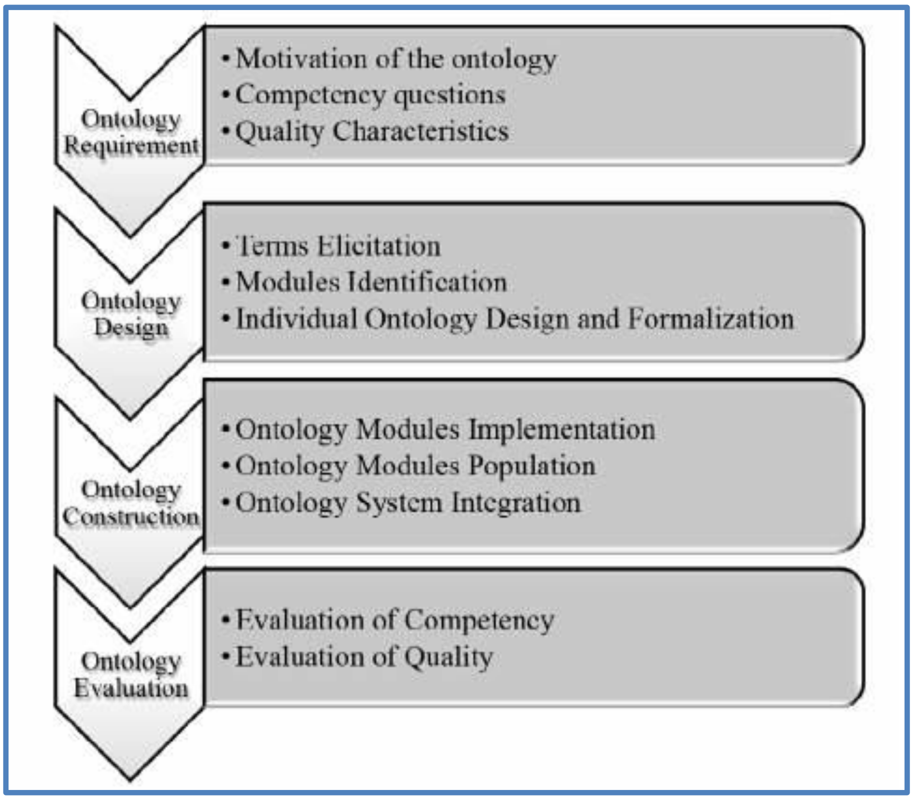


Figure 6 Ontology design and construction methodology phases and procedures (Bravo et al., 2019)

4.1. Requirements

The main objective of the requirements phase is to define the purpose and scope of the ontology. According to Fernández et al. (1997) the purpose is "the use to be given to the ontology, the use scenarios and the end users involved"; and the scope is “the set of terms to be represented, their characteristics and granularity”. The purpose of UDLOntology is to infer educational resources that best suits specific learning abilities and skills, based on UDL Guidelines. The scenario where the ontology will be used is that of a student requesting for a specific educational material and UDLOntology inferring the educational material version that best suits its learning abilities based on UDL Guidelines.

In the following, we present a list of questions to assist the identification of the main concepts on the domain:

1. What information of the educational resources is relevant to determine if it is appropriate for the learning abilities of a particular student?
2. What information is necessary to determine what UDL Guideline recommendations best suit the learning abilities for a particular student?
3. Do the recommendations require specific detail information?
4. What are the concepts we would like to represent?
5. What properties do those concepts have?

4.2. Design

The design phase aims to describe a formal ontology's model. It consists of three steps: term elicitation, group identification and formalization. Bravo et al. (2019) defines term elicitation as the process of "producing a seminal list of terms that are relevant for the particular domain of knowledge". The first group of terms identified, based on the questions presented in the specification phase, are in Figure 7.

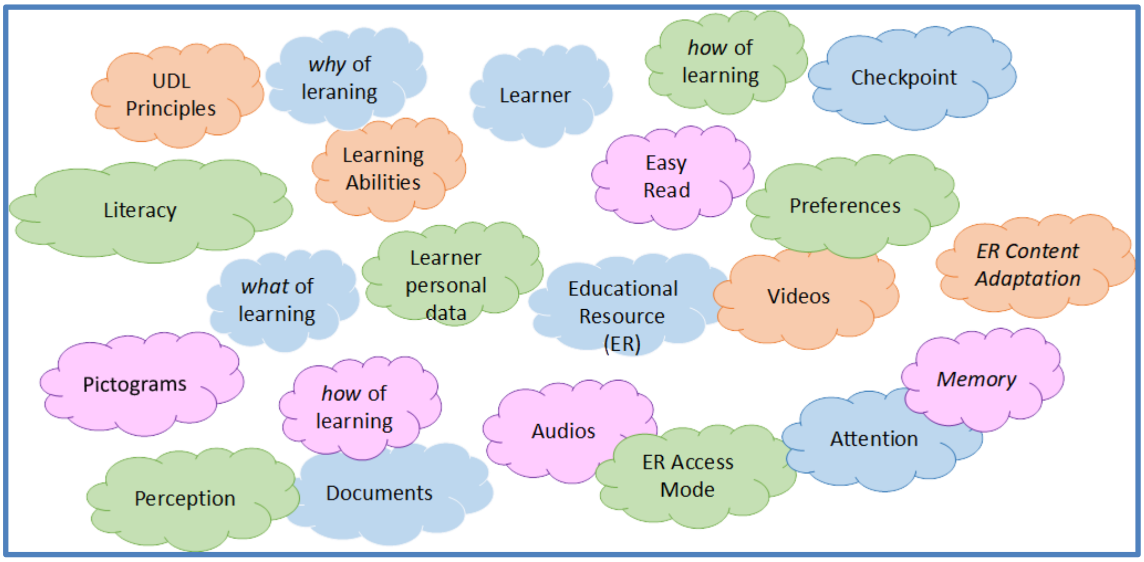


Figure 7 First identified terms (own production)

The next step is to group similar terms under a main concept, taking as input the terms from list in Figure 7. Four groups are defined, as seen in Figure 8: Learner, Learning Ability, Educational Resource, and UDL Guideline.

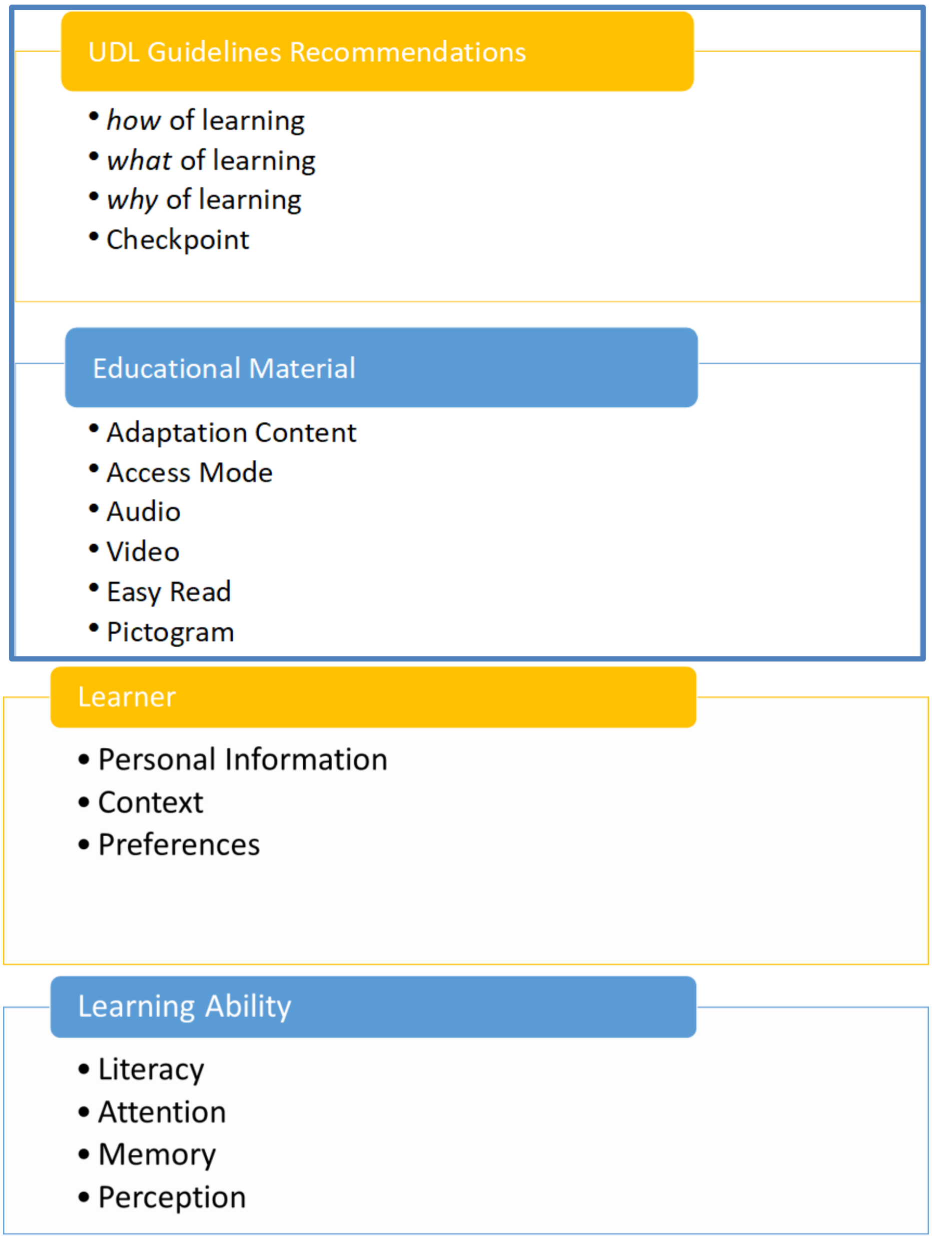


Figure 8 Main concepts' groups (own production)

Figure 9 shows the phases required to infer educational resource that best fits learner's learning ability based on UDL guideline using this first clustering.

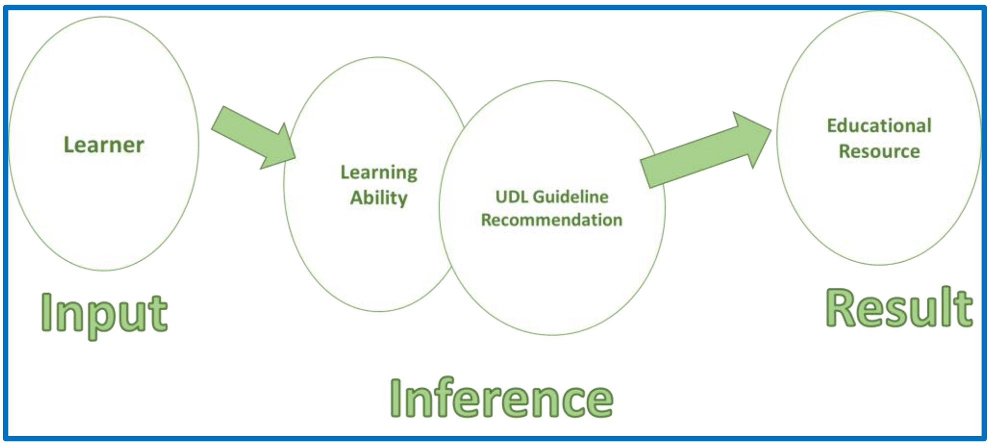


Figure 9 Infer phases (own production)

Learner group clusters learner's personal information such as name and age, learner's learning abilities, context, and preferences. Educational Resource group has the characteristic of the educational resources like access mode and adaptation content. Learning ability group represents the cognitive aspects related to learning. UDL Guidelines group is used to model UDL Organizer as per Figure 2, where the educational resource's design guidelines and checkpoint recommendations are defined for each UDL principle.

As per the formalization step, we apply the following steps: taxonomy creation, identification of data properties relationships, and identification of object properties relationships. It was mention above that one of the main contributions of UDL Guidelines is to recommend multiple means of representation for educational resources. Consequently, access mode and content adaptation, from Educational Resource group, are modelled as independent classes with their own properties and relations.

The proposed main concepts in the taxonomy are: *UDLLearner*, *EducationalResource*, *LearningAbility, ContentAdaptation, AccessMode, UDLPrinciple and UDLCheckpoint. UDLLearner* models personal information and the profile of the learner as per the IMS Global Learning Consortium (IMS Global AccessForAll (AfA), 2020) using Personal Needs & Preferences (IMS AFA PNP, 2020). *EducationalResource* models the properties of the digital material as per the standard IMS Digital Resource Description (IMS AFA DRD, 2020). *LearningAbility* addresses the various way in which the learner perceives, processes, comprehends and retains information. *ContentAdaptation* intends to represent the way in which the intellectual content of educational resources is presented. *AccessMode* is the sense "through which the intellectual content of a described resource or adaptation is communicated" (IMS AFA DRD, 2020). *UDLPrinciple* models the three principles where UDL framework is ground, and *UDLCheckpoint* models each checkpoint addressed in the UDL Graphic Organizer (Figure 2)Figure 2 UDL Graphic Organizer (Cast,2020).. Except for *UDLPrinciple*, all the concepts presented no sub-classes. Based on UDL Graphic Organizer, UDL principles are sub classified as Representation, Action&Expression, and Engagement (Figure 10). In addition, each specific principle has also sub classes (UDL Graphic Organizer's rows) as presented in Figure 11.

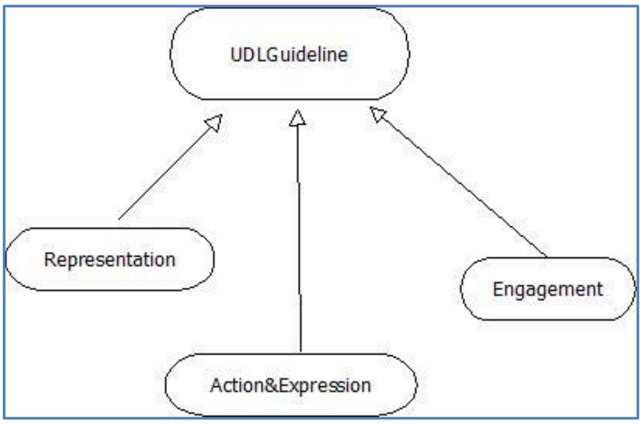


Figure 10 UDL three principles

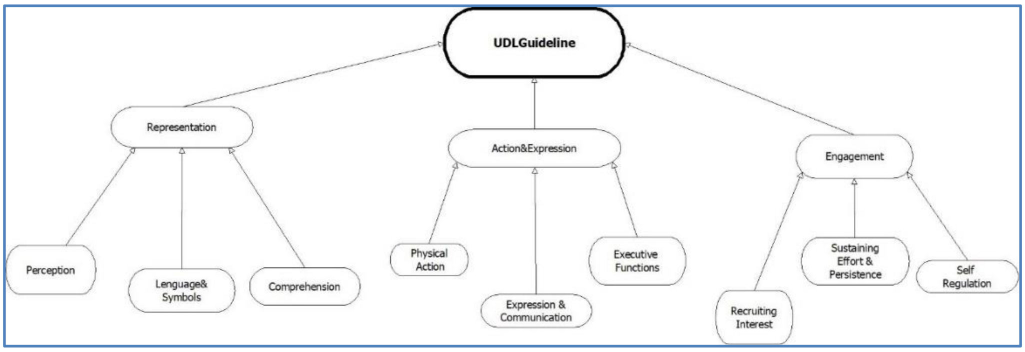


Figure 11 Classes of Representation, Action&Expression and Engagement

4.3. AccessibleOCW

As already stated in the introduction, UDLOntology extends AccesibleOCW. In the work “Why the Universal Design for Learning need Ontology” (Deambrosis et al, 2020) we state that AccessibleOCW ontology “is an ontology that can be taken as a starting point to be extended, reused, or combined with other ontologies to achieve a complete UDL”. AccessibleOCW has sixteen classes. The relevant ones for this work are: Learner and *DigitalResource*. Learner models the learners´ profile, and *DigitalResource* models any digital educational resource. The learners’ profile refers to disability, preferences and needs. For disability information, Leaner is defined as a subclass of User class of the ACCESSIBLE ontology (ACCESSIBLE, 2020) inferring disability, functional limitations, and impairment information according to ICF (ICF, 2020). For preferences and needs, Learner class is modelled by properties based on IMS PNP. These properties are:

- data properties for preferences:

  hasReqAccessMode, hasEducationalLevelOfAdaptaion,

  hasLanguajeOfAdaptation and hasLanguajeOfInterface

- object properties for needs:

  hasEducationalComplexityOfAdaptation,

  hasHazardAvoidance and hasInputRequirements

DigitalResource refers to the characteristics and adaption of digital educational resource. It is modelled by properties based on IMS DRD specification. These properties are: *hasAdaptation*, *isFullAdaptationOf* and *isPartialAdaptationOf* data properties for adaptations, and *hasAccessMode*, *hasHazard* and *EducationalComplexityType* object properties for characteristics.

AccessibleOCW accomplishes required conditions to be a good candidate to be reused in this work. First, AccessibleOCW represents part of the domain corresponding to the scope of UDLOntology, and the main concepts are consistent with those of UDLOntology. Learner and *DigitalResource* classes are both modelled based on IMS AfA specifications and are consistent with UDLLearner and *EducationalResource* classes, respectively. Second, AccessibleOCW is available and, beyond the lack of documentation, there are four research articles that explain the ontology. Another aspect evaluated is whether the required knowledge is represented with the degree of coverage required with respect to the scope defined for each work area. It is identified some incomplete areas to cover the scope of UDLOntology such as that related to the knowledge for learning abilities and UDL Guidelines.

Relationships

In this task, binary relations between concepts are identified. Figure 12 presents the complete conceptual model for a better understanding. In this model there are two actors: students accessing educational resources, and teachers designing educational resources. The scope of this work is the one within the coloured area. The identified relations for the scope of this work are:

1. There is a relation between learners and learning abilities to model learner´s abilities

2. There is a relation between learners and educational materials which refers to the **inferred** educational resources recommended to specific learner's learning abilities based on UDL Guidelines.
3. There is a relation between learning abilities and UDL checkpoints to model the access mode and adaption recommended by UDL checkpoint to be applied to the educational resources, taking into consideration the specific learning abilities.
4. There is a relation between UDL checkpoints and content adaptation, to model content adaptation to educational resources recommended by checkpoints.
5. There is a relation between UDL checkpoint and access mode to model access modes recommended by checkpoints.
6. There is a relation between educational resources and access mode to model the different means educational resources can be accessed.
7. For scenarios where the original educational resource does not have the recommended access mode by checkpoint, there is a relation between adapted educational resources and access mode to model the different means adapted educational resource can be accessed.
8. There is a relation between content adaptation and educational resources to model the different content presentations that the original educational resource might have such as EasyRead, and pictogram.

The next relations are not within the scope of this work because they are defined to model knowledge form the teacher's point of view. However, it is important to mention them as they do to the complete model as presented in Figure 12. They model those relations used by teacher when designing curricula or assessment.

1. There is a relation between UDL Principle and UDL checkpoints to model the checkpoints used to apply each UDL Principle based on UDL Graphic Organizer, and its inversed.
2. There is a relation between teacher and learning abilities to represent for which learning abilities the teacher is designing the resource.
3. Similarly, to the previous one, the teacher might want to designing educational resources taking into consideration specific UDL Principle. In this context, there is a relation between teacher and UDL principle that models this scenario.
4. There is a relation between teacher and UDL checkpoint that infers those UDL checkpoints that best suits the learning abilities or UDL principle that a teacher is focusing on.

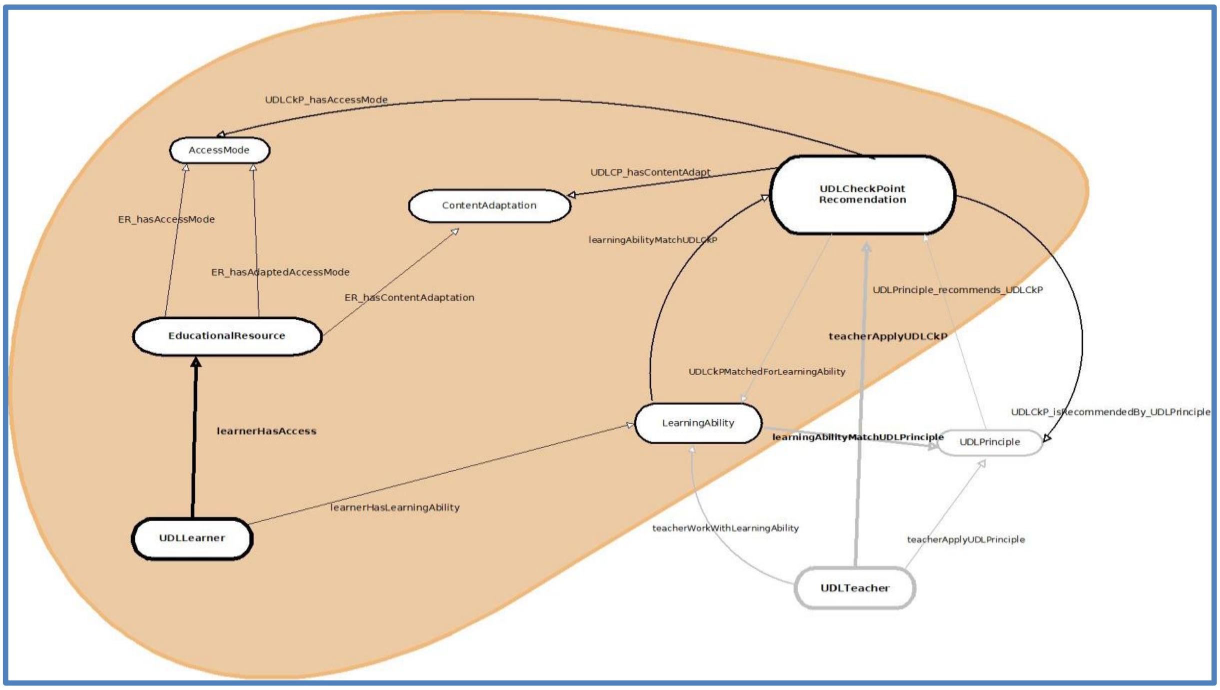


Figure 12 UDLOntology Conceptual Model

Individuals

Individual instances are the most specific concepts represented in a knowledge base and therefore, they are the lowest level of granularity in the representation. The level of granularity is determined by the application of the ontology. Good candidates for individuals constitute those specific concepts that answers the competency questions.

The following procedure is applied. First, those learning abilities from Table 2 that share the same UDL principle and checkpoint are unified. Table 3 has the initial concepts.

Table 3 Learning abilities & UDL Principle & UDL checkpoint

Learning abilites	UDL Principle	UDL Checkpoint Recomendation
Visual Multimedia media ilustrations	**Representation** 1: *Perception* Offer visual means of representation to sound and voice.	1.2: Share information in more ways than sound and voice alone
Clear syntax instructions and vocabulary	**Representation** *2: Language & Symbols* Clarify syntax and structure Ilustrate through multiple medias	2.1 : Construct meaning from words, symbols, and numbers using different representations 2.2 : Make the patterns and properties of systems like grammar, musical notation, taxonomies, and equations explicit. 2.5 : Make learning come alive with simulations, graphics, activities, and videos

Next, concepts from Table 3 are mapped to UDLOntology proposed classes and instances as seen in Table 4.

Table 4 Classes & Individuals

	CLASSE			
	LearningAbility	**UDL CheckPoint**	**AccessMode**	**EducationalComplexityOfAdaptation**
INDIVIDUAL	MultiMediIlustrationAndRepresentation	CkP1.2	Visual	
	ClearSyntaxInstructionVocabulary	CkP2.1 CkP2.2 CkP2.5		EasyRead Pictogram AAC

We implemented a first prototype of the UDLOntology with the following classes, objects relations and data type relations:

Classes

1. UDLLearner
2. EducationalResource
3. LearningAbility
4. *UDLCheckpoint*
5. AccessMode
6. ContentAdaptation

Objects Relations

1. learnerHasLearningAbility
2. learnerHasAccessTo
3. UDLCkPHasContentAdaptation
4. UDLCkP*HasAccessMode*
5. ER*HasAccessMode*
6. ERHasAdaptedAccessMode
7. ERHasContentAdaptation
8. learningAbilityMatchUDLCkP

Data type relations

1. hasProfile

4.4. Evaluation

Ontology evaluation is an important activity improving the quality of the ontologies and identifying modelling errors and inconsistencies. Gómez-Pérez et al. (1995) first addressed the meaning of ontology evaluation as making "technical judgment of the ontologies, their associated software environments, and documentation with respect to a frame of reference during each phase and between phases of their lifecycle. Then Vrandečić et al. (2009) define ontology evaluation as "the task of measuring the quality of an ontology." The work of Suarez-Figueroa et al. (2013) refers to ontology evaluation as "the activity of checking the technical quality of an ontology against a frame of reference".

Ontology evaluation also applies different approaches. Gómez-Pérez et al. (2004) define ontology evaluation in the context of two concepts: verification and validation. Ontology verification refers to building an ontology correctly, ensuring that its definitions implement the requirements precisely. Ontology validation is concerned with building the correct ontology, by ensuring that the meaning of the definitions models the world for which the ontology was created.

Brewster et al (2004), and Hlomani and Stacey (2013) group ontology evaluation in four categories: gold standard, corpus-based, task-based, and criteria-based. Gold standard compares the proposed ontology with a previously created reference. Corpus-based is used to evaluate if the coverage of the ontology on a specific domain by comparing the proposed ontology with the content of a text corpus. Task-based is used to measure how far an ontology helps improving the results of the task it was created for. Criteria-based measures how far an ontology represents certain desirable criteria. In addition, Hlomani and Stacey (2013) state that ontology evaluation must consider two quality and correctness perspectives, addressing several criteria such as accuracy, completeness, adaptability, clarity, and consistency, among others.

For Raad and Cruz (2015), ontology evaluation "is based on measures and methods to examine a set of criteria".

To evaluate UDLOntoly, we follow two approaches: verification by applying the reasoner on a set of instances, and validation by applying a competence question. The verification process was conducted by applying the reasoner HermiT with Protégé and the OOPS![1] Tool. OOPS! (OntOlogy Pitfall Scanner!) is a web-based tool that automated the detection of potential errors for modelling decisions, requirements completeness, wrong inference, real world modelling/Common sense, and ontology clarity, understanding and language (Poveda-Villalón et al, 2012). OOPS is free, and it is a simple to use tool. It can detect up to 36 pitfalls grouped in three dimensions: S*tructural dimension* such as creating a property chain with only one property, *Usability-profiling dimension* such as using different naming criteria in the ontology, and *Functional dimension* such as defining unconnected ontology elements. For each detected pitfall, information on the elements affected is provided, together with its importance level depending on its impact on the quality of the ontology. There are three importance levels defined to catalogue the pitfalls. *Critical:* for example, pitfalls that can impact the consistency and reasoning of the ontology. *Important*: for example, pitfalls to be corrected for bettering the modelling quality of the ontology. And *Minor* that are

[1] https://www.oeg-upm.net/index.php/en/technologies/292-oops/index.html

no errors. However, by correcting them makes the ontology more understandable (Poveda-Villalón et al, 2012).

OOPS!'s evaluation presents six results on the first version of the UDLOntology as depicted in Figure 13. Four of them have a *Minor* importance level, and two of them have an *Important* importance level. The result of its analysis with a list of pitfalls, its importance level, and the elements of the ontology where they appear are presented in Figure 13, Figure 14 and Figure 15. Detailed analysis of the results is presented to show the process applied to determine their eventual correction.

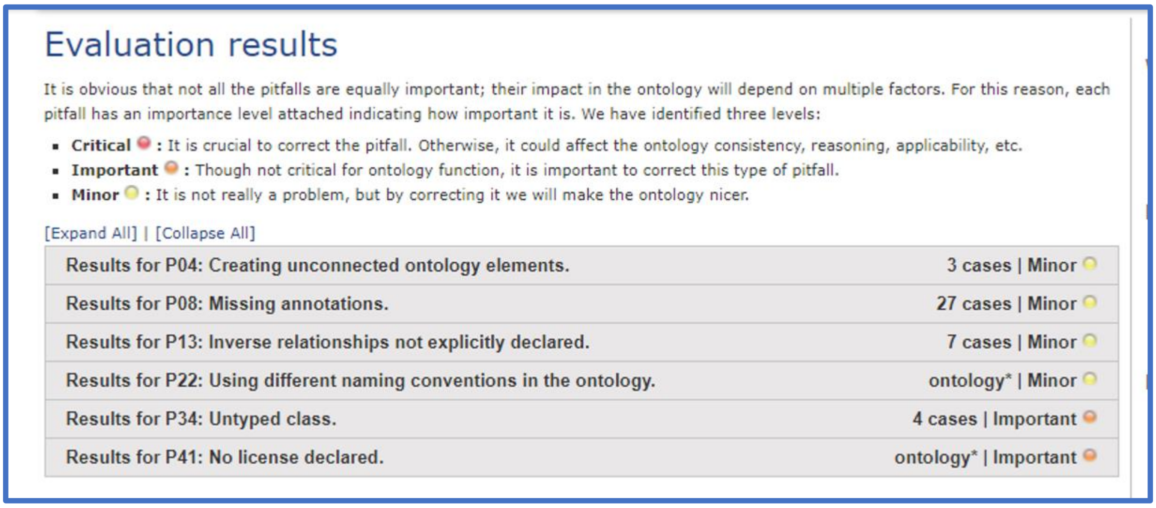
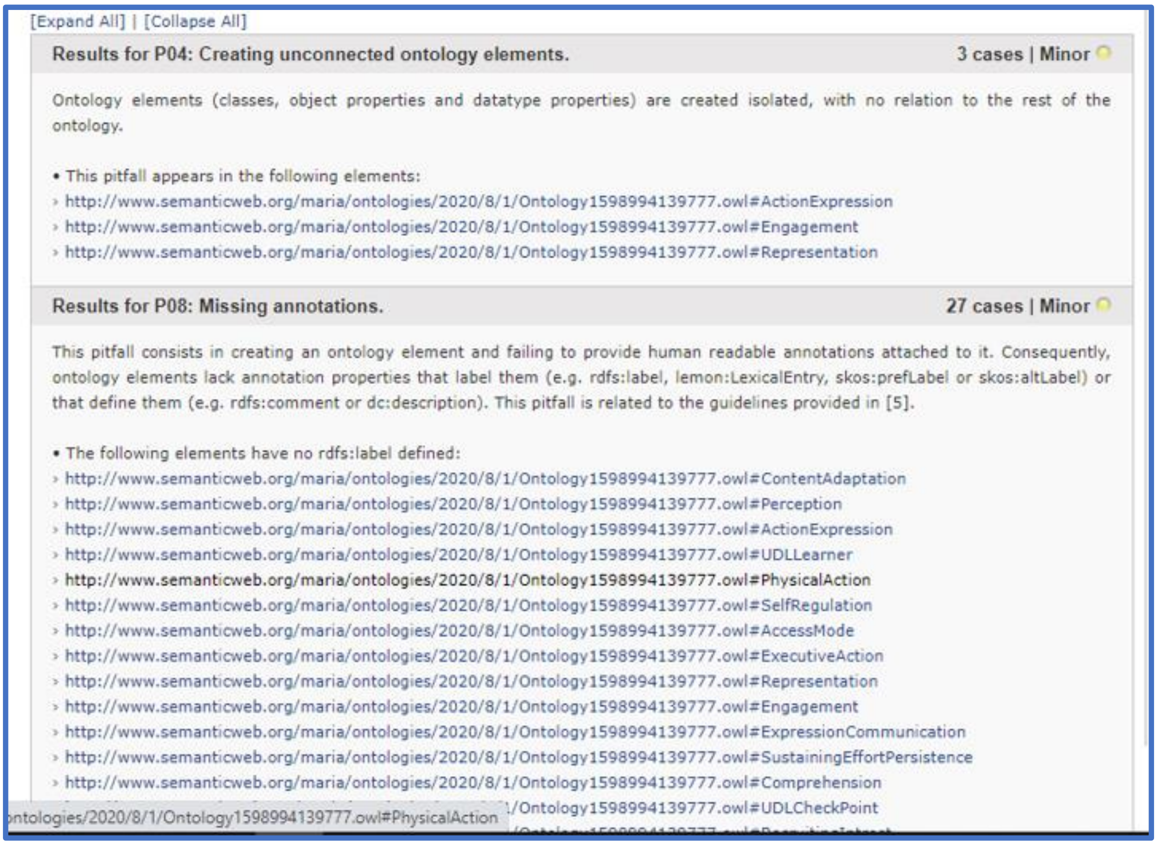


Figure 13 OOPS! Evaluation results- Collapse List


[Expand All] | [Collapse All]

Results for P04: Creating unconnected ontology elements. 3 cases | Minor

Ontology elements (classes, object properties and datatype properties) are created isolated, with no relation to the rest of the ontology.

• This pitfall appears in the following elements:
› http://www.semanticweb.org/maria/ontologies/2020/8/1/Ontology1598994139777.owl#ActionExpression
› http://www.semanticweb.org/maria/ontologies/2020/8/1/Ontology1598994139777.owl#Engagement
› http://www.semanticweb.org/maria/ontologies/2020/8/1/Ontology1598994139777.owl#Representation

Results for P08: Missing annotations. 27 cases | Minor

This pitfall consists in creating an ontology element and failing to provide human readable annotations attached to it. Consequently, ontology elements lack annotation properties that label them (e.g. rdfs:label, lemon:LexicalEntry, skos:prefLabel or skos:altLabel) or that define them (e.g. rdfs:comment or dc:description). This pitfall is related to the guidelines provided in [5].

• The following elements have no rdfs:label defined:
› http://www.semanticweb.org/maria/ontologies/2020/8/1/Ontology1598994139777.owl#ContentAdaptation
› http://www.semanticweb.org/maria/ontologies/2020/8/1/Ontology1598994139777.owl#Perception
› http://www.semanticweb.org/maria/ontologies/2020/8/1/Ontology1598994139777.owl#ActionExpression
› http://www.semanticweb.org/maria/ontologies/2020/8/1/Ontology1598994139777.owl#UDLLearner
› http://www.semanticweb.org/maria/ontologies/2020/8/1/Ontology1598994139777.owl#PhysicalAction
› http://www.semanticweb.org/maria/ontologies/2020/8/1/Ontology1598994139777.owl#SelfRegulation
› http://www.semanticweb.org/maria/ontologies/2020/8/1/Ontology1598994139777.owl#AccessMode
› http://www.semanticweb.org/maria/ontologies/2020/8/1/Ontology1598994139777.owl#ExecutiveAction
› http://www.semanticweb.org/maria/ontologies/2020/8/1/Ontology1598994139777.owl#Representation
› http://www.semanticweb.org/maria/ontologies/2020/8/1/Ontology1598994139777.owl#Engagement
› http://www.semanticweb.org/maria/ontologies/2020/8/1/Ontology1598994139777.owl#ExpressionCommunication
› http://www.semanticweb.org/maria/ontologies/2020/8/1/Ontology1598994139777.owl#SustainingEffortPersistence
› http://www.semanticweb.org/maria/ontologies/2020/8/1/Ontology1598994139777.owl#Comprehension
ontologies/2020/8/1/Ontology1598994139777.owl#PhysicalAction /Ontology1598994139777.owl#UDLCheckPoint

Figure 14 OOPS! Evaluation results- P4 & P8 Expand information

Expanded information for P04 and P08 pitfalls are shown in Figure 17. “Results for P04: Creating unconnected ontology elements” is a Minor pitfall. They are elements defined in the first iteration of the design, to model UDL principles’ concept towards implmenteing the full conceptual model defined in Figure 12. Its correction is easy to apply and eliminates unnecessary complexity. “Results for P08: Missing annotations” is also a Minor pitfall. It relates to the ontology documentation. The large number of cases for P08 are due to leaving annotation properties for further on. P08 results are also easy to implement, however they are time consuming. Adding annotations understandable from humans' point of view is a good practice, getting a better user-friendly ontology and clarity of the code.

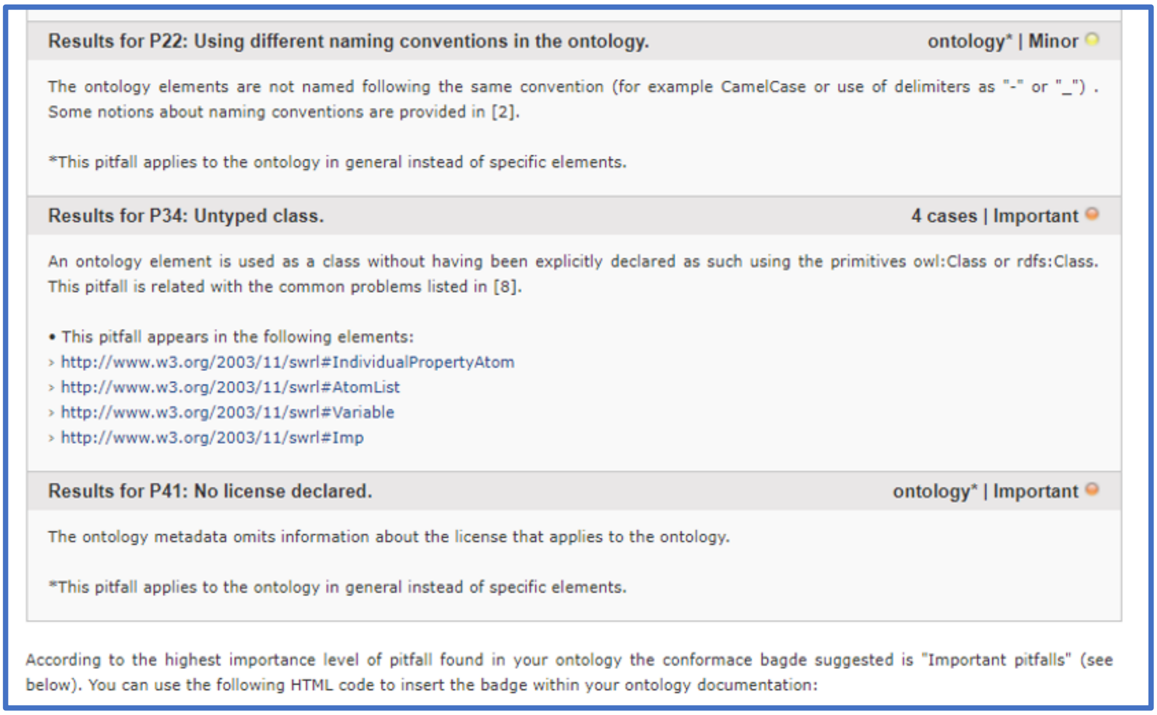


Figure 15 OOPS! Evaluation results- P22, P34 & P41 Expand information

Figure 15 presents expanding information for results P22, P34 and P41. P22 is a Minor one, and P34 and P41 are Important one. "Results for P2: Using different naming conventions in the ontology" applies to the entire ontology. This pitfall is hard to fix, and it requires a thorough work. It implies to delete those elements that do not follow the expected naming convention and eventually possible relations, properties, and instances, and to create them again along with the re-modelling of the previous knowledge. This fix can also introduce inconsistencies and absence of knowledge previously modelled, among others. P022 is a good example to support the importance of performing evaluations during the whole ontology life cycle and its building process. P34 and P41 are evaluate as Important by the tool. Although P41 is marked as important, we do not consider it critical at this time because UDLOntology is still a prototype, but we agree to use an open license. The errors in P34 are omissions from the typing definitions that in the current version of UDLOntology are not causing inconsistencies.

The validation of the UDLOntology was conducted by the competence question "which educational resources are best adapted to a learner specific learning skill, according to the UDL recommendations?".

According to Ramos et al. (2009), for the verification of an ontology the quality of the taxonomic structure is first analysed. As already mention above, the proposed ontology is a prototype ontology on the domain of UDL, whose descriptions are unique in the domain of knowledge. Within this context, UDL Graphic Organizer itself (Figure 2) was used as reference. Among the actions taken, it is emphasized the one to verify that relevant concepts from the domain of UDL Guidelines for the proposed ontology were modelled. The relevant concept is that of checkpoints and particularly checkpoint 2.1, which refers to "Clarify vocabulary and symbols" (Figure 2) within the "Language and symbols group". Checkpoint concept is represented by the UDLCheckpoint class. The CheckPoint_2.1 instance and the *UDCP_hasContentAdapt EasyRead* relationship model the concept proposed in Table 3 and Table 4.

Then, the competence question "which educational resources are best adapted to a learner specific learning skill, according to the UDL recommendations?" was evaluated with defined individuals. The following individuals were defined: *LearnerMagda* individual of *UDLearner* class, and the individuals

EducationalResource1, *EducationalResource2* and *EducationalResource3* instances of *EducationalResource* class. Two learning abilities associated to LearnerMagda were also defined: *ClearSyntaxInstruccionVocabulary* and MultiMediaIustrations by hasLearningAbility property. As per the educational resources it was defined *EducationalResource1* as a text resource by property *ER_hasAccessMode* and it was mapped it to two adapted resource. *EducationalResource1* is a visual resource and is adapted with *EasyRead* technic. EducationalResource2 has no associated characteristic, and *EducationalResource3* is a visual resource as well but adapted with *Pictograms*.

Figure 16 presents the simplified learner profile, Figure 17 the characteristics of EducationalResource1, and Figure 18 the characteristics for EducationalResource3.

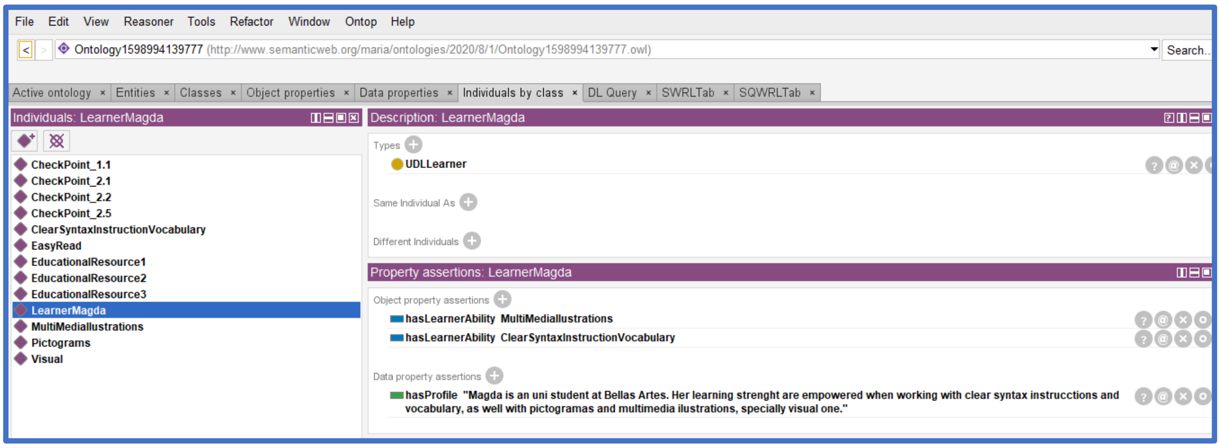


Figure 16 Simplified Learner_Magda profile

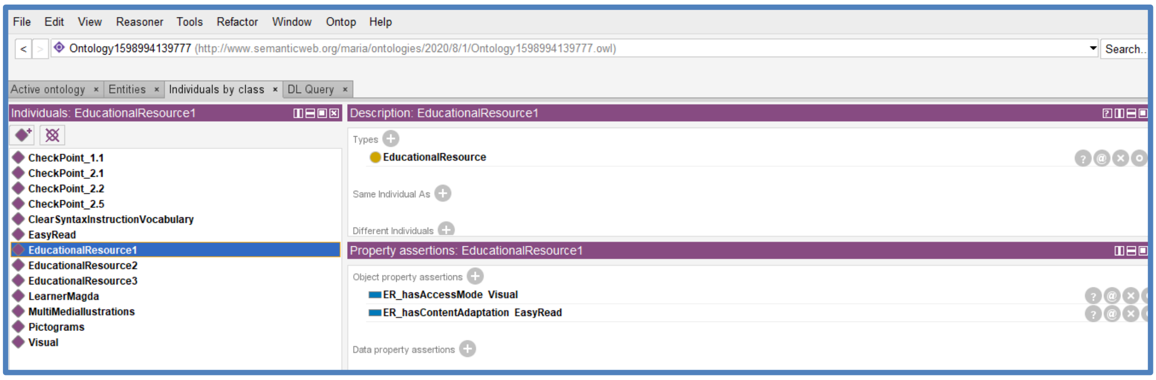


Figure 17 Simplified Educational Resource 1 characteristics

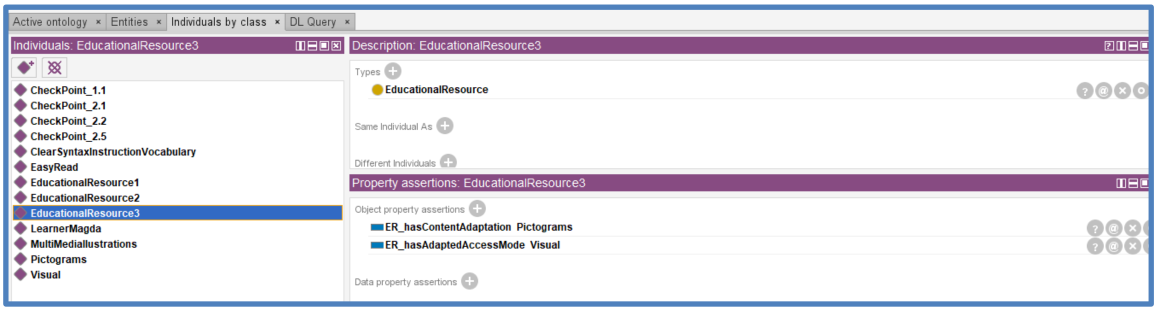


Figure 18 Simplified Educational Resource 3 characteristics

Through the *hasAccessTo* super-property (Figure 19 and Figure 20), educational resources are returned that are adjusted to the student's ability according to the recommendations of the UDL control points. Therefore, for the individual *LearnerMagda*, which has the *ClearSyntaxInstructionVocabulary* skill, based on the assignments presented in Table 3 and Table 4, *EasyRead* is recommended for *ClearSyntaxInstructionVocabulary*. To verify the consistency of the model and specifically that of the super property, the OWL reasoner was run. No error or inconsistency was detected, and in the “property assertion windows” for *LearnerMagda* a new object property was inferred (Figure 21), with the expected inferred educational resource *EducationalResource1*.

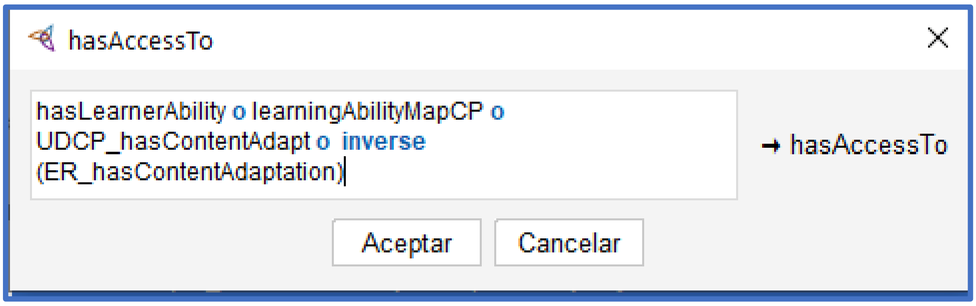


Figure 19 Super property defined for hasAccessTo

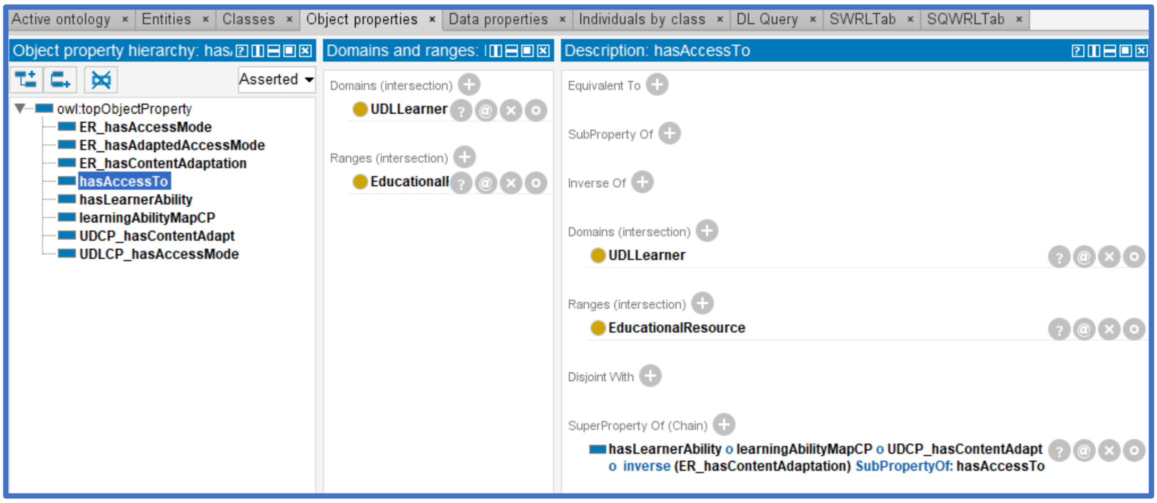


Figure 20 hasAccessTo object property description window

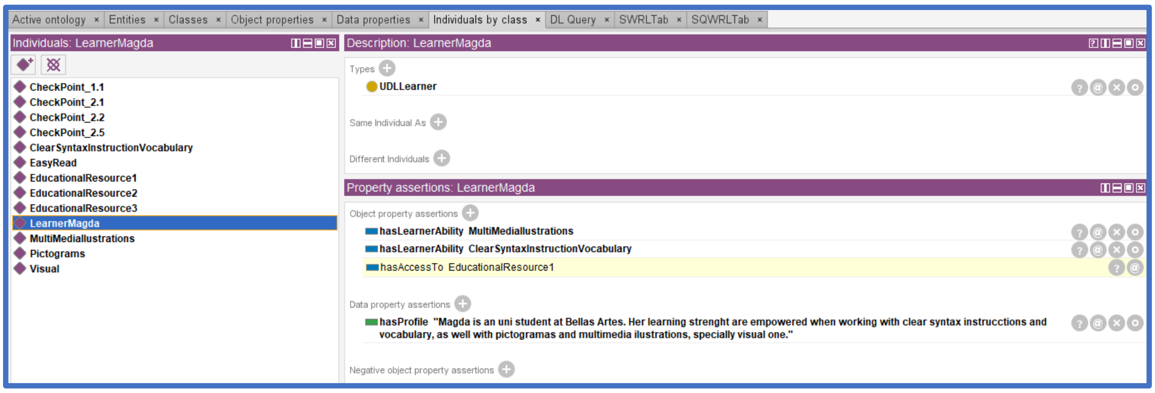


Figure 21 LearnerMagda Property assertions' window – One Educational Resource

However, by validating the competency question, we observe that EducationalResource1 is the only inferred educational resource, because it is the only one that verifies the super property in Figure 16. Therefore, this validation does not prove the correctness of the result since it cannot be asserted that EducationalResource1 is the "best" adapted educational resource to a learner specific learning skill. Within this scenario, adequate properties for *LearnerMagda's* learning abilities are redefined for EducationalResource2 (Figure 22). After synchronizing the reasoner, both educational resources are inferred (Figure 23), and no "best" educational resource was presented. In the proposed competency question, "best" is an ambiguous concept undefined in the ontology, thus resulting unfeasible for the ontology to answer it correctly. Possible solutions for the issue of the ambiguity of the term "best" in the competency questions are rephrasing the competency questions without the term "best" or modelling the concept "best" as an element in the ontology.

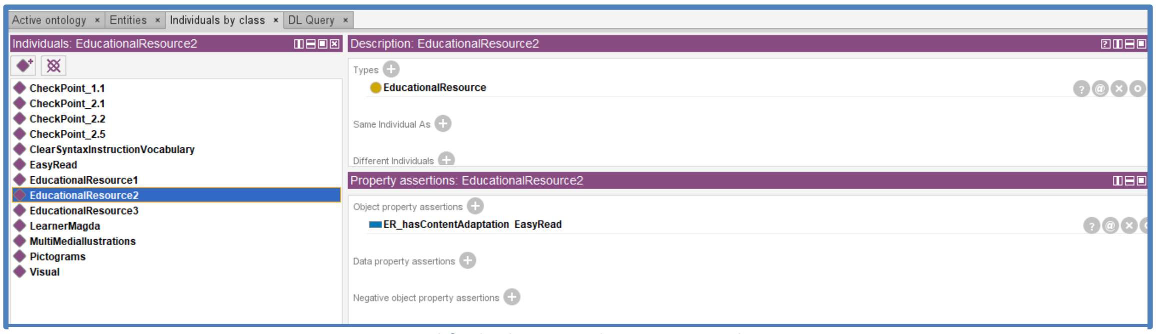


Figure 22 Simplified Educational Resource 2 characteristics

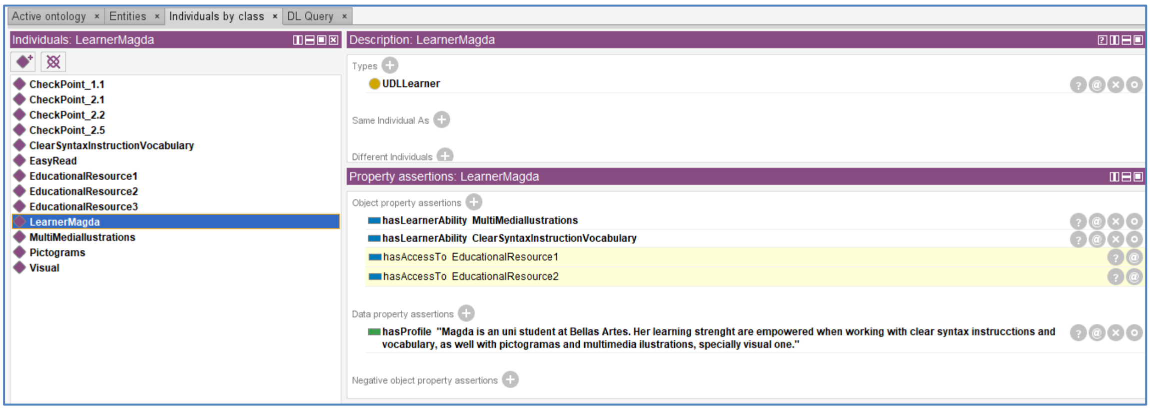


Figure 23 LearnerMagda Property assertions' window – Two Educational Resources

As mentioned by Jedrzej et al. (2020), ambiguities in proficiency questions are one of the common problems with this validation approach. However, since we do not have an interdisciplinary team that produces a precise definition of the term "best", we decided to discard "best" from the competence question.

5. Conclusions and Future Work

In this work, we identify trend in the usage of an Ontology for Universal Design Learning, and we produce a first prototype of an ontology named UDLOntology. UDLOntology models learning abilities and UDL Guidelines, allowing for the inference of educational resources that best suit student's learning strengths, based on UDL Guidelines Graphic Organizer. As stated in chapter Related Work, none of the reviewed ontologies addresses these objectives. For develop UDLOntology, we based on the AccessibleOCW Ontology, but extended for learners with intellectual learning disabilities. We present a use case for a LearnerMagda with learning abilities according to Down Syndrome.

Based in neuroscientific research, UDL is grounded in three key principles that are core to learning: representation, expression, and engagement. UDL Guidelines address areas within each of the UDL principles, and present checkpoints to suggest different ways in which educational resources might be designed for each guideline area.

To model UDL Guidelines in UDLOntology, the two main concepts of the UDL Graphic Organizer, principles and checkpoints are defined as independent classes: *UDLPrinciple* and *UDLCheckPoint*. *UDLPrinciple* models *who* and *what* to consider in the design of educational resources for all. *UDLCheckpoint* models concrete recommendations for *how* to address student's diversity in educational resources. *UDLPrinciple_recommends_UDLCkP property* and its inverse *UDLCkP_isRecommendedBy_UDLPrincple* relate *UDLPrinciple* and *UDLCheckPoint. LearningAbility,* the other major class in UDLOntology, models different skills, talents, and interests to address diversity learning styles. *LearningAbility* related to the UDL Guidelines through its two classes, *UDLCheckPoint* and *UDLPrinciple*, by two properties and its corresponding inverse: *learningAbilityMatchUDLCkP* and *learningAbilityMatchUDLPrinciple* respectively.

Students and teachers are the stakeholders that would benefit from UDLOntology. Students concept is represented by *UDLLearner* class, that also extends from AccessibleOCW. It is defined by data property *hasProfile and* two object properties, *learner hasLearningAbility* and *learnerHasAccess. learner hasLearningAbility* is a relation between *UDLLearner* and *LearningAbility* that defines the learner's strengths used to infer educational resources that best suit it. *learnerHasAccess defines the relation between UDLLearner and EducationalResource,* and it is inferred by UDLOntology. It models educational resources whose characteristics are the one recommended by checkpoints that addresses the learner's learning abilities. *hasProfile* data property allows to annotate the learner's description. Regarding teachers, UDLTeacher is defined by teacherWorkWithLearningAbility, teacherApplyUDLPrinciple and teacherApplyUDLCheckPoint properties. teacherWorkWithLearningAbiliy models the relation between UDLTeacher and LearningAbility, for teacher to define for which learning styles it will design educational resources. teacherApplyUDLPrinciple and teacherApplyUDLCheckPoint are object properties that link UDLTeacher with UDLPrincple and UDLCheckPoint respectively. These properties are inferred by UDLOntology.

For educational resources' features, three main classes are modeled: *EducationalResource*, *AccessMode* and *ContentAdaptation*. They all extended from AccessibleOCW, where educational resources are defined by properties based on IMS DRD specifications.

The implementation of instances for UDLPrinciple is out of the scope of this thesis. For UDLCheckpoint, the instances CkP are implemented to address recommendations for content adaption and access mode to educational resources.

To verify the adequacy of the ontology in the inference of specific educational materials for specifics skills some common learning abilities to students with Down syndrome are modelled. The ontology is consistent to produce the expected inferences for learners' preferences. However, further work is required in order to be proved its domain adequacy by specialist of the educational domain.

An education that values and enhances the skills and strengths of each student incorporates important advantages for learners and educators. This work contributes towards building an inclusive and equity education by modelling UDL Guidelines to recommend curricula design and access to educational resource for all.

As shown in the evaluation phase, it is fundamental for the quality and usefulness of the ontology the participation of diversity of students, teachers, domain experts, among other actors. Students are the center on education systems, and their participation is a key contribution.

Even though the prototype is incomplete, this work has shown how UDLOntology can assist to infer educational resources that best suits specific learning abilities and skills, based on UDL recommendations for students and teachers benefit.

As future work, it is necessary to insert new educational resources, complementing UDLOntology, and mapping the learning and strength skills of students with intellectual disabilities to the three principles of the UDL Guidelines: Commitment, Representation and Action and Expression, contributing to the development of expert learners in accordance with UDL objectives. We also plan to add UDLOntology to a course authoring platform to guide teachers in creating educational resources that adapt to the learning skills of each student during their course design.

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APPENDICES

APPENDIX A: Systematic Bibliography Mapping

This section presents a comprehensive literature review on ontologies in the domain of education and disability, inclusive education, intellectual disabilities, learning abilities and UDL performed following the guidelines of a systematic bibliography mapping. The review had no specific period restriction, although preference to the last five years was given. The first review was an informal and general Google search. We combined the following keywords in Spanish and their equivalent in English in different ways: inclusive education and UDL with web accessibility, high and university education, cognitive accessibility, learning difficulties, down syndrome education, educational content-design-evaluation, The first search presented medical and psychology references, organizations and institutions that work with people with intellectual disabilities (ID) and inclusive education, and articles on technology and inclusive education, web accessibility standards, and information on UDL. From the search we discard medical and psychological technical references. We then filtered standards, guides and recommendations on accessibility, inclusive education design and evaluation from organizations and institutions specialized on this domain. From ten articles on technology on 2014-2019 period, after reading the abstracts, we selected those that addressed the design and / or evaluation and / or recommendations and / or implementation of web and content and learning accessibility. On a second phase we looked for published research on ontologies in the domain of disabilities and education. It involved searching IEEExplore, Google Scholar, ReserachGate and SpringerLink. This new search retrieved 20 papers from the period 2000-2019 that are in the domain after reviewed the abstracts, conclusion and references. We filtered those that addresses ontologies in education, accessibility, and disability. We then proceed to the third phase where we look individually those references mention in the papers filtered in previous phase, and that were not already shown on first phase neither and second phase. Table 5 presents part of the selected bibliography from the criteria described above. Because the COVID-19 pandemic was declared in the middle of the of thesis development, another literature reviewed searched was done on education, inclusive education and COVID-19 for new research that could have come up.

because the pandemic effect in education.

Table 5 Selected Bibliography

Title	First Author	Date
Deployment of Ontologies for an Effective Design of Collaborative Learning Scenarios	Isotani and Mizoguchi	2014
An Ontology-Based Model for Student Representation in Intelligent Tutoring Systems for Distance Learning	Panagiotopoulos, Kalou	2012
Diseñadores instruccionales del SXXi	A.Sharif	jul-05
Personalised Learning Materials Based on Dyslexia types: Ontological Approach	Aisha Yaquob Alsobhi	2015
Effect of Universal Design for Learning. Application on e-leraning	Al-Azawei, Ahmed	2017
Evaluation of Virtual Learning Environments for the Teaching of Students With Down Syndrome	Ameliara F. S. de Miranda	2017
Evaluation of virtual learning environments for the teaching of students with down syndrome	Ameliaria Miranda	5-8 Oct. 2017
Inclusive Learner Model for Adaptive Recommendations in Virtual Education	Carolina Mejia	3-7 July 2017
Considering Student Personal Needs and Preferences and Accessible Learning Objects to Adapt Moodle Learning Platform	Concha Batanero	2014
Adapting e-learning and learning services for people with disabilities	Douce, Christopher	2010
THE REASONING PROCESSES FOR SELECTING TEACHING PRACTICES FOR STUDENTS WITH IMPAIRMENT	Eiman Almami	2014
Towards an ontology-based representation of accessibility profiles for learners	Elias M	2016
Reading comprehension in children with Down syndrome	Glynis Law	2015
An ontological network to identify accessibility metadata in learning objects: an approach based on Web Content Accessibility Guidelines, schemas, and disabilities analysis	Ingavelez-Guerra	14-16 Nov. 2018
Design of Mobile Applications for People with Intellectual Disabilities	Jan Dekelver	2015
A Virtual Repository of Learning Objects to Support Literacy of SEN Children	Janio Jadán-Guerrero	13 July 2015
Learning Models for the Integration of Adaptive Educational Games in Virtual Learning Environments	Javier Torrente	2008
un sistema de apoyos centrado en la persona. mejoras en la calidad de vida a través de los apoyos	Jos van Loon	2009
Disability-Aware Software Engineering for Improved System Accessibility and Usability	Julius T. Nganji	2011
Facilitating learning resource retrieval for students with disabilities through an ontology-driven and disability-aware virtual learning environment	Julius T. Nganji	2015
ONTOLOGY-BASED E-LEARNING PERSONALISATION FOR DISABLED STUDENTS IN HIGHER EDUCATION	Julius T. Nganji	2011
Personalizing learning materials for students with multiple disabilities in virtual learning environments	Julius T. Nganji	2015

Personalizing learning materials for students with multiple disabilities in virtual learning environments	Julius T. Nganji	2015
Hybrid ontology based e - Learning expert system for children with Autism	Karthika Venkatesan	2013
Reading interventions for children with Down syndrome	Kelly Burgoyne	
A MDA-based Approach for Enabling Accessibility Adaptation of User Interface for Disabled People	Lamia Zouhaier ,	2014
MODELO ADAPTATIVO PARA LA CARACTERIZACIÓN DE DIFICULTADES/DISCAPACIDADES EN UN AMBIENTE VIRTUAL EDUCATIVO	LANCHEROS-CUESTA, DIANA	2012
APLICACIONES INFORMÁTICAS DIRIGIDAS A JÓVENES Y ADULTOS CON DISCAPACIDAD INTELECTUAL PARA EL DESARROLLO DE LAS ÁREAS DE APOYO	m. e. baños-garcía	2018
Synchronous virtual classroom for student with ADHD disorder	M. Ibrahim	13-15 July 2016
On Personalized Adaptation of Learning Environments	Mariia Gavriushenko	2017
Ontology-Based Representation of Learner Profiles for Accessible OpenCourseWare Systems -	Mirette Elias	oct-17
Towards an Ontology-based Representation of Accessibility Profiles for Learners	Mirette Elias	2016
Ontology-Based Representation for Accessible OpenCourseWare Systems†	Mirette Elias	2018
Learning technologies for people with disabilities	Mohsen Laabidi	2014
An Ontological Learning Management System	Monika Rani, Kumar Vaibhav	2016
An Ontology-based Adaptive Personalized E-learning System, Assisted by Software Agents on Cloud Storage	Monika Rani, Riju Nayak	2015
Accessibility Metadata to improve OER Adaptability	Motz, Regina	2016
A Harmonised Methodology towards Measuring Accessibility	Mourouzis	2009
A Study on Using Learning Management System with Mobile App	Patrick Hung	27-29 July 2015
Guia de evaluacion de la accesibilidad cognitiva de entornos	Plena Inclusión	2018
Tecnologías de la Información y de la Comunicación orientadas a la educación de personas con discapacidad cognitiva	Prefasi, S; Magal, T.; Garde, F. y Giménez, J.L.	2010
PEDAGOGÍAS EMERGENTES EN LA SOCIEDAD DIGITAL	RIVERA,	2019
Changing Education Paradigms	Robinson	2019
Accessibility and Activity-Centered Design for ICT Users: ACCESIBILITIC Ontology	RODRÍGUEZ-FÓRTIZ	2018
Web Accessibility Requirements for Massive Open Online Courses Can MOOCs be really universal and open to anyone?	Sandra Sanchez-Gordon	2014
Ecosistema de accesibilidad en Entornos Virtuales - Estudio de Caso de Moodle	Silvana Tesino	2015
Assistive Technology and Educational Services for Undergraduate Students with Disabilities at Universities in the Northern Thailand	Theeratorn Lersilp	2016
Design of Cognitively Accessible Web Pages	Till Halbach	10-15 Feb. 2010
Design of Cognitively Accessible Web Pages	Till Halbach	2010
An ontology for ICF	WHO-FIC	2011
design Thinking applied to Intellectual disability	Yolanda de la Fuente Robles	jun-14
Assistive e-learning System for the learning disabled	Zinab Pirani	2015

APPENDIX B: UDL Guidelines Checkpoints

The following information is taken from CAST (2020). Detail checkpoints for multiple means of representation principle is presented, since it is the one that it is used as reference for modelling UDLOntology.

In addition, few checkpoints for the other two principles are shown as reference.

REPRESENTATION PRINCIPLE

<u>Perception | Checkpoints</u>

Checkpoint 1.1: offers ways of customizing the display of information. Use flexible materials with settings that can be adjusted based on needs and preferences.

Checkpoint 1.2: offers alternatives for auditory information. Share information in more ways than sound and voice alone.

Checkpoint 1.3: offers alternatives for visual information**.** Share information in more ways than images and text alone.

<u>Language & Symbols | Checkpoints</u>

CHECKPOINT 2.1

Clarify vocabulary and symbols

Construct meaning from words, symbols, and numbers using different representations.

CHECKPOINT 2.2

Clarify syntax and structure

Make the patterns and properties of systems like grammar, musical notation, taxonomies, and equations explicit.

CHECKPOINT 2.3

Support decoding of text, mathematical notation, and symbols

Make sure text and symbols don't get in the way of the learning goal.

CHECKPOINT 2.4

Promote understanding across languages

Use translations, descriptions, movement, and images to support learning in unfamiliar or complex languages.

CHECKPOINT 2.5

Illustrate through multiple media

Make learning come alive with simulations, graphics, activities, and videos.

Comprehension | Checkpoints

CHECKPOINT 3.1

Activate or supply background knowledge

Build connections to prior understandings and experiences.

CHECKPOINT 3.2

Highlight patterns, critical features, big ideas, and relationships

Accentuate important information and how it relates to the learning goal.

CHECKPOINT 3.3

Guide information processing and visualization

Support the process of meaning-making through models, scaffolds, and feedback.

CHECKPOINT 3.4

Maximize transfer and generalization

Apply learning to new contexts.

ENGAGEMENT PRINCIPLE

Recruiting Interest| Checkpoints

Checkpoint 7.1:

Optimize individual choice and autonomy**.** Empower learners to take charge of their own learning.

Checkpoint 7.2

Optimize relevance, value, and authenticity

Connect learning to experiences that are meaningful and valuable.

Checkpoint 7.3

Minimize threats and distractions

Foster a safe space to learn and take risks.

ACTION & EXPRESSION PRINCIPLE

<u>Executive Functions | Checkpoints</u>

CHECKPOINT 6.1

Guide appropriate goal-setting

Practice setting challenging and authentic goals.

CHECKPOINT 6.2

Support planning and strategy development

Formulate reasonable plans for reaching goals.

CHECKPOINT 6.3

Facilitate managing information and resources

Support organization and memory using flexible tools and processes.

CHECKPOINT 6.4

Enhance capacity for monitoring progress

Analyze growth over time and how to build from it.