Revista Brasileira de Informática na Educação – RBIE
Brazilian Journal of Computers in Education
(ISSN online: 2317-6121; print: 1414-5685)
https://sol.sbc.org.br/journals/index.php/rbie

Submission: 17/Feb/2023; Camera ready: 03/Dec/2023; 1st round notif.: 16/May/2023; Edition review: 05/Jan/2024; New version: 27/Jun/2023; Available online: 25/Feb/2024; 2nd round notif.: 27/Nov/2023; Published: 25/Feb/2024;

Semantic Web and Distance Learning: Euphoria, Frustration and Restart

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Abstract

In the nineties, two different trends on distance learning research arose. The first one aimed to create systems able to adapt themselves to students' characteristics, based on instructional and learning theories, while the second aimed to facilitate the creation and management of distance courses, by reusing material. Technologies available so far had hindered the creation of systems able to conjoin the benefits achieved by both groups because adaptive systems were limited to a specific knowledge domain, and almost everything had to be recreated to be used in a different subject. On the other hand, systems able to deal with different subjects could not automatically adapt their content to students' needs. The emergence of the Semantic Web, as well as Learning Objects, led researchers to develop projects based on them to solve that problem. At last, adaptive and reusable courses based on learning theories could be developed. Learning Object Metadata and other standards for e-learning, as well as ontologies about different knowledge domains, students' characteristics and learning theories were the tools that researchers were missing to solve such problems. Although much research and publications have been done in that period, few practical results were noticed, frustrating not only the students, but also the teachers and other education-related workers, as they realized that the level of system autonomy they had aimed for had not been reached. This paper describes the euphoria caused by the Semantic Web, problems related to the engineering of ontologies that led to a frustration period, as well as the current period, in which research was resumed with less ambitious objectives. Thus, some considerations about the future of the Semantic Web Based Learning are presented.

Keywords: *Distance Learning Problems, E-Learning, Learning Management Systems, Adaptive Learning Systems, Ontologies.*

Cite as: Cite as: Branco Neto, W. C. (2023). Semantic Web and Distance Learning: Euphoria, Frustration and Restart. Revista Brasileira de Informática na Educação, vol, 75-97. https://doi.org/10.5753/rbie.2024.3167.

1 Introduction

> The entertainment system was belting out the Beatles' "We Can Work It Out" when the phone rang. When Pete answered, his phone turned the sound down by sending a message to all the other local devices that had a volume control. His sister, Lucy, was on the line from the doctor's office: "Mom needs to see a specialist and then has to have a series of physical therapy sessions. Biweekly or something. I'm going to have my agent set up the appointments." Pete immediately agreed to share the chauffeuring. At the doctor's office, Lucy instructed her Semantic Web agent through her handheld Web browser. The agent promptly retrieved information about Mom's prescribed treatment from the doctor's agent, looked up several lists of providers, and checked for the ones in-plan for Mom's insurance within a 20-mile radius of her home and with a rating of excellent or very good on trusted rating services. It then began trying to find a match between available appointment times (supplied by the agents of individual providers through their Web sites) and Pete's and Lucy's busy schedules. (Berners-Lee et al., 2001)

This quote started the article published in 2001, in the Scientific American magazine, to show what the web's future would be like. According to its authors, many possibilities would arise from the assignment of meaning to the available content. The Semantic Web had been born. Resource Description Framework (RDF), ontologies and other technologies would make it possible to represent content in a machine understandable format, allowing the creation of software agents able to take decisions autonomously. Such autonomy was not possible at that time due to limitations of HTML and other languages used to make content available because they had been thought for creating human-understood pages and not for software agents' understanding.

Since the beginning of the Semantic Web, e-learning researchers realized its potential to solve some problems that challenged the field at that time, i.e. the creation of adaptive content and systems that could be reused. According to Mizoguchi and Bourdeau (2000), in the nineties the effort was focused on the customization of content and teaching-learning strategies based on students' characteristics, regardless of the development process improving, making it difficult to build systems and learning content on a large scale. There was a conflict between high functionality (quality) vs. scalability (quantity). The same authors reported ten weaknesses of Intelligent Instructional Systems (IIS) developed in the nineties that could not be solved by advances that were being made either in inference techniques or in instructional theories, they are (Mizoguchi & Bourdeau, 2000):

1. There was a deep conceptual gap between authoring systems and authors.
2. Authoring tools were neither intelligent nor particularly user-friendly.
3. Building an IIS required a lot of work because it was always built from scratch.
4. Knowledge and components embedded in IISs were rarely sharable or reusable.
5. It was not easy to make sharable specifications of functionalities of components in IISs.

6. It was not easy to compare or cross-assess existing systems.
7. Communication amongst agents and modules in IISs was neither fluent nor principled.
8. Many of the IISs were ignorant of the research results of Instructional Design Science (IS) and Learning Science (LS).
9. The authoring process was not principled.
10. There was a gap between instructional planning for domain knowledge organization and tutoring strategy for dynamic adaptation of the IIS behavior.

There were no technologies that would allow the development of agents able to automatically locate and reuse content available on the Internet for creating course because such content was, usually, spread over HTML pages. So, that work should be done manually. In addition, the rules to adapt content to the student's needs should be created from scratch, considering the specific content of the course, because it was not possible to reuse general rules defined in other systems. In Short, standardization of concepts related to e-learning so that machines could automatically process the meaning of data was missing. Not coincidently, this was one ontologies' goals, the core element of the Semantic Web.

At the same time, Vladan Devedzic published some relevant papers that demonstrated the difficulty in building intelligent instructional systems from the content spread over the Internet (Devedzic, 2004a) (Devedzic, 2004b) (Devedzic, 2006). The lack of interoperability between systems was obvious and, again, the Semantic Web, through ontologies, seemed to be the solution. In such optimistic scenario, many works had been developed and some editions of the International Workshop on Applications of Semantic Web Technologies for E-Learning (SW-EL) had been held to bring together the interested community. In Brazil, in 2007, the Brazilian Workshop on Semantic Web and Education's first edition took place to discuss the topic.

Researchers believed that ontologies that represent knowledge domain and adaptive and learning techniques would permit that content flow over the Internet, to be processed in an automatic way by software agents aiming at creating lessons and courses that could be adapted to student's characteristics.

The Hype Cycle methodology, developed by the North American research and advisory firm Gartner (http://gartner.com), aims to represent the maturity, adoption, and application of specific technologies. Devedzic (2016) presents a variant of this graph to explain the interest in the application of the Semantic Web in education (Figure 1).

Devedzic (2016) points that the time t1 happened around 2005-2006, and the time t2 happened around 2011. In the meantime, many researchers migrated to other research areas and the lack of interest in Semantic Web in education was growing. Probably the main hurdles to be overcome were the lack of a methodology for ontologies' development and the hardship to define a common vocabulary. As posteriorly mentioned, it is possible that the ontologies' attained success in other areas of knowledge was not the same in education due to the topic's inherent subjectivity. Different theories and approaches exist in order to define the psych pedagogical aspects involved, learning theories, the relations between students and teachers, making it difficult to standardize a vocabulary which can be represented by an ontology.

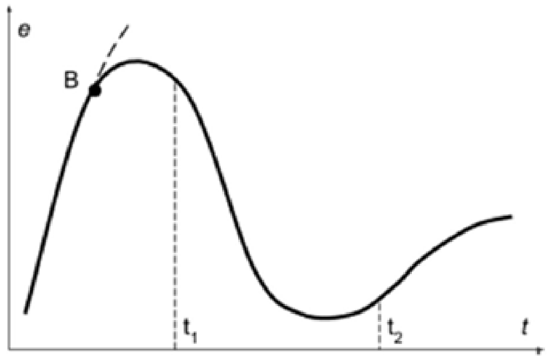

Figure 1: Hype cycle adapted to Semantic Web in education.

After frustration period interest has risen again, some technologies have matured and others have been created, the experience in the first projects could be used to improve ideas and assist in the design of new projects.

Based on the Hype Cycle, this paper discusses past expectations about the benefits that the Semantic Web would bring to education; it analyzes what happened in these years and why; and presents some trends for the field in the future.

This paper´s roadmap is similar to Devedzic (2016), the main difference between them is that Devedzic has played a major role in such history and contributed a lot with it, which makes it possible for him to write a paper from his point of view, using a few references. On the Other hand, this paper´s author was a spectator and needed to use other authors to support his ideas. Thus, as its main contribution, this paper presents the ideas described by Devedzic (2016), supporting them on other relevant researchers and complementing them whenever possible with more recent work, which demonstrates what occurred in the area following Devedzic's publication in 2016.

Aiming to achieve the proposed objectives, after reading Devedzic (2016) and Mizoguchi and Bourdeau (2016), all papers related to the application of ontologies or other semantic web technologies in education cited by them have been read and summarized. In addition, bibliographic research was carried out with the terms: ((semantic web or ontology) and (distance learning or e-learning or education)), from 2016, in order to know what has been done since then.

2 Distance Learning in the 20th century

Distance Learning (DL) is a teaching-learning modality that usually happens in a different place than the teacher and requires special techniques for course planning, distinguished instructional approaches, special communication methods, as well as specific organizational and administrative structure (Moore & Kearsley, 1996).

The focus of the DL has been modified as new technologies appeared. Until the early 90s, the key point was the freedom in space and time that it brought, through a self-learning process based on books, audio and video tapes, and CD-ROM. This freedom has been replaced by virtual approximation since network technologies have been made available and virtual learning environments have been bringing teachers and students together in real time.

E-learning arose from the integration of the web to past practices of Distance Learning. Due to the euphoria of this new possibility, the first systems were developed without proper planning. They were only adaptations of the instructional programs previously distributed on CD-ROM. In that period, it was necessary to create a complete structure for each new course, as it was impossible to reuse resources and services.

As time went by, the number of courses and students increased. Providing structures able to perform basic functions that could be used in different courses was necessary. Faced with these challenges and thanks to the growth of the teams that built such systems, the concept of Learning Management Systems (LMS) emerged in the early nineties.

LMS are specialized systems that provide education and training following the distance learning paradigm (Avgeriou et al., 2003). The arising of LMS provided an even faster development of the e-learning, as they were not designed for a specific course or subject. They only offered a framework to be filled with the content to be taught, thus facilitating its reuse. LMS met the need for an organizational and administrative structure cited by Moore and Kearsley (1996). Moodle (https://moodle.com) and Blackboard (https://www.blackboard.com/) are important LMS used all around the world.

The desire to facilitate the creation of systems and learning content also led to the concept of Learning Objects (LO) (Schoening, 1998). The greatest advantage of LO is their reusability, because once created and made available, they can be used by any LMS that supports the search and linking of these resources.

Thus, the creation of a DL course became an easier task, since teachers did not need to prepare all the material, they only needed to integrate the LO that interests them into their courses. Despite this evolution, it was still difficult to locate LO with the desired content, pedagogical approach, type of media, etc. In addition, LMS that were very efficient in terms of activity management, were educationally poor.

While LMS and LO were arising, another group of researchers had been developing projects aiming to improve the virtual approximation and to assist students in their learning process. They defined that their main line of research would be to search for the students' identity in order to adapt systems to their needs, characteristics, and learning difficulties. Intelligent Tutoring Systems (ITS) (Murray, 1999; Self, 1999; Vicari & Giraffa, 2003) and Adaptive Hypermedia Systems (AHS) were their main approaches (Brusilovsky, 1996, 2001).

Self (1999) defines ITS as "computer-based learning systems which attempt to adapt to the needs of learners and are therefore the only such systems which attempt to 'care' about learners in that sense". From an educational perspective, ITS are like a teacher who uses different approaches to teach different students. To accomplish that object, ITS needs to know, besides the subject being taught, the students' characteristics and needs, and instructional theories. Two thousand, three hundred and sixty-six papers were returned by Science Direct when searching for "intelligent tutoring system", the first ones date from 1998 and the last ones from 2022, which demonstrates how important this topic is. Some commercial examples of ITS are: MATHia (https://www.carnegielearning.com/solutions/math/mathia/), from Carnegie Mellow University, Alta (https://www.knewton.com/what-is-alta/), from John Wiley & Sons, Inc, and others.

Considering the DL migration from CD to the web, technologies which make ITS' adaption possible in the web were required. According to Brusilovsky (1996, 2001), AHS "build a model of the individual user and apply it for adaptation to that user, for example, to adapt the content of a hypermedia page to the user's knowledge and goals, or to suggest the most relevant links to follow". In educational context, ITS and AHS together have been used to adapt content over the web to students, considering their prior knowledge and learning style, and different instructional theories.

Despite the success of those technologies in specific case studies, several factors hindered the development of systems with such features. According to Mizoguchi and Bourdeau (2000), the strong relationship between knowledge domain and adaptive and learning techniques made it difficult to reuse systems or courses. This problem turned the development process expensive and slow, resulting in most commercial education systems of that time lacking such features. AHS and ITS met the need for special techniques to plan the course and differentiated instructional approaches mentioned by Moore and Kearsley (1996). However, they were not integrated with the LMS that provided the administrative part and facilitated the construction of the courses.

Analyzing the technologies that marked the nineties - ITS, AHS, LMS and LO - the existence of two different trends on distance learning research, with different objectives and some conflicting points was evident. As the purpose of part of the researchers was to make student learning more productive with the use of ITS and AHS, others aimed to facilitate the construction and availability of courses and educational materials through LMS and LO. Over the course of time, it became clear that building e-learning systems that incorporated the advances in all these areas was a major challenge.

Mizoguchi and Bourdeau (2000) discussed problems faced by researchers and pointed out that the solution was supposed to be based on knowledge and ontology engineering. They also introduced a road map towards the new direction. According to them, "Challenges are threefold: 1) the sharing among humans, and through computer technology, of the knowledge we have accumulated thus far. 2) The sharing extended from among humans to among computers, 3) The operationalization of this knowledge to support the building of IISs".

3 Euphoria: The Semantic web has been born (from 2000 to 2006)

The Semantic Web seemed to be the ideal structure for e-learning to develop in. As it integrated different technologies developed at the end of the 20th century it makes it possible to have quality and scalability. According to Hendler et al. (2002), "The Semantic Web is an extension of the current Web in which information is given well-defined meaning, better enabling computers and people to work in cooperation".

It is true that Pete and Lucy's agents, that illustrated the example presented in section 1, did not perform their tasks on the web that existed at the beginning of the century. Documents written in natural language and formatted with HTML lack the necessary structure so that machines can make so many decisions without human intervention. At that time, it was imagined that the whole story would be possible thanks to the Semantic Web, which provides a framework able to allow data to be shared and reused between applications, companies, and communities.

According to Berners-Lee (1999), the consolidation of the Semantic Web would require the development of:

- Languages that can be processed by the computer to express metadata about documents.
- Standardized terminologies on the most diverse domains.
- Tools and architectures based on these languages and terminologies to provide support for searching, accessing, presenting, and maintaining information.

A key technology developed for the Semantic Web is the Resource Description Framework (RDF). According to Manola and Miller (2004), it is a language used to represent information about resources on the World Wide Web. RDF is the basis that enables the creation of metadata that can be analyzed and processed by computers autonomously. RDF, alongside XML, met the need for a language to express metadata about documents.

The next step towards the solution was to create standardized terminologies through ontologies. As stated by Gruber (1993), "ontology is a specification of a conceptualization". Noy et al. (2001) defined that "An ontology is an explicit specification of the concepts in a domain and the relationships between them, which provide a formal vocabulary for the exchange of information".

In practical terms, ontologies help people to model the knowledge domain providing a well-defined vocabulary that makes it easier to build systems and share knowledge. Since the Web Ontology Language (OWL) had been adopted as the standard language to represent ontologies (M. K. Smith et al., 2004), the entire support structure was ready. It was only up to the researchers to start building them.

Thereby, many people started building ontologies that would enable the development of e-learning systems capable of adapting themselves to the user's needs. These systems were based on appropriate instructional theories, and they incorporated the benefits to create and manage courses offered by the LMS and LO.

Many architectures, ontologies and systems were proposed in the early 2000s, presenting the Semantic Web as the solution. In general, all of them had a common purpose, to allow constructing systems that would join the advantages to create and manage the courses offered by LMS and LO with the advances brought by STI and SHA regarding students' learning. Among other important research papers, we can stand out:

- Brusilovsky (2003) presented Knowledge Tree, "an architecture for adaptive eLearning based on distributed re-usable intelligent learning activities". It was a distributed architecture based on re-using of educational activities, which is the reason for the LMS' success, aiming to replace the monolithic style that was present in most of the adaptive e-learning tools in that time. The architecture was composed of three kinds of servers: activity servers, learning portals, and student model servers.
- Simic et al. (2004) proposed Multitutor. "Multitutor is designed as a Web-classroom client-server system, ontologically founded, and is built using modern intelligent and Web-related technologies. This system enables the teachers to develop tutoring systems for any course. The teacher must define the metadata of the course: chapters, the lessons and the tests,

the references of the learning materials". Despite they have used Multitutor to teach only telecommunication, the authors point out that they developed a domain independent system that provided a useful environment for many courses. Multitutor provided two main users, the teacher and the student, who access the content stored on the Web server through any browser. The Multitutor had three fundamental modules: 1) Expert, which was used by teachers in order to create the course content; 2) Student model, where the student's personal data and results were stored; 3) Tutor, responsible for pedagogical strategies. Tutor analyzed the data coming from the student model and decided what content should be presented, when and how. The proposed architecture, a priori, did not present great advances when compared to ITS. But the difference was how each module was implemented, based on metadata and ontologies. The system provided an ontology for the course and another for the student model.

- OntAWare was a system proposed Holohan et al. (2005) that supported the authorship and management of instructional content. It received an OWL ontology as input and generated several static courses as output. After selecting the ontology, the user must choose which concept (represented by an ontology class) is the main learning objective, so that the system could generate LO based on it. The course created included a lesson built automatically from the ontology information (HTML file) and by LO, which can be HTML, PPT, PDF files, etc. Besides that, OntAWare generated courses that could be dynamically adapted based on users' needs. But unlike the static course, which could be run in any web browser, the dynamic course required a proprietary system.

- Denaux et al. (2005) presented OntoAIMS and Power et al. (2005) proposed MOT. Each of them had their own specific characteristics, but, in general, they were similar to the systems described earlier

Several papers were published on the subject in that period, many promising case studies, prototypes tested and successfully validated. Everything suggested that the e-learning´s problems would be solved soon. The conflict between high functionality (quality) vs. scalability (quantity) would no longer exist.

4 Frustration: The ontologies' hindrance (from 2006 to 2011)

According to Devedzic (2016), the dashed line after point B in Figure 1 represents the existence of educational agents and servers everywhere, full of content semantically described flowing among authoring systems, revolutionizing the way e-learning would happen. But it was just a projection, as the graph shows, the reality was different. Interest in the subject began to decrease, as the promises made at the beginning of the century had not been fulfilled.

Shah (2012) presents a review about Semantic Web for e-learning, pointing out its benefits and making people imagine how good it would be when all those benefits came true. In addition, she listed tools, some of them were commercial tools, as WebCT and Blackboard, and other prototypes based on ontologies, RDF and so on, as Conzilla, Edutella and PADLR (Personalized Access to Distributed Learning Repositories). Even though it has been written more than 10 years after the Semantic Web had been born, Shah's paper shows that technologies in prototypes were still not present in commercial systems.

From the beginning, all researchers' bets were related to the development of ontologies, which could be represented by a standard language, OWL. Too many articles were returned when searching on websites like ScienceDirect, IEEE Explore, ACM Digital Library and Springer. Systems based on such ontologies were presented and discussed, always with promising results. However, little practical change had been being perceived.

Gradually it was understood that the language to represent ontologies was not the only relevant aspect, since the processes of construction, maintenance and integration of ontologies were not trivial. Gasevic et al. (2011) stated that "ontology development and maintenance remain the key research challenges to be solved before ontology-enhanced learning environments are widely used".

A survey carried out in 2006 with 627 researchers and developers in the Semantic Web field identified that 60% of them did not use any pre-established methodology to create their ontologies. It was an ad hoc process, often based on trial and error (Cardoso, 2007). Those practices went on and they have, possibly, contributed to the failure of many projects, as well as the lack of a development process led to the period known as the Software Crisis in the 1970s. Ontology development was hindered because there were few trained professionals who could build ontologies. As shown by Neuhaus et al. (2011), there was a great demand for trained ontologists, but few formal courses or training on the subject, making it difficult for companies to identify qualified candidates.

There was no methodology that would help in the development of ontologies, there were not enough trained people, and even so lots of ontologies had been built. However, the reuse and integration of these ontologies were incipient. According to B. Smith et al. (2007), the success of ontologies at that time led to a proliferation of ontologies, which hindered their integration, a difficult problem to solve.

Ontology development and integration, which are complex jobs in any knowledge domain, seems even more challenging when it comes to education. The existence of divergent theories, divergent visions regarding the same object makes standardizing a vocabulary even harder. As George and Lal (2019) point out, "While ontology has the vantage of being reused by any person on the Web, the names given to the different classes, properties, and individuals of the ontology model are a challenge."

Another relevant point was the longevity of the projects. Because it was strongly related to the academic area, the Semantic Web suffered with the interruption of projects developed as research projects and course completion works. Many of them were not continued by their authors after finishing their courses, nor by other research group members.

Few studies had demonstrated the evolution of a long-term project, as can be seen in the research performed by Mizoguchi and his group (Bourdeau et al., 2007; Hayashi et al., 2009; Mizoguchi & Bourdeau, 2000). They presented and improved OMNIBUS, an ontology which represents knowledge about different learning and instructional theories. In addition, they proposed SMARTIES, an IMS-LD compliant authoring system to create instructional scenarios based on the OMNIBUS ontology. Its authors highlighted that this was the result of an eight-year work carried out based on the ideas of Mizoguchi and Bourdeau (2000). Generating courses in the IMS-LD standard was pointed out as a relevant factor for the success of that work, since the generated courses could be run in any IMS-LD compliant Learning Management System.

These factors meant that most initiatives around the world did not lead to the transformation proposed by the Semantic Web in e-learning. When realizing that the solution to these problems was more complex than previously thought, researchers' interest in the area was reduced due to the delay in reaching the proposed objectives, causing them to be greatly frustrated.

5 Restart: is it possible Now? (from 2011 to 2023)

After living the dream of the Semantic Web, sharing initial expectations, as well as experiencing frustration due to the lack of practical results, it is easy to realize that this was a particularly challenging project. It seems the architect designed a wonderful project, but without first checking with engineers and builders if they could build it. The necessary tools were provided, as the architecture of the Semantic Web was clearly defined as a set of layers that indicates the technologies needed for its implementation. Probably, what was missing was to check if the engineers and builders knew how to use them and, especially, if they were willing to use them, if they were able to realize that the cost-benefit ratio of this new proposal to organize the data was advantageous.

Aware of the past mistakes and the limitations of the Semantic Web, a new period began, around 2011 (instant t2 in Figure 1), marked by a reduction in expectations. The noun Semantic Web gave way to less presumptuous terms like Linked Data (Linked Data) and Linked Open Data (Berners-Lee, 2006). The term Knowledge Graph was coined in 2012 by some Google engineers to refer to semantic knowledge's use in web search. "From a broader perspective, any graph-based representation of some knowledge could be considered a knowledge graph (this would include any kind of RDF dataset, as well as description logic ontologies" (Paulheim, 2017). That change in perspective provided good progress in other sectors after the period of frustration, as demonstrated by the fact that 75% of the companies on the Fortune 500 list in 2018 already had some projects related to semantics or Linked Data (Cagle, 2018).

However, even considering advances brought by research on LOD and Knowledge Graphs, few practical results could be perceived specifically in the education domain.

Regarding education, many research projects have been developed in such new period, in order to solve e-learning's problems through Semantic Web technologies. They are still the same problems that generated the euphoria as soon as the Semantic Web was proposed. Among others, there are:

- Yehia et al. (2012)) proposed POLSS (Personal Ontology Learning Style System), whose main function is to help users find teaching resources quickly and accurately according to their interests and learning style, which are represented in an ontology.
- Chu and Lee (2013) created ORALS (Ontology-Based Assistant Learning System) by integrating Jena, Graphviz and SPARQL API. It provides online editing ontology and rules that simplify the processes of ontology's development, through search concept and reasoning items, visualized as concept maps.

- Isotani et al. (2013) presented CHOCOLATO, an intelligent authoring tool based on "Semantic Web technologies (e.g. ontologies) in order to represent knowledge about different pedagogies and practices related to collaboration". They undertake an experiment with 58 teachers that created collaborative learning scenarios with and without their authoring tool and with 218 students from a Brazilian public school. The results suggest that the guidance provided by CHOCOLATO does help novice teachers plan collaborative learning scenarios. They also suggest that the continuous utilization of well-designed theory-based collaborative learning activities create favorable conditions so students can improve their overall performance throughout the school year.
- Luna et al. (2015) proposed an approach based on an ontology that represents the interaction process between users and contents. The methodology consists of three stages. Some experiments were carried out in order to evaluate it and they set it up as future works, including it in recommender systems.
- Jevsikova et al. (2017) carried out a systematic review in order to analyze the problem of personalizing learning by applying RDF in this period. The research was carried out in the Clarivate Analytics Web of Science database, with a search filter from 2009 to 2016 and returned 381 documents. After data analysis, they stated that "RDF proves to be a widely used Semantic Web framework to solve the problems address in the article" and they present a recommender system and an original methodology to create RDF triples that lead to the development of corresponding OWL ontologies.

During this period, many works related in this line were carried out in Brazil. Searching Brazilian Journal of Computers in Education's database, and the Brazilian Symposium of Computers in Education's annals and its workshops it is possible to identify multiple articles offering methodologies and tools that use Semantic Web's technologies to solve education-related issues. Among others, stand out:

- The work of Bittencourt and Costa (2011), published during the transition between frustration and restart periods, makes an important contribution by mentioning Semantic Web's use in building adaptive educational environments. The work suggests, initially, four research questions, they are: How to conceive semantic and adaptive educational virtual environments? How to guarantee knowledge reuse? How to build a model based on software reuse? How to guarantee interoperability between applications? In sequence, they present a concept model, a computational model and an infrastructure model, which demonstrate how to answer each one of these questions, opening up a vast possibilities range for future research and improvements in each created model.
- Rezende et al. (2015) present PERSONNA, a student's context and profile ontology, which aims to standardize student's information, considering the context, to facilitate learning objects' recommendation process. In their conclusion, the authors claim that "The use of ontologies in educational systems favors the applications, because a formally defined ontology represents a domain and its collective knowledge's terminology".
- Challco et al. (2016) offer a set of ontological structures which make the application of gamification possible in order to solve motivation problems in different Computer Supported Collaborative Learning's scenarios. As a result, the authors state that "we believe

that the results of this work are the first steps in order to create new semantic web authoring tools that will provide assistance and recommendation to gamify CL scenarios, making them more motivating and engaging to the learners".

- Reis et al. (2017), Reis et al. (2015) e Reis et al. (2016) present an ontological structure of Collaborative Affective Roles defined in order to represent the relation between the student's personality traits and collaborative role. These works' goals go beyond representation of student's profile or an individualized learning-teaching strategy. They aim to represent how the scholar's characteristics influence his or her interactions and, consequently, learning in a collaborative system, which makes the challenge even bigger.

- Oliveira et al. (2020) present an ontology to classify learning objects. Among other relevant aspects, the authors highlight that it uses Bloom's Taxonomy to match the objects to different learning goals and that the authors follow the ontology development methodology proposed byNoy et al. (2001). The use of a widespread and well-accepted theory in the education for modeling the ontology is noticed in this article, which favors its acceptance and integration, besides following a methodology for developing, which aims to reduce the probability of errors in the resulting ontology.

Besides the works described above, many others were published in Brazil during this period with promising results regarding this new unifying moment between ontologies and the adaptive educational systems. Some examples are: Challenges in Creating Adaptive Instructional Materials and their Use in Popular E-Learning Environments (Publio et al., 2013), Challenge of the Use of Gamification in Intelligent Tutoring Systems Based on Semantic Web (Andrade et al., 2013), OBAA-LEME: A Learning Object Metadata Content Editor Supported by Application Profiles and Educational Metadata Ontologies (Behr et al., 2014), Systematic Review of the Use of the Semantic Web for Virtual Learning Environments (Pereira & Siqueira, 2014), Semantic Description of Learning Experience Based on xAPI Specification (Rabelo et al., 2015), Comparative Analysis of Association Approaches between Felder–Silverman Learning Styles and IEEE LOM Standard Metadata (Aguiar et al., 2015), Training Monitoring in e-learning Made Possible by the Integration between Learning Management Systems and Personal Learning Environment (Melo Filho et al., 2014) and A Reference Ontology for Pedagogical Architectures (Silveira et al., 2021).

Analyzing those works and others developed in the new period of the Semantic Web, it is noticed that new models and prototypes have been proposed. Many interesting ideas were suggested, but the initial problems remain, as well as the hope they can be solved by the same technologies of the past. During their work's introduction, Rezende et al. (2015), highlight the hardship in standardizing the educational area, a previously pointed out issue, claiming that "the available standards in literature present a large diversity of elements and approaches, which compromises data interoperability. The lack of standardization in the instances creates several issues, with emphasis on the lack of data reliability, integrity and quality".

It is possible to notice that, despite the quality of the results and progress achieved by this and other works, the solution for the lack of standardization and interoperability is still not clear. We actually have commercial LMS that make course creation and management easier, and lots of interesting proposals that aim to adapt content based on learning theories and students' needs. However, we still do not have one LMS that attends all requirements together. Sometimes, it seems that the research area is going around in circles. While some researchers get tired and drop it, other ones get interested and (re)start research projects like the ones carried out in the first period, with some advances in theoretical and academic aspects, but without the desired practical relevance.

Rahayu et al. (2022) carried out a systematic review about ontology use in recommender systems for e-learning which corroborates the problems presented. They searched for "(learner OR student) AND (adapt* OR personali* OR recommend* OR intelligent*) AND ontology" in journal articles published from 2010 to 2020. This initial search returned 90,619 articles across 7 databases (i.e., IEEE Xplore, JSTOR, Proquest, SAGE Journals, Science Direct, SpringerLink, and Taylor & Francis Online). After some steps, 72 articles were picked up for full reading and, at last, 28 were selected. Some interesting findings are:

- Most prototypes of the recommendation systems are standalone systems, i.e they are not integrated into the LMS.
- Only five studies documented ontology building methodologies. "Hence, we predict that the remainder of the major research would have created ontologies from scratch tailored to the specific courses" (Rahayu et al., 2022).
- Interoperability standards are rarely employed.

The difficulty to build consensual and quality ontologies in any field remains and it seems to be the hardest hurdle. Lopes et al. (2018) analyzed ontologies available in the LOV repository (https://lov.linkeddata.es/dataset/lov/) and concluded that only 30.40% of them have been reused. This number rises to 78.02% when only considering ontologies supported by W3C, which demonstrates the importance of associations acting as articulators or regulators of this process.

The systematic review undertook by Tarus et al. (2018) recovered 229 papers about e-learning recommendation systems based on ontologies published between 2005 and 2014 and, out of those, selected 36 papers for a detailed analysis. The obtained conclusion corroborates the already pointed out issue, when the authors state that "There are still some challenges faced by researchers in this field. First, creating ontologies is a difficult and time-consuming process which requires skills in knowledge engineering. Furthermore, acquisition of ontology knowledge in the context of e-learning requires experts in this area. Secondly, evaluation of ontology-based recommenders for e-learning is another challenge experienced by many researchers in the area. This is partly due to scarcity of available standard public e-learning datasets for recommender systems evaluation".

Some activities towards reuse were started during frustration period and have been successful in the new moment of the Semantic Web. The creation of OBO Foundry - Open Biological and Biomedical Ontology (http://www.obofoundry.org/) is a successful example. It was born with the mission of developing a family of interoperable ontologies that are logically well-formed and scientifically accurate. The relevant point of this initiative lies in the effort to build general ontologies which will serve as the basis for the development of specific ontologies. Analyzing this success case, three important aspects can be seen:

- The knowledge that many sparse ontologies hinder integration.

- The concern regarding ontology quality, which is expressed at OBO Foundry´s mission.
- The establishment of an association to solve the two previous problems.

Another positive point was the expansion of the International Association for Ontologies and their Applications (http://iaoa.org), founded in 2009. Among its creators is Nicola Guarino, one of the field´s most influential researchers.

However, likely the main transformation that occurred in this period is outside the boundaries of the Semantic Web: It is Web 2.0. In this new approach, the web can be seen as a platform that enables a different user experience through information sharing and collaboration on websites such as blogs, wikis and social medias. According to its creator, "The central principle behind the success of the giants born in the Web 1.0 era who have survived to lead the Web 2.0 era appears to be this, that they have embraced the power of the web to harness collective intelligence" (O'Reilly, 2007). People that have been driving the development of the web today have not realized the benefits of the Semantic Web and have not been involved in semantic annotations and linked data creation, likewise they have been involved with social networks and other collaborative technologies.

After understanding the power of collective intelligence present in Web 2.0 and its ability to engage people in a common purpose, some Semantic Web researchers have been trying to approximate these two perspectives. Kurilovas and Juskeviciene (2015), after a systematic review, presented an ontology that combines learning activities with Web 2.0 tools. Khaled et al. (2019) describe a learning environment that analyses social media posts semantically annotated to make recommendations to the student. Bezerra et al. (2017) describe the PUYW ontology, which takes the user's preferences regarding YouTube videos, channels and playlists, as well as Wikipedia texts, into consideration to base the Youubi recommendation system's decisions.

Sanches et al. (2019) highlight the difficulty of manual semantic annotation and propose an automatic annotation algorithm based on the Open Information Extraction paradigm (Open IE) presented by Etzioni et al. (2008). Phiakoksong et al. (2013) used the Structural Modeling Equation, a statistical technique that explores main concepts and their relationships obtained in empirical data, in order to build an ontology with good teaching practices.

Collaborative tagging has enabled the creation of several folksonomies, which are classification systems in which end users add tags on items online. This bottom-up approach aimed at formalizing knowledge is opposed to the Top-down approach used to build ontologies at the beginning of the Semantic Web and considers the collective intelligence highlighted by O'Reilly.

The use of folksonomies as a basis to create ontologies can facilitate their acceptance on a large scale, since their terms and relationships were not created from the ideas of a small group, but from information processed from millions of users (Gasevic et al., 2011). In addition, methods such as those presented by Alruqimi and Aknin (2019) and Wang et al. (2015) can automatically generate the terminology for a domain and the relationship between its concepts, from the data collected from folksonomies. Algorithms like these have great potential to ensure that the benefits proposed by the Semantic Web at the beginning of the 21th century can finally be achieved, as they facilitate the construction and acceptance of ontologies by users.

Just like Web 2.0, Artificial Intelligence (AI) is another area that showed significant evolution over the past few years. The growing data volume created every day and the rise in processing capacity has made it possible to build even more powerful tools. Artificial Intelligence techniques have been used for mining, classifying, and grouping data and its relations, which serve as a basis for the system's decision making. For example, Support Vector Machines (SVM) and Artificial Neural Networks were successfully used to predict users' interests by Amarasinghe et al. (2019). One chatbot was introduced by Shukla and Verma (2019) in order to make a LMS users' experiences better. Cantabella et al. (2019) used a Big Data framework to analyze students' behaviors. Sivakumar et al. (2015) proposed an architecture capable of: to apply Data Mining Techniques to categorize students learning styles; to apply AI techniques (clustering) to come up with an enhanced new e-learning platform; and to explore contents necessary for learners based on the learning style through the new platform. Santos et al. (2021) introduce a multiagent system with similar goals and promising results.

These techniques' progress allows that ontologies knowledge formalization problem to be solved in the opposite direction. Instead of using traditional Knowledge Engineering techniques, which hardships are well known, more flexible and easier solutions reached through Machine Learning-based approaches solutions can be incorporated to LMS.

After a review about AI techniques applied to e-learning, which led to the study of 207 papers published between 2018 and 2020, Aldahwan and Alsaeed (2020) conclude that LMS still lack in adaptability. According to the authors, "While the state-of-the-art work identifies existing problems and offers potential directions for the implementation of the new program in engineering and education disciplines, the key issues lie in:

- the incorporation of these developments into an all-inclusive program build;
- their techniques integration to allow implementation in real-time;
- the measurement of relevant pedagogical factors for that can be used in algorithms".

While analyzing the last point listed by Aldahwan and Alsaeed (2020) – "the measurement of relevant pedagogical factors for that can be used in algorithms", it can be noted that AI techniques should allow this measurement to be as exact and detailed as possible, so that the generated results can support quality decisions by LMS. In virtue of that, Cantabella et al. (2019) highlight that "There is a need for analytical tools to help analyze LMS data, and to provide new information to develop and even design new eLearning techniques and methodologies, according to several studies", which is the Learning Analytics' goal.

Learning Analytics (LA) is defined on website of LAK11 - the first conference on LA - as "the measurement, collection, analysis, and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs" (Long & Siemens, 2011). As previously mentioned, AI techniques' progress has been making it possible to better know the students and creating adaptive environments in a simpler way than the one required by knowledge formalization and its representation through manually created ontologies. Learning Analytics' importance is evidenced by Lee et al. (2020), as they demonstrate that the number of returned articles in the SCOPUS base after searching for the term "learning analytics", which was 29 in 2011, the first considered year in the study, got to 401 in 2015 and reached 819 articles in 2019, the last considered year in the study.

While problems regarding ontologies' integration and quality will not be completely solved, the effort applied to develop quality ontologies will certainly decrease. As Mizoguchi and Bourdeau (2016) argues, an important point to be considered for the evolution of the area is the creation of a methodology that integrates the top-down and bottom-up approaches to create ontologies. On the other side, progress obtained by AI techniques applied to Learning Analytics are making the interest in its use to solve e-learning issues grow continuously, representing a different approach in order to solve the e-learning standardizing and personalization issue.

The research conducted by Chen et al. (2022) analyzed 4519 published papers between 2000 and 2019 in different bases. Amongst its main conclusions are:

- The interest in applying AI techniques in education is growing. From just over 50 articles found in 2000, there were approximately 350 published papers in 2009. After a fall in the first years of the 2010 decade, confirming the frustration period indicated in the graph created by Devedzic (2016), the number of articles started growing again, surpassing 450 in 2018 and getting up to almost 550 in 2019.
- However, in his conclusion he highlights that "As for AI technologies, ontology use declined, whereas advanced techniques such as ML, ANNs, EDM gained popularity in scenarios such as CSCL."

As this study also points out the cutback in ontologies interest and the growth in other AI techniques, it is possible to notice the large path that must be trod so that all the generated expectations in the beginning of the Semantic Web, relating to its contribution regarding education, can be met and its results perceived by all involved in the process, such as students, professors and managers.

Likely, the creation of hybrid solutions – built from the integration of machine learning techniques such as SVM, ANN, Bayesian Networks, Decision Trees, etc. with knowledge engineering techniques, such as ontologies and logical inferences – is the approach that could lead to new advances and enable practical benefits to be felt by everyone involved in the e-learning process.

In short, Semantic Web's new period has been characterized by:

- the resumption of interest in the field.
- the increasing adoption of the Semantic Web by companies.
- the low adoption of the Semantic Web in education, so far.
- The growth in Artificial Intelligence technique's use with approaches that differ from the ones offered by the Semantic Web.

Taking all these facts into account, integration with Web 2.0 and with other Artificial Intelligence approaches opens a new perspective for the future. According to Anshari et al. (2015), the concepts of Semantic Web and social medias are strategic to, along with other concepts such as Cloud Computing and Big Data, evolve the scenario of online learning resources to generate pervasive knowledge-based systems.

6 Conclusions

From the exposed context and the papers cited in this article, it can be concluded that all expectations of the beginning of the century were partially met. Currently there is published knowledge on how to create ontologies; there are ontologies that model instructional theories and student interaction which make it possible to create adaptive environments; metadata standards to describe learning objects, activities, courses have been established; and tools that benefit from the collective intelligence of Web 2.0 in education have been being developed. But they were only partially met. Even though this exists and works, it has not yet been able fulfill the promises made two decades ago.

The promised benefits do not seem to justify the effort required to annotate resources. There is no collective engagement for the Semantic Web to happen, at least not in the same way as it happened with Web 2.0. Devedzic (2016) argues that the Semantic Web seems like a solution looking for a problem. But the problem exists, perhaps what is missing is to explain it in a simple way so that users can understand it and be able to realize what it will be able to do.

The adoption of semantic technologies by 75% of the companies on the Fortune 500 list in 2018 is a sign that something has been changing. But it also makes it possible to conclude that in education the situation is more difficult, because in the list of the 200 best tools for teaching in 2019 (https://www.toptools4learning.com/) there are no tools explicitly based on the Semantic Web. However, many of these tools use other AI techniques, which goes to show its potential in contributing to build quality educational systems. The approximation of these techniques which, in general, are from the machine learning domain, with ontologies and their formalization tends to be a promising research field in the future.

The subjectivity inherent to Education é another problem to be faced. In other areas, such as Exact and Technological Sciences, definitions are more precise and less controversial. As they deal with experiments related to the laws of chemistry, physics, mathematics, and their derivations, after a result is proved, it is generally recognized by everyone. It is different in Education, however, as even widely accepted theories are questioned by other groups. The existence of different theories on the same subject, often at odds, is part of education and is important for its evolution. Such features make the creation of ontologies that represent a consensus in this area a harder task than in other ones, such as OBO Foundry. Its solution can also depend on the use of other Artificial Intelligence techniques together with ontologies.

Another important point is that people are not concerned with whether the tools they have chosen to assist in their learning are semantically based or not. Just as a home buyer does not want to know the details of its foundation, users do not want to know how the information handled by the systems is organized and stored. For the buyer of the house, what matters about its foundation is that it is solid so that the house does not fall on his head, but more important than that is whether the part he sees meets his needs or not.

Likewise, system's users do not want to know if there are ontologies, semantic annotations, and diverse instructional theories in the systems they use. They just want the system to make it possible for them to learn. At first, it might be surprising that in the first place on the mentioned list is YouTube, which was not originally created for instructional purposes, but has been perceived by users as an effective tool for learning. Despite this fact may seem strange, it really is not, because success does not depend on the intention of those who created a technology, but on the value understood by the users of such technology.

In the top ten positions are Google Search, considered the second-best tool for learning, and Wikipedia, ninth place. Explicitly, these tools are not ontologies, and they have not been developed within the context of the Semantic Web. However, both use semantic resources to organize information.

From these examples, it is easy to see that the success of the Semantic Web applied to e-learning will demand the development of tools that use semantic resources as a means to achieve the purposes considered important by users, i.e. learning. The semantics will be transparent and will serve as a basis to build the systems required by these users. This view is a counterpoint to what has been happening in these two decades, when technology itself has been the main goal and the needs that have guided its development arose from the researchers' own ideas.

Acknowledgements

My special thanks to Beatriz de Bem Castello Branco for her help with English proofreading.

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