Investigating Student and Teacher Perceptions in e-Learning with Learning Analytics and Ontologies

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Abstract—This work is an approach that brings together Learning Analytics and Ontologies for a data classification that promotes improvements and behavioral changes for students and teachers on e-Learning platforms. Combining training courses, dashboards, user's evaluations, and based on Design Science Research (DSR) methodology, artifacts were created. One of the most important artifacts of our work is the Sapes tool that aims to improve students' perceptions of their learning path and to promote a better teacher overview to follow their students' progress. The results showed high approval by the participating students and teachers, who perceived the Sapes tool as a good facilitator of the teaching-learning process, with possibilities for self-monitoring, dynamization of the learning sequence and better interactivity with colleagues, highlighted as absent in standard e-Learning courses. In addition, the application changed the behavior of users towards the content provided by the teacher, with students performing self-management and self-regulation that were not commonly performed previously.

Keywords—Learning Analytics, ontology, Learning Management System, educational technologies

1 Introduction

With the COVID-19 crisis and the wide-spread adoption of asynchronous teaching methods combined with new information technologies for e-Learning, the ongoing debate on how to evaluate, assess, and measure the knowledge of students in this modality grew and has extended the application of technology-enhanced learning environments that provide opportunities for students to self-regulate their learning processes and activities to better achieve intended learning outcomes, as well as help teachers improve their teaching methods [1]. Commonly in this teaching modality, users, both teachers, and students interact with Learning Management Systems (LMS), usually software for management, documenting, tracking, reporting, automating, and delivering educational courses, to gain access to educational content, interaction with peers and teachers, and knowledge assessments. Consequently, in an e-Learning context, a vast amount of data and knowledge are gathered by these LMS [2]. The data gathered from LMS are used by educational organizations for purposes such as business intelligence, evaluations and descriptive and predictive analytics as students using an LMS have their clicks, navigation patterns, interactions, and information flow recorded [3, 4].

Current LMS technologies include intelligent algorithms to make automated recommendations based on a user's skill profile, as well as extract metadata from learning materials to make those recommendations even more accurate [2].

LMS can be designed to identify training and learning gaps using analytical data, often through Learning Analytics (LA) [4]. LA is the measurement, collection, analysis and communication of data about students and their contexts, with the aim of understanding and optimizing learning and the environments in which it takes place, helping teachers in their teaching process, as it is possible to make early pedagogical decisions due to predictions and better data visualization.

Although LA tools are commonly used, there are no flexible monitoring or diagnostic approaches that can be applied to a wide variety of data and related to the context of didactic-pedagogical action planning. Thus, this work investigated a research gap using ontologies in the educational context and in coordination with LA. The use of ontology was motivated by the fact that it formally represents abstract concepts and provides the ability to infer knowledge about the information represented. The use of these elements together with ontologies contributes to the improvement of the teaching-learning process and, according to the survey data, the relation-ship between these terms allowed decisions to be taken to support gains in the instructional path.

With the popularization of e-Learning technologies, such as LMS, the interest in learning and educational software faced a huge growth due to the emphasis on remote learning during the COVID-19 pandemic [5, 6]. Consequently, there has been a boom in the adoption of LMS by a multitude of educational institutions and it is a focus of interest for educational institutions. This boom also has led to an increase of data gathered and a growing field of study for LA.

Given this situation and seeing the expansion of the use of digital educational tools, LMS and online teaching platforms, even more so with the current pandemic context, the amount of data now collected and stored has drawn the attention of researchers and experts on how to make the best use of educational data order to better support students in their learning process.

This paper presents an approach that integrates LA and the formalization of Taxonomies of Educational Objectives (TEO) in ontology for use in evaluating the academic performance of students in e-Learning. To evaluate the proposed approach, a supporting tool, named Sapes tool has been developed. Unlike other works [7, 8, 9, 10], Sapes tool: i) encompasses parameterization through ontologies (allows the educator to parameterize architecture with an ontology that formalizes a taxonomic structure of educational objectives); ii) provides feedback to educators and students, and; iii) performs an assessment of the academic performance through the inference of information guided by a Learning Unit (LU) and Learning Objectives (LO) taxonomic structure.

The use of an ontology for this purpose was adopted based on a systematic review about the use of ontologies in LA carried out by Costa *et al.* [11] who found a gap in the concomitant adoption of these two technologies. The present paper then comes out with the proposed architecture and the subsequent investigation to verify its viability in a real environment, with volunteer students from a master's course in Professional and Technological Education from a Brazilian Institution.

This research sought to determine if the approach is capable of evaluating the student's academic performance based on LO and presenting consistent information that promotes gains in teaching and learning process. Moreover, the research questions to be answered in this study are: *Q1. How Sapes tool can improve the teaching and learning process through the use of Learning Analytics and Ontologies. Q2. Was Sapes tool well perceived by the students and professors?*

The structure of this paper is as follows: In Section 2, Literature Review, related works are presented. In Section 3, Methodology, the procedures of this research were carried out is presented, as well as a presentation of Design Science Research (DSR), which served as a guide for the elaboration of the project phases, as well as the ontology used alongside the participants involved and the process of data collection and data analysis. In Section 4 the results of questionnaires and usability evaluations are presented, as well as some of the interviews carried out. In Section 5, the considerations made from the results collected are presented, as well as ethical considerations, social impacts and an overview of the research results. Finally, Section 6 is where the conclusions are presented, as well as the strength and weakness of this research along with future works.

2 Literature review

Studies about Online Education and LMS were identified by a systematic literature review conducted by Costa *et al.* [11]. However, none of the studies found [7, 8, 9, 10] by the authors addressed the integration of LA methods with explicit information about the pedagogical structure of an online course, formalized through TEO in order to promote learning by assessing academic performance and monitoring achievement of learning objectives. Despite this, some studies should be highlighted. Yago *et al.* [12] proposed a model to identify the student's profile based on a network of ontologies in order to offer educators several indicators about the student's profile, such as: (i) properties about the students and their learning style, (ii) characteristics of the activities and (iii) characteristics of the objectives. With these indicators, educators will be able to detect problems early in the learning process, adjust the planned course, and thus improve knowledge acquisition. This proposal, called ON-Smile, is an ontology-based method that can be applied with LA, which aims to provide educators with the student's academic status to improve their supervision. Unlike Sapes tool, ON-Smile does not relate students' state of knowledge to the course curriculum and the LO planned by educators.

Cabrera-Loayza *et al.* [7] describe a tool to present students' progress, high-lighting those who are at risk of abandoning the course. This LA-based tool al-lows a dynamic visualization of educational information from interaction events discovered in log files of the learning environment. Unlike Sapes tool, this proposal does not promote the triangulation between the student's academic situation with the learning experiences carried out and the fulfillment of educational objectives to assess the educational situation.

Nussbaumer *et al.* [8] present a conceptual architecture to detect and analyze cognitive learning activities in personal learning environments. Their architecture aims to identify non-observable cognitive behavior and provide feedback to the students to raise awareness of their own cognitive processes that cannot be observed directly in the environment. The architecture, however, does not propose the verification of the acquisition of knowledge related to the educator's planning, although the authors state that the results can be applied in applications with LA techniques.

It is recognized that teaching alongside information technologies tends to be adaptive due to the transactional distance between students and educators, Huang *et al.* [9]. So adequate methods for evaluating academic performance are needed for these environments since, as Cabrera-Loayza *et al*. [7] stated, standard methods applied to monitor and evaluate students' academic performance in common classrooms are neither effective nor appropriate for application in e-Learning. This is also identified as one of the causes of school dropout, which is greater in e-Learning than any other modality, Kim *et al.* [13]. To avoid this, personalized feedback to teachers about their students and their overall course performance is usually recommended. Thus, LA can be used to define and establish identified learning metrics and benchmarks that can be communicated to all students as feed-back through dashboards, recommendation systems, personal emails, or even phone calls to instructors [14, 15]. These authors also argue that educators must guide students according to a pedagogical plan that allows each student to build an autonomous learning process based on clear educational objectives to promote gains in learning, providing personalized feedback systems to promote self-regulated learning. Furthermore, as Iterbeke *et al.* [15] stated, technology also offers personalized learning material. In particular, technology can support teachers and students by facilitating the process of assessing student interests, providing instructional suggestions, and providing engaging interactive content.

To achieve this, the formulation of LO or Educational Objectives is recommended. According to Bloom *et al.* [16], LO are resources for pedagogical use, inherent to the teaching process, which guide the planning of the discipline and allow the assessment of the student's academic performance. Students can monitor with the help of personalized feedback the fulfillment of planned educational goals, enabling self-assessment and, consequently, self-regulation of their learning process.

In general, students build knowledge and their progress in the course occurs through interactions with the pedagogical activities available in the LMS. The educator, therefore, plans didactic-pedagogical actions to build knowledge or skills in the student. The observation of Learning Experiences (LE), instructional sequencing, and the students' learning trajectory allows them to follow their behavior and achieve the goals planned by both the educator and the student.

3 Methodology

Our study was conducted based on DSR methodology. This methodology emphasizes the design and construction of artifacts, such as systems, applications, architectures and methods that could contribute to the efficacy of an organization, purpose, or even another artifact Peffers *et al.* [17]. In this research three artifacts were developed: The OntoLO Ontology, the Sapes Architecture, and Sapes Tool, which are presented in the sequence.

3.1 Artifact I: OntoLO ontology

There are several definitions in the literature for the term ontology in the Computer Science domain. According to the definition by Gruber [18], ontology is an "explicit specification of a conceptualization," which is, in turn, "the objects, concepts, and other entities that are presumed to exist in some area of interest and the relation-ships that hold among them." Thus, it can be said that an ontology formally describes a knowledge domain that can be applied in a plethora of fields, such as serious games [19] and education [20].

The artifact called OntoLO [21], which aims to formalize the Educational Objectives Classification Taxonomy, is detailed in this section. OntoLO is a pedagogical tool to support the educator and is useful for teaching, learning and evaluation processes, categorizing learning goals and objectives. This taxonomy is a scheme to classify didactic-pedagogical actions, providing an organizational structure that offers a commonly understood meaning to the objectives classified in their categories.

Bloom's Taxonomy [16] was the first objective classification structure and is still widely used by educators. Bloom's original structure has been revisited by researchers who recognize it as effective in the evaluation of the teaching-learning process, in the planning and execution of classes, in addition to being a tool that allows the creation of teaching strategies. One of these revisions, carried out by Anderson *et al.* [22], proposed alterations to the description of skills based on verbs in the infinitive form, as well as the position of some levels in relation to the original taxonomy.

The work of Ng [23] was the base for the construction of the OntoLO Ontology. The formalization of the OntoLO corresponds to its specification in a formal language. The language used was OWL and the OntoLO was implemented using the Protégé tool.[1] OntoLO has seven classes that model the Bloom [16] and Bloom Revised classification [22] structures.

Besides, OntoLO allows one to infer the taxonomic level of a cognitive ability according to the formalized taxonomy. Inferences are made from the students' Learning Experience (LE) and from the planning of didactic-pedagogical actions in accordance with the planned educational objectives.

3.2 Artifact II: Sapes architecture

Sapes is a software architecture based on LA and ontologies that was built to analyze educational data and produce information about students' LE, which can help educators in the process of evaluating students' academic performance [24]. For that, an LMS was integrated with both LA techniques and a taxonomic structure of educational objectives. This architecture allows the processing and analysis of educational data, the inference of new information about the student's academic performance and the prediction of their performance based on a Taxonomy of Classification of Educational Objectives, in addition to relating the desired skills to LO planned by educators. Overall, this architecture was based on the model of Cho and Lee [25], although it was improved to include ontological measuring (Figure 1).

[1] https://protege.stanford.edu/

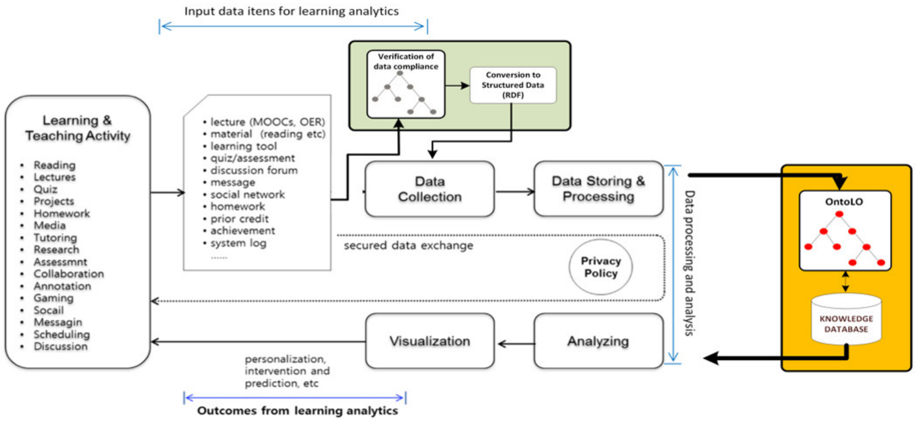

Fig. 1. Improvement of the LA application model [25], with the inclusion of ontologies in the highlighted area in yellow color

As mentioned, ontologies can provide pedagogical information about educational objectives, as well as inferences about academic progress and student achievement. Sapes Architecture was developed in three modules, integrating ontologies in the first and second modules (Figure 2). In the first module, the ontology of the xAPI framework2[2] (xAPI Ontology) allows the conformance of the collected data with the Learning Activities Sensor (LAS) ontology which aims to eliminate bad and noisy data. In the second module, the ontology formalizes the OntoLO that parametrizes Sapes Architecture with information about the educator's planning and will produce inferences about the students' LE. In this module, educational data classification algorithms are applied. The third module introduces visualization metaphors (dashboards) used to abstract information about the educational landscape to users (educators and students).

3.3 Artifact III: Sapes tool

The application built was based on Sapes Architecture, shown in Figure 2, and can be used for both students and professors. To guarantee access to information relevant to each one, access profiles were defined for different types of users. For example, a student profile provides access to information about their learning path, thus the student can monitor their progress and self-regulated learning, while the educator's profile allows the professor to monitor the class situation and make pedagogical decisions based on information produced by the Sapes tool.

[2] https://adlnet.gov/projects/xapi/

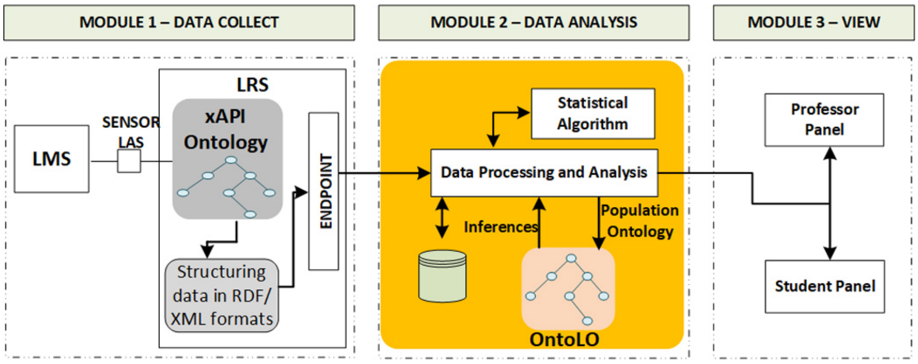

Fig. 2. The three modules of the Sapes architecture. The orange area in highlight presents the expansion of the model [25]

The Sapes architecture was designed to be a web tool and it was implemented using JSF (JavaServer Faces).[3] The architecture modules were developed as independent web services, which allows scalability and architecture optimization.

Module 1 of the proposed architecture is responsible for receiving data from the LMS and storing them in a repository of learning records. In this module an Endpoint for queries in SPARQL language[4] was implemented, which allows communication with Module 2 (Processing Unit and Analytics). To this end, an open source Learning Record Store (LRS) Learning Locker,[5] made available by HT2 Labs and which we integrate with the semantic data query service through the Apache Jena Fuseki framework.[6] Modules 2 and 3 (front end) were developed in JSF and communicate with Module 1 (back end) through HTTP requests of the REST type. Figure 3 shows the Sapes tool panel and Table 1 presents the aspects of the Sapes architecture implemented in the Sapes tool.

[3] It is a Java specification for building component-based user interfaces for web applications.

[4] SPARQL is an RDF query language for databases able to retrieve and manipulate data stored in Resource Description Framework (RDF) format.

[5] Learning Locker—it is a data repository designed to store declarations of learning activities compatible with the xAPI (Tin Can) framework.

[6] Is a SparqL query server accessible via the HTTP protocol that can run as a Java web service or as a standalone server, https://jena.apache.org/.

Table 1. Aspects of the Sapes tool

Aspects	Description
Educational Data Processing and Analysis Phase	The Sapes tool was based on LA, Ontology and Statistical Algorithms
Supported LMS	According to the Learning Activity Sensor (LAS) and the xAPI framework specification
Taxonomy of Educational Objectives used	The Sapes tool is parameterized through an ontology that formalizes a taxonomy for classifying educational objectives
Architecture implementation	Sapes tool was developed in Java JSF language
Ontology manipulation	Sapes tool uses the Apache Jena Fuseki framework
Statistical analysis	The analysis of educational data is based on classification algorithms (Linear Regression Analysis and Naive Bayes)

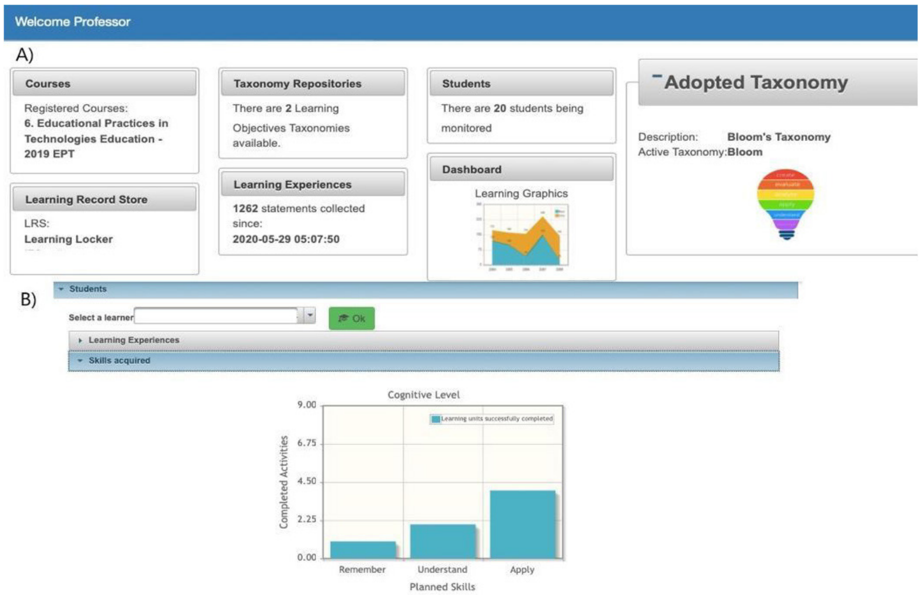

Fig. 3. Sapes tool web panel. A) Layout and information of the professors, B) An example of the students' view

3.4 Materials and methods

Design. This study used qualitative and quantitative methods alike, following works such as that of Duffy [26], who states that the use of *quali-quanti* methods in conjunction minimizes the subjectivity and overcomes the main criticism of these approaches when used in isolation. This study was based on the participants' interpretation of the impacts that the solution provided on the educator's teaching and students' learning process.

As detailed in Figure 4, interviews were conducted with two groups of participants from a postgraduate course. The interview allowed both the researcher and the participant to focus on the facts and phenomena arising from the research objectives without distancing themselves from the original purpose [27, 28].

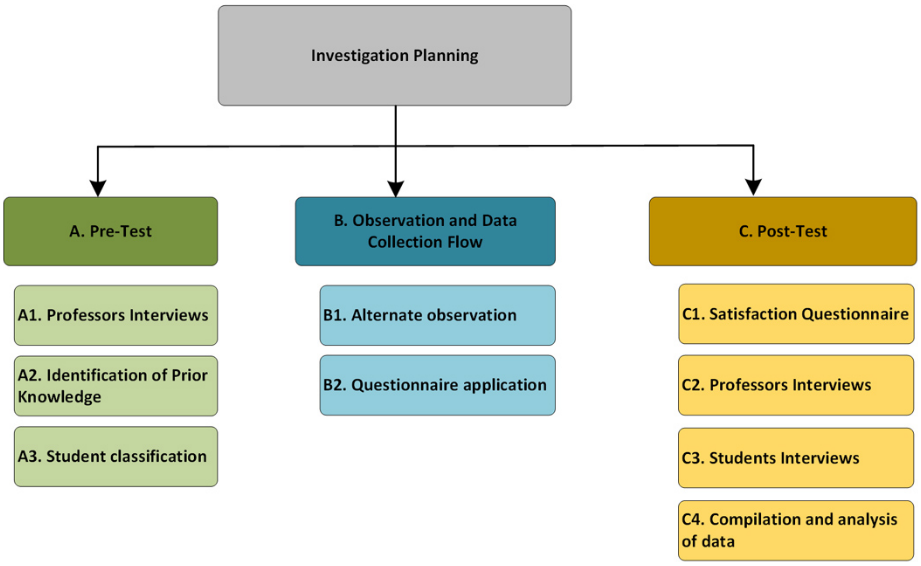

Fig. 4. Flow of the investigation followed in our work

Figure 4 shows the scheme carried out with participants for projection, observation of use, and evaluations of the Sapes tool. Initially, a pre-test was carried out with the aim of identifying previous user experiences with e-Learning platforms, following this field notes were carried out[7] with a real application of the tool in a virtual classroom, where information was obtained on how the tool behaved and what were the user's expectations for it. For the last step, a post test, the analysis of the satisfaction questionnaire and the data analysis were carried out the post-test, the analysis of the satisfaction questionnaires, and the data analysis.

Participants. The participants in this study were professors and students of an online Brazilian postgraduate course in Professional and Technological Education. The course was held during the period of the COVID-19 pandemic, from April to July 2020. A total of 24 participants, including professors (n = 2) and students (n = 22).

[7] Field notes are records collected during an observation, representing a data collection instrument for qualitative research. In order for the notes to be in accordance with the research objective, prior planning of what should be noted and observed is necessary, clearly delimiting the focus of the investigation so as not to deviate from the initial research proposal.

Data analysis process. Questionnaires[8] were used to summarize the information provided by the participants during the evaluation of the instrument. In addition to identifying significant suggestions, the impacts that the solution has on the teaching and learning process and identified suggestions for improvements was highlighted.

Due to the characteristics of the quantitative and qualitative research, different data collection instruments were used (Interviews, Questionnaires, Document Analysis and Observation) and applied to both groups of participants.

As there were only two professors, a narrative interview was conducted and the questions were categorized into three central segments: (1) challenges of e-Learning in relation to the student assessment process; (2) methods/resources used to monitor the student's learning trajectory; and (3) the use of tools to assist the investigation into the students' processes of knowledge systematization. Then, the behavior of professors regarding the use of the proposed tool was observed in the real context, as well as their experiences with the use of the LMS of their choice. By the third stage, a narrative interview was carried out to collect qualitative data related to the use of the proposed tool in support the teaching process-mainly if the solution helped in the assessment of students' academic performance, promoted learning, enabled pedagogical decisions to be carried out with adjustments to the planned objectives, and whether it enabled the monitoring of students, in addition to enabling the identification of improvements in the tool.

The process of data collection and analysis with the second group of participants, composed of students, was divided into four stages: In the first, a sociodemographic questionnaire was applied, where information about the students' profile was obtained. In the second stage, a questionnaire was applied about the students' perception of involvement in learning and self-learning to collect evidence about elements that keep students engaged in the context of e-Learning and whether they use or have used the tools available in the LMS that help them to monitor skill acquisition and academic performance based on educational objectives. In the third step, a questionnaire to evaluate applied the proposed solution. The opinions of the participating students were collected on information about the use of the proposed tool, such as ease of use, perception of satisfaction and gains in the learning process. Finally, for the fourth stage, a narrative interview was carried out to collect qualitative data and analyze satisfaction from the participants. Limitations of the proposed solution, suggestions and proposed improvements were also collected in this stage.

Sapes tool aims to extract information about academic progress and carry out a consistent evaluation of students' academic performance planned by the educator. Educational data are collected from the LMS and analyzed based on the formalization of the TEO in an online learning environment so as to assess student performance. A set of information is, then, available to the educator in order to assist in the process of monitoring the acquisition of skills and competences.

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[8] Supplementary material (questionnaires and graphics): https://cutt.ly/k1BoTHG and https://cutt.ly/f2NV2mM

The questionnaire applied to collect participants' answers was based on the 5-point Likert scale. For the purposes of analyzing the responses to the 61 statements in the questionnaire,[9] it was divided it into two parts:

1. Engagement: categorized through prerequisites of academic training, aptitude, individual characteristics of students, faculty and course structure that enable the perception of a good level of engagement; and,
2. User Satisfaction about Learning Experiences: categorized by perceived student satisfaction with the tools, dashboard visualization and information available about their learning path.

In the third stage of the investigation with participating students, a questionnaire was applied to assess students' perceptions about the ease of use of the Sapes tool, their satisfaction and the impacts that the tool provided on the learning process.

The collection instrument consisted of 13 questions,[10] and 11 of which were constructed on a Likert scale and two discursive questions, one question being the impacts that an instrument provided on the learning process and the other for suggestions for new functionalities. To analyze the reliability of the responses to the questionnaire used in this second stage, Cronbach's alpha coefficient of internal consistency [31] was applied and achieved a high score of 0.944, which according to the recommendation criteria is considered "Excellent" [29, 30]. Thus, the consistency of the questionnaire was confirmed.

4 Results

This study presents an investigation that aims to analyze how the proposed Sapes architecture and its supporting tool Sapes was able to help participants, both professors and students, in their teaching and learning process. The study also evaluated whether the use of LA and ontologies is capable of creating new capabilities for virtual environments, changes in the student learning path and better visualization of performance for professors and students. The results were divided by their respective groups.

4.1 About the professor

Professor participants' reports showed they are familiar with e-Learning (average teaching time in this modality was 11 years). They reported a high demand of students per teacher (average of 120 students) and also a high demand of parallel administrative activities besides teaching, leading to difficulties regarding the monitoring of their student's academic difficulties. A semi-structured interview was carried out to analyze the evidence on the assessment of the academic performance process. It is essential to understand the educator's path in the student evaluation process, which allows observing the factors, procedures, and methods used to investigate the acquisition of skills by the student.

[9] Questionnaire A: https://cutt.ly/k1BoTHG
[10] Questionnaire B: https://cutt.ly/f2NV2mM

The main arguments of the professors were related to the fact that the evaluation process of students in e-Learning is laborious and complex. Respondents also justified that they only carry out the evaluations through the quantification of learning through evaluative activities and that the volume of data makes this process onerous (41.7%).

After the Sapes tool was used, an interview was carried out to collect evidence on its use and impacts on the teaching process. According to the participating professors, the proposed solution is easy to handle and the dashboards provide clear information, enabling a better understanding of the students' learning process. Professors unanimously expressed that the proposed tool made it possible to make a pedagogical decision based on the student's actual academic situation.

Regarding the professors' perceptions about the impacts caused by Sapes tool in the student's evaluation process, the professors reported that the solution is important due to the feedback on the students' learning experiences. The information provided enabled the educator to compare the student's current situation with the initial planned didactic-pedagogical actions and, with Sapes tool, professors realized that they needed to change their academic planning.

The tool also helped professors to modify the course plan, stated by two reports: 1) "*(…) with the use of the Sapes tool, we realized that, in fact, we needed to change the planning and that we could have planned the course, providing for a certain stage to discuss with the students what was built during the course. What we imagined (planned) was that we could build, step by step, this design thinking process, when at the end of the activity the students would have achieved the objective. But they still didn't feel completely ready to perform the final activity, they needed feedback on what they needed to improve in the development of the activity. At this point, it would contradict a little what had been planned, so we changed the planning to make a formative evaluation and not a summative evaluation, considering only what was delivered at the end of the activity (…)*" and 2) "*(…) we have to have the view that changes in the teaching process also shine through in the learning process. Because from the moment we reflect on teaching, we can generate good results in the learning process as well. The Sapes tool makes it possible for professors to constantly reflect on the planning of the discipline, as the tool always presents the objectives to be met and the expected skills (…)*". This means a greater dynamism of how the content is passed on to students, showing that the tool was able to modify what was initially a sequential planning of information.

Several reports also showed professors' concern regarding their workload. Since e-Learning tends to accommodate more students than face-to-face environments, how to manage such a volume of students is a constant concern. The Sapes tool, however, proved to be useful in making it easier for professors to see more clearly the performance of their classes.

4.2 Student's perceptions

In this section, the results of the analysis of the collected data regarding students' perception of the tool, its use and behavior change regarding their learning path are presented. Concerning the gender of the participants, the data indicate that the sample was composed mostly of women (63.2%) in contrast to the group of male participants (36.8%). The age of participants ranged from 26 to 54 (mean of 37 years old), since it is a post-graduation and continued education course, which indicates the presence of experienced participants.

Sociodemographic data reveals that they were distributed in 3 regions of the Brazil. Among the students, 83.33% had already experienced some kind of e-Learning courses, while 16.67% reported it was their first contact with this modality. The high level of experience in e-Learning is due to most of the participants having already been enrolled in distance learning programmed before.

Regarding the categories of courses that participants have already taken in e-Learning, 58.82% took *lato sensu*[11] postgraduate courses, 35.30% short-term academic courses and 5.88% reported having completed a graduation (bachelors' or licentiate degree) in this modality.

All students that were familiar with e-Learning stated that they used the Moodle platform as the LMS. Regarding the availability and use of tools for monitoring the learning path based on educational objectives, 94.7% of the participants reported that they had never used any type of monitoring tool. On the other hand, 5.3% reported that the Moodle learning environment itself provides this monitoring.

Among the participants who answered "Yes", they reported monitoring their grades through tools such as dashboards present in the LMS Moodle, personal spreadsheets and notebooks to record their progress.

Still on the participants' learning experiences with the LMS, it was questioned whether the environment allows the monitoring of students' academic performance in relation to the fulfillment of Educational Objectives. Among the participating students, 68.4% reported that LMS Moodle does not allow this monitoring and 31.6% stated that it is possible to monitor through a grade map. It is noteworthy that the grade map, available in Moodle does not allow the correlation of LU with the LO planned by the educator. Thus, the Moodle grade map does not allow connecting the activities carried out with the planned LO and the expected competences.

In the second stage, student participants were asked about their perception of engagement and self-adjustment of learning in the context of distance learning. The objective of this stage is to analyze data, from the perspective of participating students, on the factors that determine student engagement and how academic performance interferes with the self-adjustment of learning.

From the responses of the participants to the items related to the Engagement dimension, the participants declared that they agreed favorably with the statements. From the responses of the participants to the items related to the Engagement dimension regarding the structure of the course, the participants reported that they agree favorably with the statements. Regarding the Academic Progress dimension, it was observed that the respondents also agree with the statements, according to supplementary materials.[12] Based on the weights of the participating students' responses and the Likert scale, the scores for the five scale indicators were condensed, data shows that 70,00% of

[11] *Lato sensu* comes from Latin and means "in a broad sense". In Brazil, at the end of the one-year *lato sensu* program, which includes both classroom and on-the-job training in practical and focused on everyday work, participants receive a postgraduate certificate.

[12] Supplementary material (questionnaires and graphics): https://cutt.ly/k1BoTHG and https://cutt.ly/f2NV2mM

respondents agree with the statements that the usability of the tool is satisfactory. There was also a positive perception on the part of students, related to satisfaction, ease of use and impacts on learning provided by the tool.

In the fourth stage of the investigation with the group of participating students, a narrative interview was carried out. The methodology of this interview aims at the explanatory perception, from the perspective of the students participating in this research. The data collected is intended to present information on the use of the Sapes tool and the positive and negative outcomes associated with it. Therefore, the participants expressed their perceptions, exposing their considerations about the impacts that the tool provided.

To extract the most of the results, the data were organized and analyzed according to thematic axes and their respective categories. A previous analysis of the responses was carried out and 15 context categories were identified, grouped around 3 thematic elements: (1) Aspects about the tool in the learning process; (2) perceptions provoked by it; and (3) comments and general suggestions. Regarding the category "Aspects about the Tool", the main argument identified as a positive aspect of the architecture was the quality of the information provided in relation to the learning path (64.3%). The usability category was also identified as positive. The observation item allows us to perceive the difficulties encountered by the participants regarding access to information and navigation within the tool. Some participants reported: *"(…) (If) is it easy to use? I found it very easy to use, very simple. And I think it's a very intuitive tool. So it really made it easier, I had no difficulty in accessing it, so looking for some information was easy (…)*" (Translation by the authors) and "*(…) I found the tool easy to use, some difficulty I had was only in generating the pass-word, a personal issue because I was using two different e-mails, so I received an e-mail from your contact via two different e-mails and I couldn't remember which one I had logged in and such, but everything besides this was ok (…)*" (Translation by the authors). This can be corroborated by the statistical analysis that 70,00% (42,00% Strongly Agreed that is easy to use, while 28,00% Partially Agreed) of the students found it easy to use.

In the category "Aspects about the Tool in the Learning Process", students described the tool as a resource that allows them to supervise, promote and self-regulate learning. Respondents positively describe how the tool made it possible to investigate academic performance and supervise the learning experiences carried out in the LMS, reproducing the following: *"(…) I believe that yes, the tool made it possible to monitor my performance after using it. I realized that I was more concerned with monitoring my performance […] even though I'm carrying out the activities in the virtual environment both synchronous and asynchronous, but this tool gave me a bigger view is what I could see (…)*" (Translation by the authors).

Regarding the participants' insights and suggestions as general aspects of the tool, the interviewees' main argument describes aspects related to the use and purpose of the proposed tool. The main arguments of the participants were such: *"(…) I view the tool as positive and extremely viable in the process of promoting learning and that it can even be extended to other activities on campus (…)*", *"(…) I think the tool has an important role, it can be constantly improved. It's about filtering academic performance further. (…)*", and *"(…) I think that if this Sapes tool had existed since the beginning of the course, I think that the learning, engagement and involvement would have been better. And even the access to the feedback, so that we could monitor this performance, would improve our performance (…)*" (Translation by the authors).

5 Discussion

In regards to the objective of this investigation, which is to verify the feasibility of the proposed architecture in a real context and the promotion of learning gains in e-Learning, several statements can be highlighted.

The first discussion that can be drawn from the collected data is how the adoption of progress visualization methods changed the way users, both student and teacher, deal with discipline-related obstacles. An example of how this approach can be beneficial for e-Learning is how the results helped professors and students identify difficulties in a course. This can lead to more educational and motivational interactiveness between students and professors, as professors who are able to recognize greater pervasive difficulties may change teaching methods or activities to focus more on these difficulties. The difference between this and more traditional methods is that the recognition of these difficulties was usually only recognized after evaluations or tests, and the knowledge with the use of the tool based on OntoLO Ontology, the recognition of these difficulties is more fluid and can be identified early with predictive tools.

Based on the high acceptance of students and faculty for the Sapes architecture, it can be stated that the information provided by the LMS is an opportunity to explore students' academic performance and that the data can be used to generate and implement new types of activities that generate positive results. The results indicate that an LMS together with LA and ontology makes it possible to produce new information about students based on their actions within the digital environment. This makes it possible to obtain information about the investigation of student performance to generate and implement new types of activities that result in positive outcomes.

Regarding education information generated in Sapes architecture, the visualization of information not only allowed a better understanding of students' progress, but also changed the way students shape their academic path. This dynamic learning also allows a break from the traditional and static learning models that assume that knowledge can only be acquired through a linear sequence of academic content.

This same change promoted by the use of LMS and LA and ontology also allows changing the way professors evaluate their students: professors can assess their students in a different way instead of just adopting tests and grades. Assessing student interaction through the LMS, showing how tasks were performed, can also be used for a less content-based form of evaluation.

As the field of research is new, Pargman and McGrath [31] also stated that there is a lack of research that focuses on how educational institutions should intervene in the data collected for the benefit of student performance. Considering that the system is capable of grouping and synthesizing information that was previously "invisible" to users, a certain apprehension in the correct use of this information is understandable as this lack of certainty on how to use data also implies an issue of what data to collect. This question was also highlighted by Pargman and McGrath [31] that stated that LA systems are still a relatively new and under construction field, with practices still emerging. In such fields of study, further work on the use of such systems by students, academics and institutions has yet to be undertaken for a deeper understanding of the technical and ethical issues raised here.

For instance, Bjerre-Nielsen *et al.* [32] stated that models using Big Data, like class attendance and time on virtual campus, are indeed able to predict academic performance. However, models using only low-dimensional and less privacy-invasive administrative data, like sociodemographic background, age, gender, and past performance were able to perform better in the prediction and did not improve when they added high-resolution, privacy-invasive data. This is an important finding that can lead to optimized LA techniques, faster and cheaper, that delivers good enough results to assist in the teaching-learning process. Bjerre-Nielsen *et al.* [32] also argue that combining Big Data with administrative records can allow the identification of task-specific privacy-preserving features that can be employed instead of the current indiscriminate use of data, with better privacy and better predictive results.

In this sense, it is necessary to uncover how the technical and ethical aspects of LA systems unfold in educational practices. This is important, as computer systems for e-Learning need to be based not on claims about how digital technology as a tool for improved teaching/learning is "capable of solving all problems", but on accounts of how the use of digital technologies is able to change the student learning path. Sapes architecture, in addition to being able to collect and assist students and professors in their teaching-learning process, also revealed, through questionnaires, how users changed their learning process, reaffirming how technological tools shaped these processes.

The use of LA and Ontologies was able to provide consistent information about the relationship between academic performance and learning paths with the planning of didactic-pedagogical actions developed by the teacher. These results previously endorse findings on the use of ontologies to improve information visualization [33, 34, 35]. This coordinated use allows the educator to carry out the monitoring of student's progress throughout the teaching sequence, which would not be possible with the use of LA alone.

As stated, LA allows a source of educational data from a virtual learning environment. According to Quadrii and Shukor [4], LA is gaining strength in educational institutions for positively impacting the teaching and learning process in e-Learning. Also, Husni *et al.* [36] indicated that the planning of didactic-pedagogical actions based on the educational information inferred from LA helps educational professionals to appropriately design pedagogical strategies. The research here carried out reinforce some benefits such as:

- Relevance of the architecture and agreement with the adopted procedures: 100.00% of the participating professors fully agree with the importance of the proposal as an aid to the educator in the process of evaluating academic performance and to the student as a way of monitoring the academic trajectory in accordance with the educational objectives;
- Tool utility: 100.00% of the participants consider the solution extremely useful in the evaluation process of the students' learning path and 80.00% of the students consider it only as useful;
- General aspects of the tool: the tool was classified by participating students as: adequate (average 3.76), easy (average 5), satisfactory (average 3.29) and presents consistent information (average 3.70), on a linear scale of five points (1 to 5);

- The teaching participants compared the Sapes tool with their traditional methods of monitoring the academic performance of students in Distance Education. It was evident that all participants agree that the tool's functionalities present a great differential and help considerably in the process of evaluating the students' academic performance;
- Notable positive perception of students regarding the promotion of learning (79.00%), average level of motivation (78.00%) and ease of use (100.00%) regarding the use of the Sapes tool.

However, it is not common for these data to be associated with the didactic-pedagogical actions planned by the educator. The formalization of the course's learning objectives and its relation to learning units, through an ontology was essential to fill this gap, as it was able to infer pedagogical information from the students' learning experiences and associate them with the LOs planned by the educator.

This can be seen in the responses of the participants as the tool based on Sapes Architecture was able to provide feedback consistent with the initial planning of the discipline that allowed them to carry out pedagogical diagnoses expressed in terms of educational objectives supported by Bloom's taxonomy, cognitive diagnosis expressed in objects of knowledge based on expected competences; and make pedagogical decisions to combine initial planning with the student's instructional learning path.

Regarding the participating students, they reported that it was possible to better monitor and compare their academic performance with that of their peers, as well as compare their performance with the educational objective to be achieved, which led them to seek more knowledge and feel more engaged with the discipline under study.

6 Conclusion

Thus, it was identified in the investigation that the coordinated use of LA and computational ontologies made it possible to consistently present and relate educational information on the students' learning trajectory with the initially planned didactic-pedagogical actions.

It was also identified that the proposed artifact (Sapes tool) helps educators in the process of evaluating academic performance, correlating the students' learning trajectory with the educational objectives and course competencies. The Sapes tool allows educators to make pedagogical decisions based on educational information from the learning landscape of specific students or the class. The tool also helps students, enabling them to investigate their academic path, which favors the promotion of self-assessment and self-regulation of learning.

Regarding the research questions, both *Q1* and *Q2* were fulfilled. This study was able to measure how the tool was able to measure student and teacher performance and that the same tool was well perceived by both actors. Besides, the Tool was also able to change students' learning path, which is an important aspect for self-learning management, as the tool offered important support in the process of evaluating the students' academic trajectory and support in the planning of didactic-pedagogical actions, helping professors in decision-making.

LMS needs to be considered more than simply professional teaching and learning tools. They can provide meaningful services to individuals and educational institutions that go beyond a system to deliver academic content. This research demonstrated how these systems are affecting instruction and assessments, as well as provide insights into how LA can contribute to pedagogical approaches using Bloom's model.

It is now time to understand the types and volume of information being collected and how to extract most of it in addition to determining the implications of its use for decision-making in courses, programs and institutions.

However, limitations were found: one of the main limitations of this work is the small group evaluated. This was due mainly because of the COVID-19 pandemic. In addition, due to the time space and application of the Sapes tool, the results regarding ease of use, satisfaction and impacts may vary, as different courses from different fields of studies may result in different perceptions. One way to generalize these results would be to apply it from the beginning of a course, and not just in a discipline, in order to supervise the performance and trajectory of the student throughout the entire course.

6.1 Ethical considerations

This study was approved by the Ethics Council, Protocol No. CAAE 28087520.0.0000.8052 (Brazil Platform[13]). All phases of the study were carried out according to the Informed Consent Term (FICF), the data were transcribed and anonymized according to the term. It is noteworthy that participation was voluntary and that the participant could withdraw at any time, without justification. The authors have no conflicts of interest to declare. All co-authors have seen and agreed with the content of the manuscript and there is no financial interest to report. We certify that the submission is an original work and is not being reviewed in any other publication.

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