A framework for designing applications to support knowledge construction on learning ecosystems

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Abstract. We are building a society increasingly immersed in digital contexts. In this transformation process, mainly because of the daily use of technology, several contexts of our lives are changing, including education and the school itself, which have especially received IT support to be carried out in an informal and personalized way. Learning ecosystems, if properly promoted, could be a partner of this school. In this paper, we propose a Framework to support the modeling of Smart Learning Environments (SLE) capable of stimulating interactions (including location-based interactions) in the diverse ecosystems in which we participate and thus support the construction of knowledge. We also present some SLEs designed with the Framework to demonstrate the practical result of its use and others for validation purposes.

Keywords: Learning Ecosystem, Framework, Smart Learning Environments.

1. Introduction

The advancement of digital communication technologies makes it possible to create new possibilities for interactions between people and between them and computers. We are increasingly dependent on the facilities provided by our smartphones and computers. With simple movements of our fingers, we pay bills, choose the best route to a destination and interact with each other. In these operations, we generate many data that suit to optimize tasks. With that, a new area of knowledge emerged, called Big Data, which studies the development of artificial intelligence techniques to treat, analyze and obtain information in sets of data that are too large for the traditional systems. These techniques can also benefit our learning processes.

We have been researching learning ecosystems that can provide the conceptual basis for using computational agents capable of acting as personal and collective learning assistants, not only at school but in different social contexts and throughout life. [27] pointed out the limits of the instructional school and its unpreparedness to deal with the changes that education will undergo, given that personalization, collaboration, and informal learning will be at the core of learning, enhanced by the ubiquity of information and communication technologies as stated by the European Commission's report on learning in 2030 [23].

Learning links to interactions between humans, between humans and synthetic artifacts, or between humans and the environments where they belong. The literature contains many reports supporting the idea that learning strongly depends on interactions [43], [44], [45], [46]. Still, learning results from individuals' interactions both in academic and social life [19].

Our challenge is to (I) support the interactions of learners (between them and with the environment in which they are), (ii) support teachers in mediation actions, and (iii) enhance the learning process with the ubiquitous contribution of intelligent technology and artificial intelligence to help humans to (i) avoid unnecessary tasks, (ii) understand where to focus on each ecosystem in which be present, (iii) gather and record production knowledge in these contexts and (iv) facilitate information retrieval. This challenge requires innovative tools at the service of learners, facilitating and managing their interactions.

As a solution to this challenge, we propose a conceptual structure that inspires and supports the modeling of intelligent educational systems that make learning ecosystems smarter, including the following aspects: (i) support formal and informal education, (ii) support personalized and lifelong learning, (iii) acting at learning ecosystems in generic contexts. This configuration makes up the research gap that we want to explore, supporting learning in any environment where one wants to learn.

We then propose a framework to assist in designing intelligent computational environments that favor the integration of scattered data and the interactions of individuals (teachers and students) with each other and/or with the environment, making it possible to perceive and work with the elements of learning ecosystems in an integrated manner. In other words, we propose a conceptual framework to model Smart Learning Environments (SLE) that offers support for the construction of knowledge in learning ecosystems. One of the great powers of SLEs comes from the ubiquity provided by location-based services to promote interactions between individuals and meetings from different perspectives on the same domain.

We organized the article as follows: Section 2 contains the theoretical background; Section 3 presents the related works and highlights the contributions of the framework; Section 4 contains the methodology; Section 5 talks about the context of action, the framework, and how to use it; Section 6 presents the results and discussion; Section 7 contains the final considerations and future work.

2. Theoretical background

In this section, we discuss some concepts necessary to understand our proposal. We emphasizing the learning ecosystems, the importance of interactions on learning, smart learning environments, and location-based services for education.

2.1. Smart Learning Environments (SLE)

Chen *et al*. [5] highlight the emergence of smart learning environments to allow students to access digital resources and interact with learning systems anywhere and anytime. Besides, they provide guidance, tips, support tools, or learning suggestions in the right place, at the right time, and in the right way.

To build the framework, we rely on the Spector [29] definition, which says that a learning environment can be considered “smart” when it uses adaptive technologies or is designed to include innovative features and capabilities that improve users' understanding and performance.

Based on the characteristics of human intelligence transferable to technologies and learning environments, an SLE will have several of the following features: (i) Knowledge - access to relevant information and the ability to add or modify that information; (ii) Task support - performing a task or providing the individual with the necessary tools to perform it; (iii) Apprentice sensitivity - maintain and use an apprentice profile to provide adaptive support; (iv) Context sensitivity - the ability to recognize specific situations, including those in which an apprentice may need assistance; (v) Reflection and feedback - the ability to criticize a solution and provide meaningful and timely feedback to individuals [29].

SLEs have been used to support learning in different age groups, not only at school, but at other contexts where people want to learn (work, chess club, cinema, etc.). However, their use requires some basic requirements, such as: knowing how to read/write and having access to smartphone-like technology.

2.2. Learning ecosystems and the importance of interaction in the process of knowledge construction

Interactions are so important for ecosystems that without interactions the ecosystem ceases to exist. Interactions are equally crucial to learning. Perret-Clermont's work [19] explored the influence of social interactions on cognitive development. This theory assumes that learning happens within each individual but is dependent on interpersonal exchanges.

The ecosystem concept has been applied to contexts, like business ecology in economics [16], ecology of the mind in psychology [3], and many other domains [20]. So, the metaphor is adequate to demonstrate activities in different social interaction environments. In human ecosystems, the ecological perspective considers people in their physical, social, and virtual environments as a unitary system that occurs within a particular context, consuming, recycling, and producing resources, including knowledge, learning, and developing through interactional processes.

Richardson [24], when he writes "Toward an Ecology of Learning", presents some characteristics that determine how to establish a learning ecosystem: (i) an adaptive, open, and complex system that encompasses interdependent elements, (ii) something that is adaptable to new contexts due to its incentive to diversity and (iii) a collection of overlapping communities of interest, in constant evolution and self-organized. Based on this conceptualization, a formal definition of a learning ecosystem is the agent-environment union in which cognitions and resulting learning occur, based on agents' interactions with each other and the environment [26].

2.3. Educational location-based services

A Location-Based Services (LBS) describe an application that depends on a particular location. Two broad categories of LBS can be defined as (i) triggered for the user and (ii) requested by the user. The user retrieves his/her position once in the first type and uses it in subsequent requests. This type of service usually involves personal or service location. In the second type, a triggered LBS depends on a configured condition that, once satisfied, retrieves the position of a given device [8].

The location-based scheme is the most frequently used model of ubiquitous learning [37]. The central feature of this model is the positioning technology, which provides learners with relevant materials [38] and helps them focus on their studies [39]. The positioning technology used in a ubiquitous learning environment comes in two forms: indoor and mainly outdoor.

Ecological education is a typical example of outdoor learning, where learners are usually aided by guides, who organize the learning materials, teach and interact with highly motivated learners [37]. Successful outdoor learning must have such essential components as experiences in authentic contexts, adaptation to changes, and facilitating both hand and brain. Furthermore, outdoor learning should avoid activities targeting just one subject; instead, it should incorporate multiple subjects, fields of knowledge, and skills to create an integrated learning environment [40].

3. Related works

To verify this work in the literature on the theme “Frameworks for smart learning environments” we consulted renowned scientific digital libraries such as IEEExplorer, Springer, ACM Digital Library, and ScienceDirect. We found some works, and we will present three of them.

We implemented an automatic script to search, in the papers found, the terms “ecosystem”, “smart learning environment”, and “framework” (and their synonyms). We found 415 results in the cited scientific bases. The top search string we used was: *framework AND “smart learning environments” AND (“learning ecosystem” OR “learning ecology”)*, with some variations of synonyms. Finally, we apply the inclusion and exclusion criteria according to Frame 1.

Frame 1. Exclusion and Inclusion criteria

Exclusion Criteria	Inclusion Criteria
1. Works published before 2014. (we are working with a definition of SLE given in 2014 by Spector [29]). 2. Non-English or Portuguese papers. 3. Literature review papers. 4. Redundant papers	1. Papers that presented a framework or conceptual architecture for modeling intelligent environments. 2. Papers that consider learning ecosystems. 3. Papers that have passed by the automatic script filter.

After applying the exclusion and inclusion criteria, four interesting works remained that we consider related to ours. First, Wangoo and Reddy [33] propose a framework for designing SLEs enriched by the internet of things (IoT), interactive graphical interfaces, and *wearables* to support learning in smart educational ecosystems.

Martins *et al*. [17] feature a digital ecosystem architecture called Smart Ecosystem for Learning and Inclusion (SELI) which is being developed by people of ten different nationalities. The work aims to provide an accessible learning environment involving technologies such as *Blockchain*, *microsites*, and universal accessibility guidelines.

Ouf *et al*. [18] present framework to design solutions to customize learning environments. This research focuses on personalizing e-learning, providing students with suitable learning objects while ignoring other process components. The proposed framework was built using ontologies.

Finally, Mealha [14] presents a Research and Development (R&D) framework for building accessible dashboards to represent the data and information available in the general ecosystem of the city in a way that ordinary citizens can interpret.

To demonstrate how our proposal fills the existing research gap and the consequent contribution of the work, we present in Table 1 the comparison of the results. In question Q1, we verified whether the work promotes education inside and outside the school. Q2 verified whether the work considers aspects of personalized learning. Q3 checks whether the work formalizes its base of action (if it brings, for example, a modeling of the learning ecosystem). Q4 reveals whether the work acts in any context or thinks only a specific approach, such as inclusive education. Q5 checks whether the Framework presented in the proposal considers location-based aspects. Our Framework provides a “Yes” answer to all questions.

Table 1. Comparison of related works.

	Q1	**Q2**	**Q3**	**Q4**	**Q5**
[33]	No	Yes	No	Yes	No
[17]	Yes	Partially	Yes	No	No
[18]	No	No	Yes	Yes	No
[14]	Yes	No	No	No	Yes

4. Methodology for framework development

The term "framework" sometimes is used by the scientific community to conceptualize different things. Our proposal fits into all seven features that conceptual frameworks must have, according to Jabareen (2009) [13], which also proposes a methodology to build these frameworks. So we built our framework by an incremental process, following Jabareen's methodology.

The development process consists of the following phases: (1) Mapping of data sources; (2) Reading and categorizing the selected data; (3) Identification of concepts; (4) categorization of concepts; (5) Integration of concepts; (6) Synthesis and search for meaning; (7) Validation of the conceptual model and (8) Rethinking the framework. Thus, obtaining the framework consists of eight phases; each phase has an input and generates a result used in the next phase.

As we can see in Figure 1, the process is cyclical. After the execution of the last step (Rethinking the Framework), in some cases, we return to the first phase (Mapping of data sources) or insist on the survey of new concepts in the block containing steps (3, 4, and 5). This block outputs a new framework design.

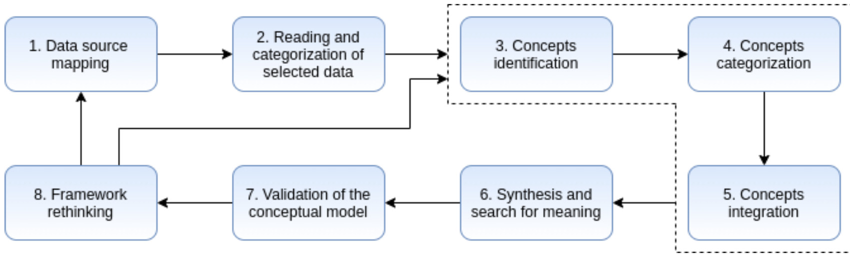


Fig. 1. Workflow of the methodology used.

In each iteration, for phases 1 and 2, we consult scientific libraries to improve knowledge, create an information base on the framework's components, and then move on to the subsequent phases. Steps (3, 4, and 5) are the phases where we design the framework, write the identified concepts, look for the connection between them, and group them according to the conceptual similarity. In our case, the framework's layers represent this grouping. In phase 6, we analyze the draw obtained, theorizing about the production and conjecturing about possible instances. In phase 7, we implement conceptually (and in some cases, empirically) one or more instances that emerged from the previous phase.

Finally, in phase 8, we rethink the built framework. At this point, we observe the validation errors presented in the previous step and possible situations not covered, and then we start a new iteration. Next, we will show and explain the framework obtained after a few iterations and which we consider desirable.

5. Framework for applications in learning ecosystems

In the next subsections, we will (i) present the conceptual Framework architecture, (ii) instantiate it, by generating an SLE for a given learning ecosystem, (iii) demonstrate the first step of validating the Framework, and finally, (iv) its limitations.

5.1. Conceptual framework model

The conceptual model is divided into five layers: (i) Data, (ii) Intelligence, (iii) Infrastructure, (iv) Application and (v) Presentation. Figure 2 shows them. One of the inspirations for the framework design is the N-Tier architecture, with adds value in the visualization and the understanding of the software development process.

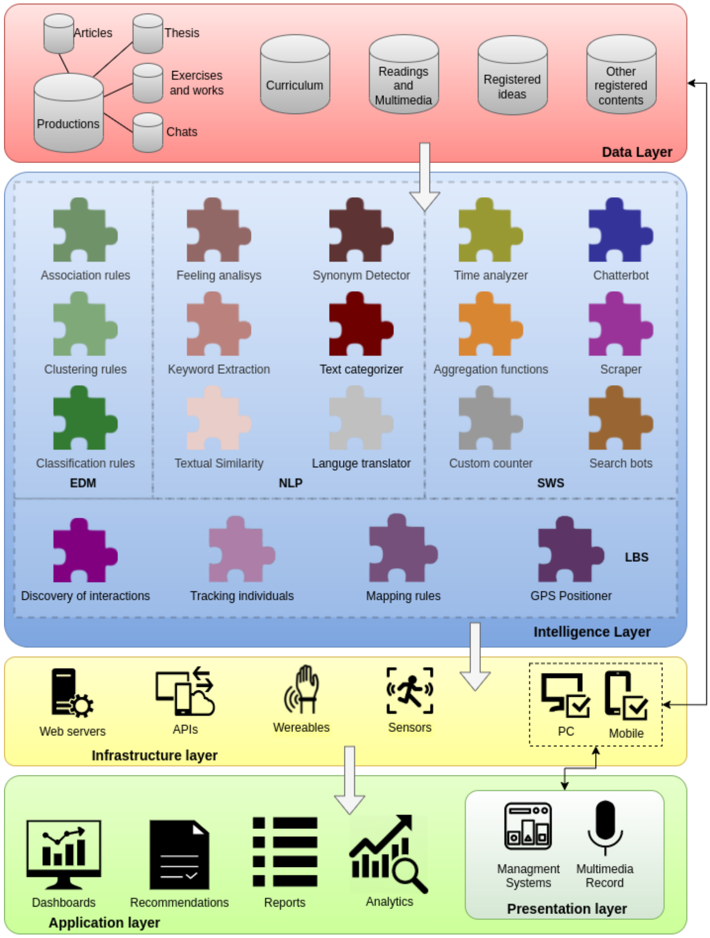


Fig. 2. Framework conceptual model. Extended from [28]

It is important to mention that the proposed conceptual model is fully extensible. It was even conceived with this premise, that with due justification, new elements can be inserted in any of its layers. We will then understand what each layer is separately, how to move between them and how to design an SLE (framework's instance).

5.1.1. Data layer

It is essential to mention that the proposed conceptual model is fully extensible. Its conception guarantees that, with due justification, it will be possible to insert new elements in any of its layers. We will then separately understand what each layer is, how to move between them, and design an SLE (i.e., a framework's instance).

5.1.2. Intelligence layer

The intelligence layer has four clusters with features: (i) Educational Data Mining - EDM, (ii) Natural Language Processing - NLP; (iii) Smart Web Services - SWS and (iv) Location Based Services – LBS.

The first cluster functions are mainly related to the use of AI to determine the profiles of individuals from their interactions and personal data and make predictions of different situations such as academic (approval or failure), production levels, etc.

The second cluster deals with textual analysis of individuals' production in their interaction path, remarkably useful for recommendation systems. The third cluster has smart functions related to the production of context-sensitive applications, such as extracting internal and external content to the SLE, creating triggers for processes from other libraries, etc. Finally, the libraries of the fourth cluster provide ubiquity support to SLEs modeled with the framework.

The intelligence layer has the libraries mutually linked to generating one or more solutions, such periodic reports of student productions made at a Virtual Learning Environment (VLE) for education managers. To get this application, it is necessary to couple the modules “Time Analyzer”, “Scraper”, and “Text Summarizer”. This will guarantee the periodicity, the extraction of information in external environments to the SLE, and the generation of the report content, respectively. From there, it is possible to add another solution to the SLE. For example, helping teachers to bring students together and thus encourage cooperation, based on a grouping carried out with the “Clustering rules” library. In addition, we highlight the following libraries:

- **Scraper** and **Search robots**: We use them together to facilitate the Extract Transform and Load (ETL) process required for handling raw data from the data layer. The first helps collect data on public web pages (external bases), while the second allows querying the web from search strings generated with, for example, the Keyword Extraction library.
- **Keyword Extraction**, **Synonym Detector** and **Textual Similarity**: We use them to extract the main idea and detect approximations in a group of contents through semantic improvement. **Keyword Extraction we** implement by ranking techniques based on the frequency of terms, **Synonym Detector,** using APIs available on the web such as thesaurus[1], and **Textual Similarity,** using TF-IDF [22].
- **Discovery of interactions**, **Tracking individuals** and **Mapping rules**: We use them, together or separately, to respectively (i) Identify proximity to individuals with the same interests (also using similarity libraries); (ii) to trace the apprentices' path within the scope of the SLEs activity and to provide “user-driven” location-based services; and (iii) Something similar to (ii) but with “requested by the user” type from location-based services.

5.1.3. Infrastructure layer

The infrastructure layer offers the means of hardware and software so that the SLE can

1 https://www.thesaurus.com/

run and, if necessary, allow the feedback of the databases of the modeled system. We make Hardware Selection according to the ecosystem. For example, we will need a communication API with the VLE database if using the SLE in distance education. The definition of the SLE operating platform (web, mobile, desktop, etc.) is also a determining factor in the choice of hardware.

This layer contains artifacts that also generate data that can be analyzed, such as the so-called *wearables* that produce information about, for example, the health of its users (heartbeat, sleep quality, etc.). *Wearables* and "sensors" are artifacts for generating and capture data. Examples of sensors are facial recognition devices, biometric identifiers, pupil movement capture devices, and classic IoT artifacts such as temperature, weight, pressure sensors, etc.

5.1.4. Application and presentation layers

The application and presentation layers make the productions generated by SLE available to the user and the communication interface between them. The elements included in the application layer, on the one hand, can support students with recommendations to assist them. On the other hand, they can support teachers or education managers, promoting personalized visualization of data and productions of students with dashboards and reports for general monitoring of individuals, identifying, for example, students at risk.

The conceptual model represents the presentation layer as an internal layer to the application layer. It contains (i) The interface for the functionalities implemented in the previous layer; and (ii) artifacts complementary to the use of SLE, such as management systems for facilitating registrations. These registers can include everything from personal data to complex information related to the individual's knowledge, such as learning records, interests, agenda, favorite links, etc.

5.2. Theoretical and practical justification for the elements of the framework

To determine the intelligence layer libraries and the purpose (Endpoint software) of the SLEs designed, we carried out a survey based on consultations in the literature and with investigators and professors of our research center, in view their expertise built with years of experience in information technology in education.

Artificial Intelligence for EDucation (AIED) is a research area that has developed a lot in the last decades. Some sub-areas stand out in the production of smart applications. They are: (i) Educational Data Mining (EDM), (ii) Educational Natural Language Processing (ENLP) and (iii) Location Based Services (SBL) [32],[6],[36],[10]. These AI tools support learning to be customizable and ubiquitous.

The most demanded of the existing EDM tasks are Prediction by Classification, Clustering, and Mining of Relationships (in Association Rules) [41]. The vision of [41] pairs with the experience we have had in our research center, mainly in the performance of benchmarks for classification algorithms using machine learning [25].

Burstein [4] discusses opportunities for research on ENLP and mentions some outstanding tasks in the area, such as semantic load increment by synonym replacement, *chatterbots*, text similarity calculation, etc. Researchers in information technology in education have still directed many efforts to encourage the analysis of students' feelings and how this impacts the quality of learning [1].

Kolvoord [15] talks about the current and future uses of LBS in the classroom. It is widespread that these uses involve teaching-learning techniques on topics related to geography, with the exploration of places through GPS positioning and mapping. Nevertheless, beyond that, we have been directing efforts in the LBS research to discover possible interactions by geographic proximity.

There is a final contingent of AI tasks that do not fall directly into any of the mentioned three groups. This group includes intelligent functionalities perceived empirically by researchers from our research center. We call this group Smart Web Services (SWS), and two of its main features are internet search robots [7], and web scraping [42] to respectively make automated queries on web search sites and extract/clean data from HTML content.

5.3. Modeling *Ubiquitous LIEd:* a smart environment for a learning ecosystem

Individuals interact, whether with environments or with other individuals, and these interactions generate productions. In a learning context, when this happens, it suggests a learning ecosystem. Figure 3 shows an example of an ecosystem with five possible niches formed by elements of the sub-environments: (i) SA1, (ii) SA2, (iii) SA3, (iv) SA1 + SA2, (v) SA3 + SA2, the latter two formed by approximation of interests. Is this ecosystem, the technologies can provide support for interactions and for the approximation of individuals.

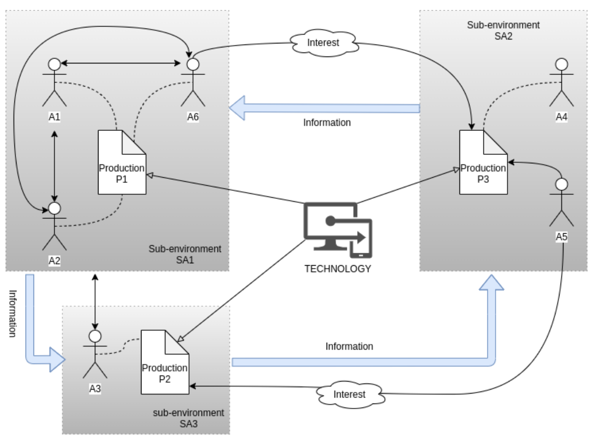


Fig. 3. Learning ecosystem example [28]

Starting from this outline, let us specify an ecosystem with the context of a research laboratory composed of some sub-environments, in addition to the physical laboratory itself, such as a conversation group of a mobile application, the classrooms of the disciplines that the participants can attend together, among others. These participants produce artifacts from the interactions, for example software, articles, texts, etc.

Around each individual, there are other networks in which he/she participates to where these interactions can flow and can easily get lost. The instances of the framework are resources that can help prevent this from happening. Thus, the concern about constructing knowledge should not fall only on the school but also on learning communities [26]. We need an SLE capable of promoting learning and managing interactions in this ecosystem, helping with our mechanical tasks. Furthermore, working as an apparatus that could contribute to teachers (in school ecosystems) with data analytics, for decision-making processes and assisting in the mediation process with tasks assignment, automatic responses, evaluative feedback, etc.

The SLE we propose is a ubiquitous learning assistant for research center members. Its primary function is to generate recommendations from the analysis carried out by intelligent agents on productions registered by the participants and on the curriculum existing on the Lattes[2] platform. The SLE has a management system that can be accessed by PCs or by mobile devices. Figure 4 presents the Ubiquitous LIEd as a model designed with the Framework.

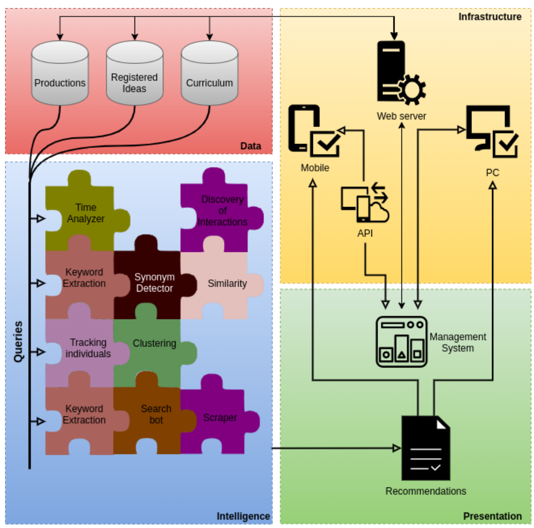


Fig. 4. Ubiquitous LIEd model designed with the framework [28].

Observing the intelligence layer of the Ubiquitous LIEd model, different libraries correlate to produce the following functionalities: (i) Recommendation for access to content: An agent observes the productions and curricula of user and compares them with their previously registered learning interests. Next, it uses a search robot to search in the internet and recommends scientific papers and digital media of interest. (ii) Recommendation for interaction: An agent, observing the same data, uses intelligent information retrieval techniques to identify the similarity between the contents registered by users and, finding similarity, suggest their approximation (as there may

2 http://lattes.cnpq.br/

also be mutual research interest). This agent considers the geographical proximity between users to recommend face-to-face interactions in some cases.

Still, we have two other important recommendation features: (iii) Recommendation for participation in ecosystems: An agent controls the time that a member is without interacting with the group and makes interventions. (iv) Recommendation of learning records: An agent observes the time that a participant remains without registering new learnings, both in the SLE management system and in an external learning portfolio and makes interventions.

The SLE project includes functions that make it a truly ubiquitous tool. These functions are split into two groups. In the first, the Ubiquitous LIEd allows the recording of information, ideas and interactions in real-time wherever the user (with the Ubiquitous LIEd port) be. In the second group, with the implementation of the "Discovery of interactions" and "Tracking individuals" libraries, the SLE is able to generate recommendations sensitive to the individual's geographic position, for example (i) suggestion of people with similar interests and suggestion of content (researched on the internet) about events and places; and (ii) grouping of individuals by tracking the route produced. This second group of features is implemented but has not yet been tested due to the pandemic moment we are experiencing.

5.4. The first stage of the framework validation

A common way to validate frameworks is to carry out exploratory and/or empirical tests with the objects resulting from their practical application [35], [2]. This will be done in a second validation step. However, we can also validate the Framework, showing that it is capable of instantiating environments that noticeably have SLEs functions. We did this, according to the methodology proposed in [11] which evaluates the applicability of the proposed models (e.g. a framework) with case studies generated from their instantiation. This is the first stage of validation.

This methodology is based on Design Science Research (DSR), which aims to expose pieces of evidence that the artifact produced can effectively be used to solve real problems. There are five forms of evaluating the artifacts generated with DSR and the Framework's first validation step falls under the *Descriptive* form, which uses information from knowledge bases (e.g. relevant research or existing products) to build an argument about the usefulness of the artifact [47].

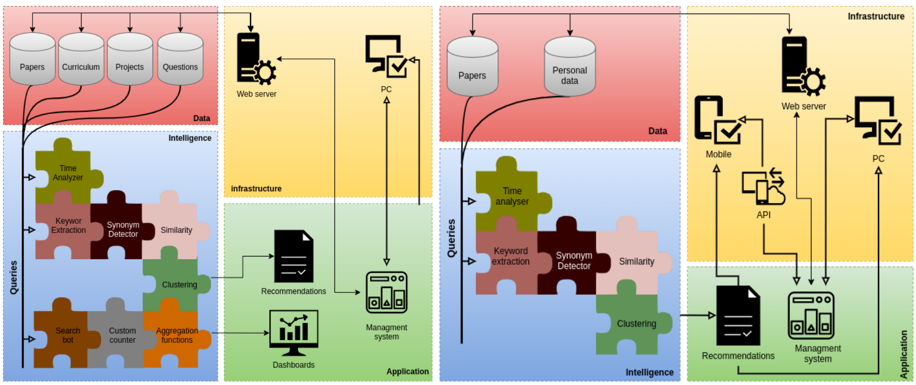
Some tools, prevalent in academia, have been used as platforms for interaction and collaboration by researchers worldwide. As examples, we cite the social networks *Researchgate*[3] and *Mendeley*[4]. These tools favor learning and are capable of providing several of the aids reported in Section 2.1, including task support, context-sensitivity and knowledge base provision.

For the conceptual representation of these environments, we are considering in the intelligence layer only the functions related to the "smart" part of both SLEs, which in our instantiation, ask for the contribution of AI. These functions include (i) recommending articles, (ii) recommending interaction with researchers, (iii) data

3 https://www.researchgate.net/
4 https://www.mendeley.com/

visualization (productions, citations, etc.), among others. The entire administrative part of the tool, related to registration and data persistence management, is in charge of the "Management System" element.

Figure 5-A shows a copy of the *Researchgate* now designed with our framework we call *FResearchgate*. In the intelligence layer, we highlight the use of libraries to build the well-known functionality for generating recommendations for reading papers that are performed from time to time. From the papers, projects, curricula, and registered questions, we use the libraries to extract keywords considering synonyms and thus calculate the similarity with other papers also registered on the platform, and then suggest them to users according to the similarities.



(A) FResearchgate (B) FMendeley

Fig. 5. Copies of Researchgate and Mendeley as SLEs designed with the Framework [28].

The *Researchgate* also has a user information panel that aggregates academic data such as several publications, projects, and works co-authored with research partners. *FResearchgate* does this with a dashboard in the presentation layer, assembled from queries of the environment, by a search robot consulting the internal database.

Regarding the reading suggestions, something very similar occurs with *FMendeley* (our instance of *Mendeley*) in Figure 5-B, differing in terms of source data and product presentation, that takes place in more than one platform (web and mobile). Both *FResearchgate* and *FMendeley*, the recommendations are powered by clustering functionality, creating user profiles from text mining.

5.5. Limitations and future perspectives of framework extensibility

The Framework does not cover all aspects of existing SLEs. Each layer has its limitations, for example, the guarantee of security in the data layer or the availability of the multitude of elements that the infrastructure layer can have. The same goes for the intelligence layer; it does not cover all the "smart" functionalities that an SLE can contain. We limit them to those considered of great value both by the literature and the experience of experts. However, it is extensible, mainly in the intelligence layer.

There are still limitations related to the current state of technology. The biggest problem is interactions registration and consequent learning management through SLEs. All interactions and productions stored in the databases are usually extracted from VLEs, conversation groups, video recordings of meetings, etc. However, many interactions are not recorded, resulting in the loss of probably relevant information sources for intelligent analysis. We talk about small conversations during a coffee break, thoughts not retained, ideas that go away, and so on.

We believe that in the not-too-distant future, especially with the large-scale evolution of IoT, ubiquitous technologies will be enough to help humans record and manage interactions and knowledge comprehensively. With the right technology, we will have body sensors and *wearables* to detect and record our interactions with other individuals or with the environment itself and our mood and health [21]. However, we know that such widespread data sharing can raise ethical questions that generate debates and analyzes of long terms.

6. Second stage of framework validation

The designed the Ubiquitous LIEd for working as a ubiquitous learning assistant for the participants of a research center. However, it has a high-performance perspective, applying it in laboratories, courses, disciplines, and other ecosystems. For this, the tool must meet the following premises:

- The main functionality of the tool is the generation of recommendations;
- Integrating productions into the learning ecosystem;
- Ubiquitously assist the registration of information;
- Promote collaboration between learners, according to their areas of interest;
- Promote interactions, based on the relevant productions and data;
- Development of the learner's autonomy;

The SLE assumes the characteristics of a technological platform composed of five main components, namely: (i) Android Application; (ii) Application communication API with database; (iii) Database (DB); (iv) Web application and (v) Smart agents.

6.1. Design of the experiment

For Ubiquitous LIEd testing, we built a course on Computational Thinking and Cooperation in Industry 4.0, offered in distance mode, with a 90-hour workload. We applied it in two different classes. The first was composed of students with university and high school levels mixed. There were 26 enrolled, and 11 completed the course (6 from university, 5 from high school). In the second edition, students of five different IT college courses participated: (i) Computer Science, (ii) Information Systems, (iii) Computer Engineering, (iv) Systems Analysis, and (v) Development and Data Science. There were 76 enrolled (19 completed the course). All students agreed to participate in the research and signed a commitment term that specifies all ethical implications related to data collection. The main reasons for dropping out of the course were: (i) unavailability of time and (ii) personal issues.

In both editions, we offered the course on the collaborative wiki platform *PBWorks* with the support of the SLE Ubiquitous LIEd. The last activity in both courses was to answer an evaluation questionnaire about the course and the Ubiquitous LIEd.

The SLE also has an evaluation mechanism for the recommendations. For each recommendation received from the mobile application and the web platform, the user assigns a score from 1 to 5. We will use these results to evaluate the Ubiquitous LIEd at the level of the recommendations generated.

6.2. Methodology for creating and applying the questionnaire

In the research problem, we investigated three aspects of evaluation: (i) the course offered quality, (ii) the teaching team, and (iii) the Ubiquitous LIEd. In this paper, we will focus on this last aspect to demonstrate the applicability of the proposed Framework. As an approach and the type of research, we use mainly closed questions with answers that obey a 5-point Likert scale. We also used open-ended questions to guide the answers to closed questions through discourse analysis.

The answers to the questionnaire that evaluated the Ubiquitous LIEd tool were based on the adaptation of the Technology Acceptance Model - TAM [9] for E-learning systems or applications for information technology in education [30], [34]. All 30 students who completed the course answered the questionnaire.

With the questionnaire application concerning the Ubiquitous LIEd, we sought to identify the following evaluation factors: (1) perception of the tool's usefulness, (2) perception of the tool's ease of use, and (3) whether the purpose of the tool was achieved (from being a personal and collective learning assistant).

6.3. Results and initial discussion

This section will show the questionnaire and raise an initial discussion about the main aspects of evaluation and validation of the tool only. We will also discuss the evaluations of the recommendations generated by the SLE.

6.3.1. Evaluation of Ubiquitous LIEd through the questionnaire

Table 2 shows the average of the values of the responses for each question. To calculate the average, we assign values from 1 to 5 in the responses, where 1 represents a total disagreement and 5 a total agreement, and so on. Later, we present the graphs of some questions to conduct a discussion.

Is noted an evaluation with values less than 5 and closer to 4, leading us to understand a partial agreement regarding the quality of the SLE (general average of 4.01 ± 0.22). These are values that indicate a positive evaluation.

Table 2. Questions and average obtained (SLE evaluation)

Statement	Average ± SD
1. Ubiquitous LIEd tool made learning easier	3,73±0,96
2. Ubiquitous LIEd tool was useful for my learning during the course	3,91±0,93
3. Using Ubiquitous LIEd system increased my productivity	3,76±1,02
4. The interaction with Ubiquitous LIEd is clear and understandable	3,76±1,18
5. Ubiquitous LIEd is easy to use	3,64±1,10
6. Ubiquitous LIEd behaves as personal learning assistant	4,18±1,00
7. Ubiquitous LIEd behaves as collective learning assistant	4,12±1,04
8. The recommendations provides by Ubiquitous LIEd were relevant to my needs	3,97±1,03
9. The recommendations of the types below, have a high degree of usefulness	
9.1. Scientific papers	4,30±0,94
9.2. Instructional videos	4,15±1,02
9.3. Interactions: Even with people I don't know, but with similar interests	3,97±0,97
9.4. Participation in the ecosystem	4,03±1,14
9.5. Registration of learnings	4,33±0,94
10. I would use the Ubiquitous LIEd outside the course. For my work, for example	4,30±1,03

We highlight statement 9 and its subset of statements, which assess whether the recommendations made by the SLE were indeed helpful for students. All five recommendations had an average response very close to 4, demonstrating that users partially agree that all recommendations were beneficial for their learning.

Statements 6 and 7 address the evaluation factor 3 (Section 6.2). More than 70% of respondents agree that the SLE is what we designed it to be: an individual/collective learning assistant. Although we tested the tool in an educational ecosystem, the average obtained with statement 10 indicates that the Framework produces tools that can be used in other scenarios and throughout life, not just at school.

The graphs of Figure 6 visually show that more than 2/3 of the students in both courses consider (partially or totally) that the SLE made learning easier about the course content, which gives us the first indication that the tool fulfills its purpose, considering the evaluation factor number one of Section 6.2.

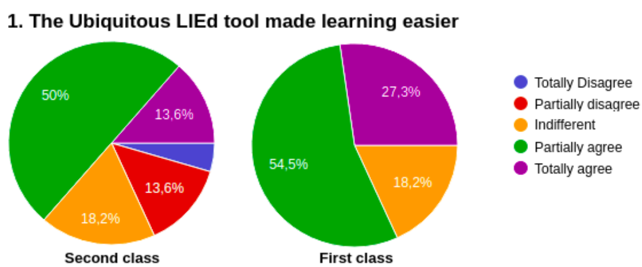


Fig. 6. Graph of responses to question 1 of the SLE questionnaire.

The graph presented in Figure 7 shows the students' answers about SLE use make the learning process easier. More than 50% of users agree partially or totally with the statement in both courses. Both graphs for questions 1 and 2 are related to the user's perception of Ubiquitous LIEd in facilitating their learning. There is a discrepancy between the classes in this respect. We suspect that this difference was due to the type of course offered. The first class had almost four months to work on the content and receive many more recommendations than the second, which worked at an intensive pace four times shorter.

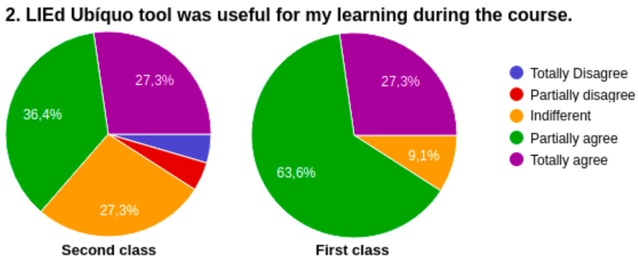


Fig. 7. Graph of responses to question 2 of the SLE questionnaire.

Finally, we comment on statements 4 and 5 of Table 2, which takes us to evaluation factor 2 in Section 6.2, which shows a lower rating, but still indicates a perception of the tool's ease of use, considering the proximity to a partial agreement (value 4). We believe the lower ratings are due to deficiencies with the user interface, which the participants noticed in the answers to the open questions.

6.3.2. Evaluation of Ubiquitous LIEd recommendations through the tool itself

We are faced with a good evaluation of the recommendations generated by the SLE. During the course period for the two classes, the Ubiquitous LIEd generated 2709 recommendations, of which 239 were evaluated. 22 were interaction, 22 were participation in the ecosystem, 26 in the learning record, 91 in videos, and 78 in papers. If we compare the averages of the evaluation made directly in the application with the evaluation of the questionnaire specifically for the recommendations, they are not far apart, as can be seen in Table 3.

Table 3. Comparison between the averages of the evaluations made directly in the application and by the questionnaire.

Type of recommendation	Average ± SD Application	Average± SD Questionnaire
Content recommendation: Papers	4,18 ± 1,26	4,30 ± 0,94
Content recommendation: Videos	4,35 ± 1,11	4,15 ± 1,02
Interaction recommendation	3,73 ± 1,68	3,97 ± 0,97
Learning registration recommendation	4,41 ± 1,19	4,33 ± 0,94
Recommendation for learning ecosystem participation	4,08 ± 1,49	4,03 ± 1,14

The assessments made on the application were carried out throughout the course in both classes on several occasions, while the assessment was made on the questionnaire in a single moment. As the averages present a tiny difference (at most 0.24, which is less than any standard deviation), we infer that this validates the questionnaire in the questions related to the evaluation of the recommendations.

Regarding participation in the learning ecosystem, the Ubiquitous LIEd recommends the insertion of content, entries in the learning portfolio, and the lattes curriculum. We grouped these three recommendations as a “Participation Recommendation”. Same for “Interaction Recommendation” that groups the recommendations made by finding similarities in (i) posted content, (ii) registered curricula, and (iii) learning interests.

After the evaluations that we presented and discussed in this section, we can state that despite the problems with the user interface, the Ubiquitous LIEd had a good evaluation on both of its purposes: to be a ubiquitous assistant for learning and as a support for fostering interactions (and consequent learning) in the ecosystem. With that, we finish the second stage of the Framework validation showing that it builds SLEs that achieve desired goals for SLEs.

7. Final considerations

We presented a framework for modeling smart environments to foster construction knowledge in learning ecosystems. We modeled an SLE with the proposed framework, and we implemented it. We also tested and validated it. Furthermore, we validated it by instantiating two SLEs that represent accepted and widespread environments.

The results showed that (i) the personalized recommendations generated by the Ubiquitous LIEd made the students not only improve their interactions but also supported learning, in a way that the SLE functioned as a personal and collective learning assistant; and (ii) the framework we propose fulfills its purpose of providing elements to model SLEs that behave like SLEs.

As a future work, we will create an interactive environment based on the Framework to facilitate de implementation of SLEs and for that it is necessary build the Framework libraries that have not yet been produced and that would be very useful for the scientific community, such as the image analyzer and sentiment analysis functions.

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