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Education 4.0: Proposal of a model for autonomous management of learning processes

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Abstract. From antiquity until nowadays, educational systems have evolved in parallel with major social and economic changes, integrating pedagogical and technological innovations into the educational ecosystem and leading to the advent of a new educational revolution, called Education 4.0. The Education 4.0 paradigm allows both, to support educational organizations in the adoption of pedagogical and digital transformations, and at the same time to meet the needs of new generations of learners and teachers. The increasing use of ICT and the power of the Internet have fostered the emergence of a new generation of learners for whom technology is an integral part of their lives and therefore of their learning style. To respond effectively to the specific needs of these new learner profiles, educational organizations must adopt significant and ongoing transformations in the way we teach and learn. Enabling student-centered teaching, personalized learning paths, and access to a variety of heterogeneous educational resources have made educational processes too complex for the educator to effectively monitor the individual progress of each student. It becomes necessary to automate the management of learning processes to provide better answers to the evolving and specific needs of the different actors (students, educators, training program managers, companies, etc.) This research project aims at proposing an autonomous architecture of Cyber-Physical systems for Education 4.0. This architecture responds to the needs of educational systems, integrating digital technologies for the development of heterogeneous learning environments, capable of meeting the needs of a plurality of learners with different profiles and supporting teachers and training managers in the management of learning processes. This architecture offers the possibility of autonomous management of learning processes to analyze the progress of students and to prescribe the necessary recommendations to increase the chances of success, facilitating the mission of teachers.

Keywords: Education 4.0, Cyber-Physical Systems, Autonomic Computing, Learning Process, Learning Analytics.

1 Introduction

The current context of educational organizations is characterized by an increasing evolution. The current context of educational organizations is characterized by an increasing evolution of the need for continuous improvement of learning and the environments

in which it occurs to provide effective responses to the expectations of the various stakeholders. Nowadays, Education 4.0 also promotes the ubiquitous availability of information with learning systems making learning processes and pathways more dynamic [1]. The sources of knowledge and competencies are increasingly heterogeneous and complex, making it sometimes difficult to effectively exploit resources in relation to learning outcomes and pathways to better guide the learner's evolution and facilitate the teacher's task. Moreover, the growing integration of ICT and the power of the Internet has encouraged the emergence of a new generation of learners with different profiles, interests, and learning rhythms. This makes it extremely complex for the teacher to optimally manage the learning process, adapt, and personalize the learning paths, and evaluate the quality and effectiveness of the educational content. For this reason, these organizations need to transform the process paradigm of technology-supported mass education into a new digital transformation approach, centered on automated management of learning processes. In this paper, we propose an architecture for autonomous management of learning processes to meet the challenges of Education 4.0, based on Learning Analytics methodologies. This model allows educational organizations to evolve towards the Education 4.0 paradigm, to automate and digitalize learning processes and pathways to increase the chances of success for learners and facilitate the work of the teacher. This document is structured around five main sections. Section 2 presents a state-of-the-art on the different educational evolutions. Section 3 provides a survey of related work in our research area. Section 4 presents an autonomic architecture for Education 4.0. Section 5 presents the implementation of the architecture and the analysis of the results obtained in the framework of the PIA-3 HyPE -13 project (*Hybridation et Partage des Enseignements*) within a consortium of 12 French higher education institutions and EdTech companies.

2 State of Art

From antiquity to nowadays, educational systems have evolved in parallel with major social and economic changes, as well as pedagogical and technological innovations in the educational ecosystem leading to the advent of a new educational revolution called Education 4.0. To understand the expected challenges of Education 4.0, it is important to review previous educational revolutions from antiquity to today [2]:

- **First educational revolution: Education 1.0** could be defined as the period from antiquity to the Middle Ages, during which the educational system was characterized by an informal mode of teaching, developed mainly within religious institutions. Each educator constructed his or her teachings according to his or her knowledge, expertise, and what he or she felt was important for the learners. During this period, it was possible for the educator to ensure quality teaching with personalized follow-up of each learner, but the transmission of knowledge and competencies was reserved for small groups of learners from a privileged socio-economic level, the majority of whom were male.

- **Second educational revolution: Education 2.0** appeared in response to society's need to democratize education and to train the largest number of individuals giving rise to education open to the public with advanced and formal teaching methods, within schools, colleges, and universities. During this period, the mode of teaching was guided by a program-oriented approach with the exit profile of the learners as a reference. Learning activities and content, as well as assessments, were decided in accordance with the learner's graduation profile. The increase in the number of learners makes it more and more difficult to provide personalized follow-ups to each learner to ensure success.
- **Third educational revolution: Education 3.0** is characterized by the increasing integration of Information and Communication Technologies for Education (ICTE). Education 3.0 is a direct consequence of the availability of information, the massive deployment of computers, and mobile devices, and the power of the internet encouraging the adoption of new methods of access and dissemination of knowledge with new paradigms of interaction between human beings. New models of open and online education such as Massive Online Open Courses (MOOC), Corporate Online Open Course (COOC), and Small Private Online Courses (SPOC) have completely disrupted our way of learning and teaching giving origin to mass education without constraints of space, time, and place. However, with a plurality of learners with different profiles and rhythms, it becomes difficult, if not impossible, for the teacher to provide each learner with a personalized follow-up. The heterogeneity of the sources of knowledge makes it more difficult to see the learning paths of the learners and makes it difficult for the teacher to evaluate the quality of the educational content. Education 3.0 has had a huge impact on the educational ecosystem by encouraging the emergence of new generations of learners who are using new forms of interaction and adopting new cognitive models that are setting the stage for the next educational revolution.

To better understand the challenges of Education 4.0, it is important to understand how the various industrial revolutions have led to major upheavals in all activities of human life, including education. Nowadays, we are witnessing the fourth industrial revolution (Industry 4.0) which is mainly based on the integration of cutting-edge technologies such as Artificial Intelligence, Robotics, Big Data, Cloud Computing, Internet of Things, Internet of Services, and 3D printing in the industry, with the aim of automating and digitizing manufacturing processes and next-generation services. Industry 4.0 encourages a fusion between the physical and digital worlds to improve the management of products, business processes, and services [3]. It is also characterized by a shift from mass production or service offering to customized production focused on the individual requirements of each customer [4]. Educational organizations are also moving towards the fourth educational revolution, entitled Education 4.0.

- **Fourth educational revolution: Education 4.0** could be defined based on two emerging trends, one of which is the integration of advanced technologies driven by Industry 4.0 in education and the other the pedagogical innovations and changes needed to meet the new challenges of tomorrow's learners and society. On the one hand, Education 4.0 is considered a direct consequence of

the emergence of Industry 4.0, with a view to preparing future generations of learners for the fourth industrial revolution and aligning education with Industry 4.0 [5]. It involves integrating the technological advances of Industry 4.0 for educational purposes [1]. With this new trend, Education 4.0 encourages the transformation of the process of integrating technological advances into teaching and learning to encourage an alignment between education and Industry 4.0 [8]. On the other hand, Education 4.0 is a vision of the future of education that encourages the use of the potential of digital technologies, personalized data, and the opportunities offered by this connected world to encourage lifelong learning [6, 7]. It is an educational revolution that allows learners to be architects of their learning, through the personalization of flexible, dynamic, and adaptive learning paths [2]. With this second trend, Education 4.0 launches educational organizations into a dynamic of adopting new technological and pedagogical transformations to better meet the specific needs of each learner. Education 4.0 is a continuation of the process of integrating digital technology into education to use the potential of digital technology and encourage continuous innovation.

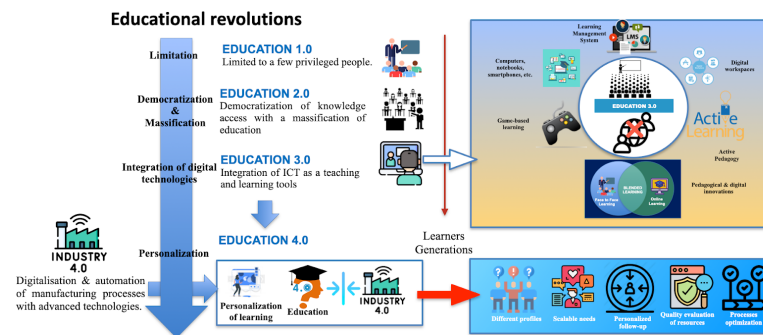


Fig. 1. Evolution towards the Education 4.0 paradigm.

3 Related works

Nowadays, proposals of application or examples of implementation of the Education 4.0 paradigm are increasingly developing in educational organizations. Most of the related works are proposals of models or cases of application of the Education 4.0 paradigm that is oriented on the adoption of new technological and pedagogical transformations. These transformations aim to encourage the personalization of learning with flexible, dynamic, and adaptive learning paths. There are also application cases focused on the integration of advanced Industry 4.0 technologies in education for better preparation of learners for the fourth industrial revolution.

Fisk [6] proposes general innovations and mutations needed to implement the Education 4.0 paradigm. This proposal is based on the adoption of nine trends in the

world of learning which are (1) *learning in diverse times and places*, (2) *personalization of learning*, (3) *adaptive and dynamic learning processes*, (4) *project-based learning*, (5) *field experience*, (6) *data interpretation*, (7) *formative assessments*, (8) *student ownership*, and (9) *mentoring system*. In this approach, the nine trends of Education 4.0 contribute significantly to the transformation of the current teacher role by putting the learner at the center of learning concerns.

Hussin [7] implements the nine trends of Education 4.0 proposed by [6] in a language course based on the use of several digital tools with varied content formats (text, video, file, and website links). The author uses educational technologies (*Open-Learning*, *Mentimeter*, *Padlet* and *Kahoot*) allowing him to implement flipped classroom, activity-based learning, diagnostic and formative assessments, active pedagogy, as well as badges to reward learners' participation and creativity. According to the author, despite the instability of the Internet connection encountered by the students, the approach was well appreciated by the latter who would like other courses to follow this approach.

Intelitek [5] develops an implementation of Education 4.0, based on the transformation of four paradigms of current education which are (1) *the empty brain paradigm to be filled*, (2) *the requirement of basic knowledge*, (3) *the interference of the computer with the thinking* and (4) *the individual learning mode*. The learning environments are inspired by Industry 4.0 and the development of transportation systems, healthcare systems, and more. The Intelitek Education 4.0 learning system is based on fundamental principles of Education 4.0 such as personalization of learning paths, formative assessment mode, mentoring, and divergence and plurality of learner profiles.

Mourtzis et al. [8] present "*The Teaching Factory Concept*" which is an application of the Education 4.0 paradigm in manufacturing education. This developed approach is based on the integration of Cyber-Physical systems and Industry 4.0 technologies in teaching. This concept is applied to a use case of a remote-control car manufacturing course based on a combination of traditional manufacturing techniques with technologies introduced by Industry 4.0. This application introduces students to advanced manufacturing techniques, integration, and analysis of data collected from design to prototype manufacturing to better perform performance testing during the process.

These related works are proposals and cases of application of the Education 4.0 paradigm that is mostly oriented to an alignment of education with Industry 4.0 or a set of technological innovations and pedagogical mutations. However, to the best of our knowledge, there is not yet an architectural framework to support educational organizations in their processes towards the implementation of the Education 4.0 paradigm.

4 Proposal

In this paper, our contribution aims to provide an architecture for the autonomic management of learning processes to support educational organizations in their transformations towards Education 4.0. The autonomic character of the system refers to the

automation of monitoring and remediation processes, based on observations and diagnosis of the learner's evolution and the proposal of resources or activities to anticipate failure and increase the chances of success. This solution proposes an architectural framework of the Education 4.0 paradigm to support educational organizations in their transformation to automate and digitalize the process and flexible, dynamic, and adaptive learning paths for mass but also individualized education. It allows for improvement and optimize learning processes, personalizes, and adapts learning paths, and ensures an evaluation of the quality and effectiveness of educational content through the implementation of Learning Analytics methodologies. With our approach, we aim to enable educational institutions to face the complexity and inefficiency of manual management of learning processes. The high-level architecture of our contribution is presented in Fig. 2, based on the *ARCADIA* (Architecture Analysis and Design Integrated Approach) methodology.

4.1 Actors

To better ensure this transition to Education 4.0, we will propose a system that considers the issues related to Education 4.0 actors such as people, connected objects, and services. The system is based on the operational needs of the actors, the activities to be performed, as well as the entities, roles, and concepts related to the application of the Education 4.0 paradigm.

4.2 Common semantic space

To automate learning processes, it is necessary to have a format for the description of all entities (resources, actors, properties, relations, events, etc.) with a language that can be understood and interpreted by both humans and machines for automated management of learning processes. It is for these reasons that we have adopted a representation of the information in the format of the xAPI standard [9]. This will allow us to have a shared conceptualization resulting in a standard and explicit specification language understandable by humans and machines.

4.3 Autonomous learning management

The autonomic management of learning processes requires a system able to implement functions of description (complete description of actors, events, and actions performed), diagnosis (identify problems in learning processes), prediction (able to make a prediction about what will happen in the future, for example predicting the failure or success of a student) and prescription (propose actions or recommendations to the student or teacher in order to improve the results and learning outcomes). This allows the automation (or semi-automation) and optimization of the management of learning processes, as well as the ability to adapt to dynamic and unpredictable changes in learning environments; for this reason, we have adopted an approach, inspired by the concept of the *IBM MAPE-K* reference architecture of *Autonomic Computing* [10, 11] to provide our system with autonomous manager modules: *Description, Diagnosis, Prediction, Prescription*.

4.4 Autonomous management architecture

The architecture of the solution we propose is based on data sources coming from the learning environment which can be composed of one or more LMS (Learning Management System), learning objects, virtual learning environments, as well as the interaction traces of the actors. After the collection and storage of learning data using a Learning Record Store (LRS), this data is destined for the autonomous learning management system based on autonomous manager modules around an LRS, provided by the LA levels of analysis methodologies [12, 13, 14]:

- **Description (What happened?):** This is the first level of analysis, based on observations and reporting. Once the learning traces have been collected and processed, the system provides, through a descriptive analysis, the progress, participation, and performance, as well as the different interactions of the learners describing their individual learning paths. As a result, we can visualize the learning path followed by each learner, organized by learning outcomes, or also by learning objects. We can visualize the link between the resources and the related activities, in other words the learning objects and their respective learning outcomes.
- **Diagnostic (Why did it happen?):** This is the second level of analysis that provides an explanation of the descriptive elements to critically evaluate why an out-come occurred. It is in the diagnostic analysis that the system allows for correlations between each learner's learning path and the results of their progress, participation, and performance assessments. With this additional information, we can quickly identify learners who need help and study their individual learning paths to understand the "Why" of their current situation.
- **Prediction (What will happen in the future?):** This is the third phase of the analysis methodology whose objective is to make predictions about what will happen in the future. The learning traces can link each learning object (resource, activity, or assessment) used by the learner to the expected learning outcomes, for which he/she might also have prerequisites. This information allows more specific predictions to be made based on the prerequisites for each learning outcome. This would also offer the possibility of predicting the success or failure of a learner based on visual indicators (semaphore model based on green, yellow, and red indicators) related to his/her progression, participation, and performance in a course.
- **Prescription (What should be done to improve?):** this is the most advanced level of analysis that will allow the implementation of action plans in the form of recommendations to the teacher or learner to help them improve their learning. Since it is possible to clearly identify the learning objects in which the learners encounter difficulties, it becomes possible for the teacher to be able to evaluate the quality of the learning content. As a result, it can be recommended to the learner that before starting a learning resource consult the content of another resource that is essential in the acquisition of a learning outcome. It also offers the possibility of recommending to the learner a learning path to follow to effectively use the learning resources.

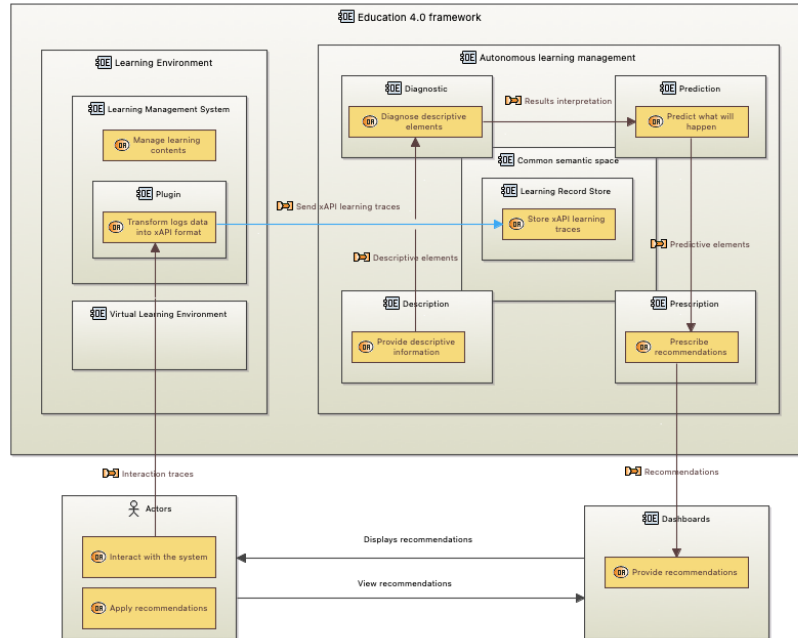


Fig. 2. Cyber-Physical Systems autonomic architecture for Education 4.0.

5 Results

The architecture proposed in this research project has been adopted in the design and implementation of a SPOC intended to train more than 200 teachers who are part of the consortium of 12 French universities participating in the HyPE13 project (ANR-PIA3: *Hybrider et Partager les Enseignements*). The goal of this SPOC was to train teachers in the design of hybrid courses integrating the analysis of digital learning traces. It also aimed to present the foundations of methods and tools for analyzing and interpreting digital learning data to help teachers provide personalized support to their students. In addition, this SPOC offered a general introduction to Learning Analytics (LA) to raise teachers' awareness and provide a methodological framework for designing lessons with LA integration. The SPOC consists of 6 learning paths (LP), each of which is composed of at least 5 learning objects (LO). The SPOC was launched in June 2021 and proposed 6 hours of training, including 4 hours of asynchronous learning activities spread over 5 learning paths and 2 hours of synchronous learning activities proposed during the 6th and last learning path, in the form of a workshop. The target audience was teachers, students, training managers, and university staff. This case study allowed us to implement and evaluate our architecture, thanks to the deployment of learning traces sensors within the learning objects and learning paths that were processed within

MAPE loops. For each student loop, a dashboard is able to show in real time the learning analytics results: describing, diagnosing, and predicting the progression, participation, and performance of each learner. Teachers have access to a global dashboard presenting the analysis results for the student's cohort (see Fig 3.)

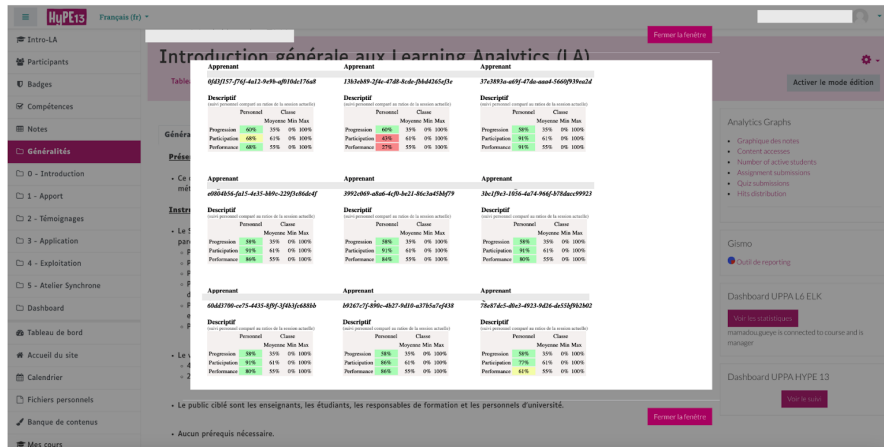


Fig. 3. Dashboard: Monitoring learner *Progression*, *Participation* and *Performance*.

For the student, the same dashboard displays individual information on his or her progress, participation, and performance, as well as that of other non-identifiable learners, since only the learner's identifiers are shown.

The system also allows the teacher to better explore part or all the learning process, to have general information on the progress of the learning process, to see the frequency of consultation of learning resources, the transition time between resources, etc. (see Fig. 4., Fig. 5, Fig. 5, and Fig. 7). Larger loops were used to identify learning patterns, based on Process Mining techniques, using the Celonis platform [15].

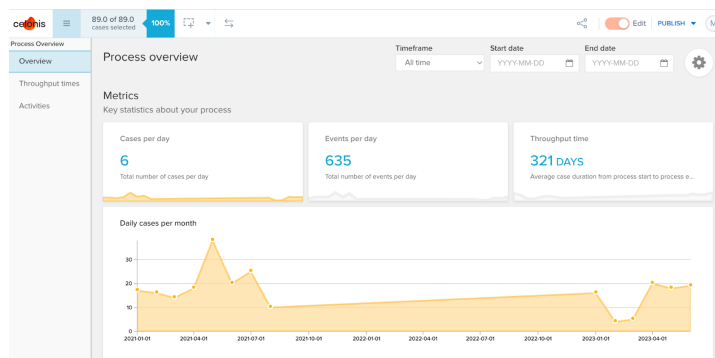


Fig. 4. General information about the learning process.

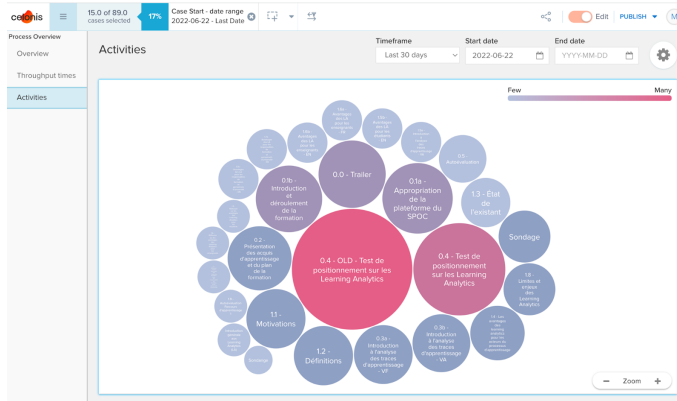


Fig. 5. Frequency of use of learning resources.

The teacher can view the learning paths followed by all learners during the learning process with visibility into the path of each learner. Based on the information used in the learning process, the system can recommend an optimal learning path.

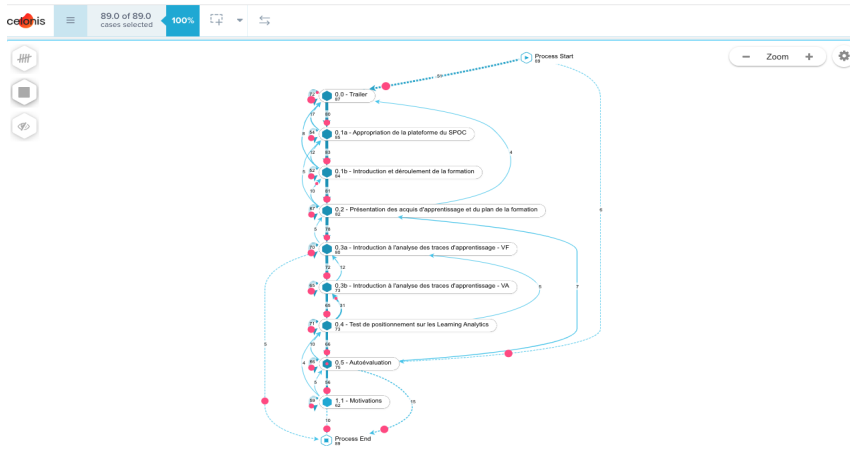


Fig. 6. Visualization of the learning paths of learners

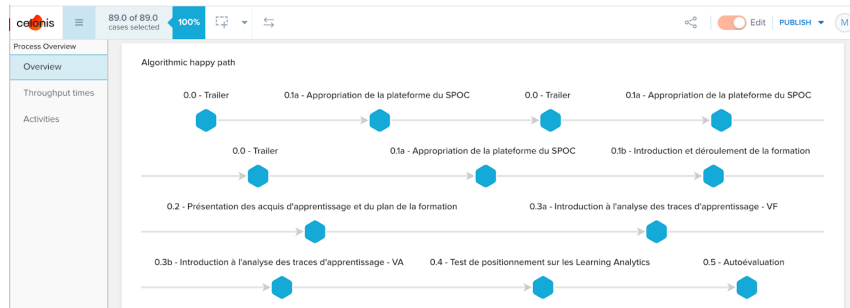


Fig. 7. Recommendation of optimal learning path

6 Conclusion and Future works

This paper has shown the need to support educational organizations in their transformation process towards Education 4.0. We have proposed an architectural framework that allows the progressive implementation of pedagogical innovations and technologies to support the digital transformation of educational organizations to evolve towards the new paradigm of Education 4.0. This architecture allows to answer the needs of personalization and optimization of learning, as well as to support teachers in the improvement of learning. It offers an incremental approach allowing organizations to progressively integrate the 4 levels of analysis (descriptive, diagnostic, predictive, and prescriptive) to implement autonomous management of learning processes. At the operational level, the results obtained support decision-making through learner monitoring with descriptive indicators, performance analysis, and the need to recommend specific learning paths or resources to meet certain prerequisites. At the management level, these results showed that it is possible to ensure overall management of the training program with the possibility to reschedule or even share the workload of learners and teachers, to increase and encourage success. At the strategic level, it is possible to perform a qualitative evaluation of the training, to better understand the profile of the learners and to know if it is necessary to evolve the resources and the activities proposed, in their content and form. In our future work, we will present other implementation results based on the deployment of the solution in courses of our master's in computer science programs. In these experiments, we will work more on the maturity of the automation of the prescription function by integrating the recommendation of learning contents.

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