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# Ontology-driven approach for competency-oriented and student-centered engineering education

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**Abstract**—The evolution of education ecosystems has historically been linked to social, economic, and technological advancements, culminating in the emergence of education of the future, what we might call Education 4.0. To comprehend the challenges and opportunities presented by this new educational era, it is imperative to examine the preceding educational revolutions, ranging from antiquity to the present day. Education 4.0 should respond to the learning challenges posed by modern society's dynamic education needs, while drawing insights from the benefits of past education generations. In this new context, learners should become architects of their education, and institutions must adapt to cater to individual needs. To fully exploit the potential of technology in education, we require a conceptual model that allows us to optimize the benefits from its utilization while emphasizing new pedagogical approaches. This model must include all stakeholders in a common generic semantic space, enabling students to acquire competencies and teachers to design learning resources that precisely meet the needs of our society. Having this generic common semantic space would facilitate the integration of initiatives proposed by major players, such as the curricula recommendations proposed by the ACM and IEEE. The research results are being applied in the development of the ISA NUM program, a new French computer science engineering training initiative. The program leverages an ontology-driven competency model, aligned with the ACM Computing Curricula 2020, to address the current societal demands in the field of computer science. This model forms the basis for an intelligent cyber-physical education system that integrates virtual and physical learning environments, integrating advanced technologies like virtualization, artificial intelligence, IoT, and semantic web. Moreover, this system integrates learning analytics features aimed at facilitating designing and developing personalized, flexible, and dynamic learning paths. Education 4.0 represents a promising future for education, aligning it with the ever-evolving digital landscape and the specific needs of modern learners and society.

**Keywords**—Education 4.0, student-centered learning environments, digital transformation, future-oriented and personalized educational concepts, learning paths, competency-based curricula, ontology-driven approach, learning analytics, cyber-physical systems

## I. INTRODUCTION

Throughout history, education ecosystems have evolved in conjunction with significant social and economic transformations, accompanied by pedagogical and technological innovations. These developments have led to the emergence of a new educational era that could be named Education 4.0. To comprehend the challenges that Education 4.0 presents, it is

imperative to examine prior educational revolutions, spanning from antiquity to the present day [1].

Education 1.0 could be defined as the era covering antiquity to the Middle Ages. During this period, the education ecosystem was characterized by an informal mode of teaching, primarily developed within religious institutions. Educators individually crafted their teaching methods based on their knowledge, experience, and what they deemed essential for their students [2]. While this approach allowed for personalized guidance for each student and ensured the quality of education, the transmission of knowledge and skills remained limited to select groups of students from privileged socioeconomic backgrounds, mainly males.

Education 2.0 emerged as a consequence of the democratization of access to information. This era marked the advent of education accessible to the general public through formal teaching methods in schools, colleges, and universities [3]. During this period, teaching methods were program-oriented, with the learner's output profile serving as a reference point. Learning resources, activities, and assessments were designed based on the expected learner outcomes. However, the increasing number of learners made it progressively challenging when providing individualized supervision to ensure their success.

Education 3.0 is a consequence of the growing development of Information and Communication Technologies (ICT). This evolution is a direct result of the widespread availability of information and knowledge, the extensive deployment of computers, mobile devices and the rich set of services provided by the Internet [4]. These technologies have facilitated novel methods for accessing and disseminating knowledge, along with new paradigms for human interaction. However, given the diversity of learners with varying profiles and learning paces, it becomes challenging for educators to provide personalized guidance to each student. The abundance of knowledge sources further complicates the supervision of students' learning paths, their evaluation as well as the quality and the actualization of pedagogical contents. Education 3.0 has left a significant impact on the educational landscape, giving rise to new generations of learners engaging in novel forms of interaction and adopting new cognitive models, thus laying the groundwork for the forthcoming educational revolution. Overall, we can observe a trend in the evolution of education over time: the number of learners and sources of information

is increasing, while the teacher/student ratio is decreasing (see Table. I).

TABLE I  
A TREND IN THE EVOLUTION OF EDUCATION

	Number of learner	Supervision	Information sources
Education 1.0	Small	High	Low & restrained
Education 2.0	Medium	Medium	Medium & High and restrained
Education 3.0	Massif	Low	Large & open
Education 4.0	Massif	High	Very large & open

We believe that the new educational revolution should effectively handle the increasing number of learners and information sources while providing a high level of supervision for each learner (i.e., individual 1:1 tutoring ideally). It would respond to the learning challenges posed by the digital revolution, while offering the benefits of past revolutions: personalized training and supervision, democratization of access to education, and efficient use of information and communication technologies combined with adapted pedagogical approaches. Education 4.0 represents a vision of the future of education based on the exploitation of technologies such as virtualization, artificial intelligence, IoT, connected environments and semantic web, to assist educators and learners in the implementation of learning processes [5]. This new educational revolution should enable learners to become the architects of their own training through the customization of flexible, dynamic, and adaptable learning paths. Education 4.0 should lead educational institutions to adopt new technological and pedagogical transformations to better respond to the specific needs of each learner. It is a continuation of the process of digitalization of the society, particularly in the area of education, in order to take advantage of the full potential of digital technologies in its process of continuous evolution and innovation. To address these challenges, the education ecosystem needs, more than ever, to reconsider its education programs for enhancing the acquisition of knowledge and competencies, and continuously adapt the curricula to the needs of modern society. However, education ecosystems are not alone, and should rely on the guidance of organizations. For example, in the field of computer science, the Association for Computing Machinery (ACM) provides curricula recommendations to address the rapidly changing landscape of computer technology [6]. Nevertheless, these global paradigms for computing education still need to be designed and implemented to design flexible, dynamic and adaptive learning paths to concrete use cases.

This paper is organized as follows. Section II introduces state of the art of existing solution and related work on learning theories, pedagogical approaches and personalized learning paths. Section III presents our ontology-driven competency model approach as a solution to design flexible, dynamic and

adaptive learning paths. Section IV presents one case study implementing our approach based on the ACM computing curricula recommendation. Section V presents the conclusions and future work.

## II. STATE OF THE ART

The rapid pace of technological advancements and the widespread adoption of new technologies and knowledge in our modern world is drastically changing all sectors of the economy, including education, industry, agriculture, transportation, energy, health care and medicine, and more. Furthermore, with increasing lifespans, people are likely to experience multiple career shifts and phases of change. The future of jobs is uncertain, in 2023, the World Economic Forum estimates, based on a dataset of 673 million employees, that within the next five years, 83 million jobs are projected to be lost, while 69 million are projected to be created, resulting in a net change of 152 million jobs, which will impact 23% of the workforce [7]. Consequently, learning becomes essential to address the rapid changes in all sectors of economy, this new learning paradigm must align with the evolving world and the opportunities it offers. In 2021 UNESCO published a report from the international commission on the futures of education to present a new social contract for education to fulfill the right to quality education for all, addressing past injustices and paving the way for sustainable collective futures [8]. Redefining the future of education proves challenging; it must encompass the evolution of jobs [7] while integrate social, economic, and technological changes [8]. It's crucial to identify what to learn/teach and how to learn/teach it. Fortunately, educational actors can rely on learning theories and pedagogical approaches to enhance learning processes.

### A. Learning theories and pedagogical approaches

Embarking on the evolving landscape of education is a journey through time, where theories have emerged across ages, shaping our understanding of learning. This condensed tour explores the rich history of learning theories that paved the way for modern education.

In the early 20th century, behaviorism emerged, focusing on observable behaviors and emphasizing the role of external stimuli, reinforcement, and repetition in learning. Techniques such as positive reinforcement and behavior modification were widely used in classrooms, where desired behavior was rewarded while undesired behavior was not rewarded [9], [10]. However, behaviorism tends to oversimplify the learning process and neglect cognitive aspects in general.

Concurrently, Maria Montessori introduced an innovative approach that continues to influence early childhood education. Emphasizing self-directed learning, hands-on activities, and mixed-age classrooms, Montessori's method designs materials and activities to foster independence and exploration [11]. Yet, this approach may not suit all learners, and the emphasis on self-direction may require careful monitoring.

In the 1950s and 1960s, influenced by the advent of computers, information processing theory gained prominence.

Viewing the learner's mind as a processor of information, akin to a computer, it examines how individuals encode, store, and retrieve information [12]. Nonetheless, it leads to oversimplifies the complexities of human cognition and may not adequately address social and emotional aspects of learning.

Moving into the 1960s, social cognitive theory (cognitivism) extended behaviorism, emphasizing the importance of social interactions, observational learning, and modeling in the learning process. In education, it underscores the significance of role models, peer interactions, and the modeling of desired behaviors [13].

Later in the 20th century, constructivism emerged, positing that learners actively construct their own knowledge through experiences, connecting new information to prior knowledge. This approach leverages project-based learning, problem-solving, and inquiry-based approaches [14]. However, implementing constructivism can be challenging in certain structured educational settings, and assessment methods can be a concern.

Parallely, experiential learning theory proposes a model where learning is a continuous process involving concrete experiences such as internship, reflective observation, abstract conceptualization, and active experimentation [15].

In the early 21st century, connectivism emerged with the rise of digital technologies. Emphasizing networked and distributed learning, online learning (e.g., MOOCs), social media, and the integration of digital tools became prominent in education [16]. Connectivism faces criticism for its perceived lack of clarity, overemphasis on technology, and challenges in assessment and follow-up of learners.

While motivation, self-regulation, and development are not standalone learning theories, they play integral roles in shaping the learning process. These cross-cutting themes are considered in the context of various learning theories, influencing how educators design instructional strategies and create environments that support optimal learning experiences. These concepts address the dynamic and individualized nature of learning, recognizing that learners bring unique motivations, self-regulatory abilities, and developmental characteristics (i.e., cognitive, social, and emotional development) to their educational journey [17]–[19].

Additionally, educational frameworks, such as knowledge-based approaches that affirm the importance of knowledge acquisition with levels (e.g., Bloom's taxonomy) [20], and competency-based approaches evolved as responses to the need for more flexible and adaptive learning. They focus on mastering specific skills or competencies rather than adhering to a fixed curriculum (e.g., personalized learning paths, formative assessment, and competency-based assessment models) [21]. These approaches align with the broader movement towards student-centered, outcomes-focused education that aims to better prepare learners for real-world applications of knowledge and skills.

In conclusion, a comprehensive understanding of learning theories and pedagogical approaches involves recognizing the

strengths and limitations of each paradigm. Modern educational practices often incorporate elements from multiple theories, recognizing the diversity of learners and the need for flexible, dynamic and adaptive approaches. In any case, education technologies are required to cope with the complex needs of these approaches.

### *B. Personalized learning paths*

In the context of Education 4.0, the definition of flexible, dynamic, and adaptive learning, which we propose to design personalized learning paths emphasizing learning theories, could be described as follows:

**Flexible:** It describes an educational system offering multiple pathways that transparently illustrate the ultimate goals of learners' education programs. These pathways are represented as evolving graphs that continuously adapt to learners' objectives. This flexibility empowers learners to architect their training by making informed choices about their educational journey, fostering a sense of autonomy and ownership in achieving their goals.

**Dynamic:** It means a learning environment characterized by continuous motivation, interactivity, self-regulation, and development. It positions the student as an active participant who can observe their progress, receive feedback, and engage in positioning within the educational landscape. The dynamic system encourages collaboration by allowing students to find and connect with other learners, fostering a sense of community and shared learning experiences.

**Adaptive:** It refers to a learning environment where learning resources are adapted and adjusted to learners' individual levels, preferences, and potential challenges (e.g. cognitive handicap), promoting inclusivity. Learning paths are predictively adapted using artificial intelligence, recommending the most suitable trajectory for success. This adaptive system ensures that learners receive tailored support, promoting an environment where each individual can thrive and reach their full potential.

In the realm of education, the concept of learning paths has evolved significantly over the years. The traditional fixed learning paths promoted by today's education program has given way to a more personalized learning experience that tailors the learning processes of learners.

Uddin et al. 2017 presented an adaptable e-learning model, based on a learner survey, which emphasizes a layered approach with learners' knowledge as the foundation. The model incorporates domain-specific content, pedagogy, learner information, and technology interface. It utilizes learner data to deliver adaptable content and assessments, resulting in significant knowledge improvement [22].

Barreiros et al. 2014 introduced "Soft Learn", a process mining-based platform designed to extract comprehensive and straightforward learning paths from event logs and allows teachers to better understand the real learning paths undertaken by learners [23].

Zhu et al. 2018 established a multi-constraint learning path recommendation algorithm to assist e-learners facing challenges in selecting optimal paths amid diverse resources and limited time. Validating distinct learning preferences across scenarios, the study proposes a model considering learner behaviors, resource organization, and time constraints [24].

Bendahmane et al. 2019 proposed a system that employ a Competency-Based Approach, using collaborative filtering to personalize learning paths based on individual learner needs for acquisition of competence. Technologically, the system is implemented as web services within a service-oriented architecture, promoting interoperability with diverse learning systems [25].

Chen et al. 2009 addressed the challenge of personalized e-learning. This study introduces a genetic-based curriculum sequencing scheme. Unlike existing platforms, it considers difficulty levels, learning order, and learner abilities, creating high-quality learning paths based on ontology-generated concept maps. Experimental results show enhanced effectiveness, reducing cognitive overload for individual learners [26].

Jeng et al. 2019 sought to create a comprehensive, user-friendly, and robust learning map using ontological and Petri net-based maps. They introduced Dynamic Learning Paths Framework (DLPF), based on schema theory and collective intelligence that empowers learners to contribute and enhance learning schemas with extra materials [27].

Ghouch et al. 2020 proposed an adaptive learning system architecture based on Hybrid Incremental Case Reasoning. This architecture enables real-time decision-making in dynamic learning situations through cycles of reasoning from cases. At each step of this process, specialized agents collaborate to dynamically guide learners by offering personalized learning paths in real time [28].

Shi et al. 2020 addressed the challenge of organizing fragmented e-learning content for efficient learning outcomes. Proposing a multidimensional knowledge graph framework, the model stores learning objects in distinct classes with six semantic relationships. The designed learning path recommendation model caters to diverse learning needs, generating customized paths based on the e-learner’s target. Experimental results confirm the model’s ability to recommend personalized and effective learning paths, enhancing the overall e-learning experience [29].

Terzieva et al. 2023 introduced a Knowledge Model for Intelligent Education Systems (IES), enabling dynamic personalization of learning paths. This model encompasses ontological information on prerequisites, learners, learning objectives, teaching strategies, courses, educational resources, and assessment of learners’ knowledge [30].

In order to evaluate the previous work in the way they cope with the Education 4.0 challenges, we propose the following criteria:

- **Standard curricula design approach:** use of standard guides or recommendation for curricula competency-oriented design.

- **Model-driven competency approach:** formal or semi-formal modeling approach to represent and manage competencies, knowledge, skills and dispositions.
- **Learning path personalization approach:** use of technologies to support personalization of learning paths.
- **Scope of teaching and learning ecosystem deployment:** level of deployment of the solution, including cyber or physical spaces.

TABLE II  
ANALYSIS AND COMPARISON OF EXISTING SOLUTIONS

Reference	Criteria			
	Standard curricula design approach	Model-driven competency approach	Learning path personalization approach	Scope of teaching and learning ecosystem deployment
Uddin et al. 2017 [22]	N/S	Database	Algorithm	Cyber
Barreiros et al. 2014 [23]	N/S	N/S	Process Mining	Cyber
Zhu et al. 2018 [24]	N/S	Knowledge-map	Graph theory	Cyber
Bendahmane et al. 2019 [25]	N/S	Database	ML (K-NN)	Cyber
Chen et al. 2009 [26]	N/S	Ontology	Genetic-based algorithm	Cyber
Jeng et al. 2019 [27]	N/S	Learning map	Algorithm	Cyber
Ghouch et al. 2020 [28]	N/S	Knowledge base	ML (FCM, K-NN)	Cyber
Shi et al. 2020 [29]	N/S	Knowledge graph	Algorithm	Cyber
Terzieva et al. 2023 [30]	N/S	Ontology	Reasoning	Cyber

N/S: not specified

Based on this analysis Table. II summarizes the analysis of the studied solutions based on these criteria, it is clear that the current state of research does not provide a well-adapted framework to design and implement a competency-oriented and student-centered engineering education program responding to the identified Education 4.0 challenges.

### III. OUR APPROACH

In this section, our proposed ontology-driven approach for competency-oriented and student-centered engineering education 4.0 programs is presented. The idea is to interconnect society needs, teachers and learners including lifelong learners within a generic ontology-driven competency model allowing the design and implementation of flexible, dynamic, and adaptive learning paths (see Fig. 1).

#### A. Requirements specifications

Based on the challenges of future education and after analyzing existing solutions, we have identified the following requirements:

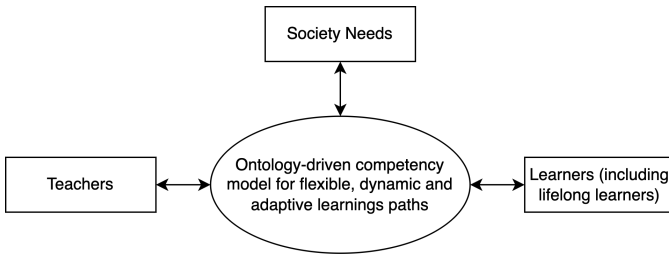


Fig. 1. Ontology-driven competency model

**Req 1.** Standard curricula design approach.

- Req 1.1.** Establishing a system for defining, assessing and tracking competency acquisitions.
- Req 1.2.** Defining levels to measure the level of knowledge acquisition.
- Req 1.3.** Ensuring alignment with evolving societal needs.

**Req 2.** Model-driven competency approach.

- Req 2.1.** Developing a model that captures relationships between competencies, learning resources and learners.
- Req 2.2.** Allowing competency model consistency, dynamic adaptation and discovery.
- Req 2.3.** Implementing query functionalities for real-time data collection, analysis and visualization.
- Req 2.4.** Ensuring compatibility and integration with existing educational systems and standards.

**Req 3.** Learning path personalization approach.

- Req 3.1.** Implementing mechanisms for real-time monitoring of learners' progress.
- Req 3.2.** Enabling descriptive analysis for understanding of learner behavior.
- Req 3.3.** Providing diagnostic insights for personalized intervention.
- Req 3.4.** Developing predictive models to anticipate success or failure and determine learner needs.
- Req 3.5.** Offering prescriptive guidance for adaptive learning paths.

**Req 4.** Scope of teaching and learning ecosystem deployment.

- Req 4.1.** Establishing an agile, scalable and self-managed broad scope for the deployment of teaching and learning ecosystem.
- Req 4.2.** Enabling real-time data exchange between physical and digital components.
- Req 4.3.** Implementing mechanisms for monitoring and supporting learners in physical and digital environments.
- Req 4.4.** Ensuring interoperability with existing education systems.

*B. Requirement analysis and potential solutions*

We are convinced that innovation for Education 4.0 program would be improved by combining competency-based curricula

approach, ontology-driven approach, learning analytics and cyber-physical systems dimension.

- **Competency-based curricula approach (CBCA):** utilizing a competency-based educational framework that focuses on learners' mastery of specific knowledge, skills and dispositions using taxonomies and based on society needs.
- **Ontology-driven approach (ODA):** utilizing a common semantic and structured knowledge model to organize and represent learning processes through semantic relation and using reasoners for knowledge inference (e.g., allowing the dynamic discovery of learning objects and learning paths).
- **Learnings analytics (LA):** utilizing artificial intelligence techniques and learning traces for descriptive, diagnostic, predictive and prescriptive analysis to facilitate personalized follow-up and competency acquisition of learners.
- **Cyber-physical system (CPS):** integrating physical processes with computational elements to enable virtualization, interoperability, real-time monitoring, analysis and autonomous creation of content based on physical work (e.g., creation of course resources based on innovative pedagogic approach and autonomic computing to implement learning path on learning management system).

Encompassing these requirements by combining the CBCA, ODA, LA and CPS dimensions must allow designing flexible, dynamic and adaptive learning path for the future of education (see Table. III)

TABLE III  
POTENTIAL SOLUTIONS

	CBCA	ODA	LA	CPS
Req 1.1.	CC2020	Reasoning	Dataviz	Real-time monitoring
Req 1.2.	Bloom			
Req 1.3.	ACM, IEEE	Reasoning		
Req 2.1.		OWL		
Req 2.2.		Reasoning		
Req 2.3.		SPARQL	Dataviz	
Req 2.4.	Generic model	OWL		
Req 3.1.	Competency acquisition	SPARQL	Learning object	LMS
Req 3.2.		SPARQL	Process mining	LRS, xAPI
Req 3.3.			Process Mining	Teacher supervision
Req 3.4.			ML	
Req 3.5.			ML	
Req 4.1.				Autonomic computing
Req 4.2.			Learning object	Sensors
Req 4.3.		Reasoning	Dataviz	LMS
Req 4.4.	Generic model	OWL		Connected classroom

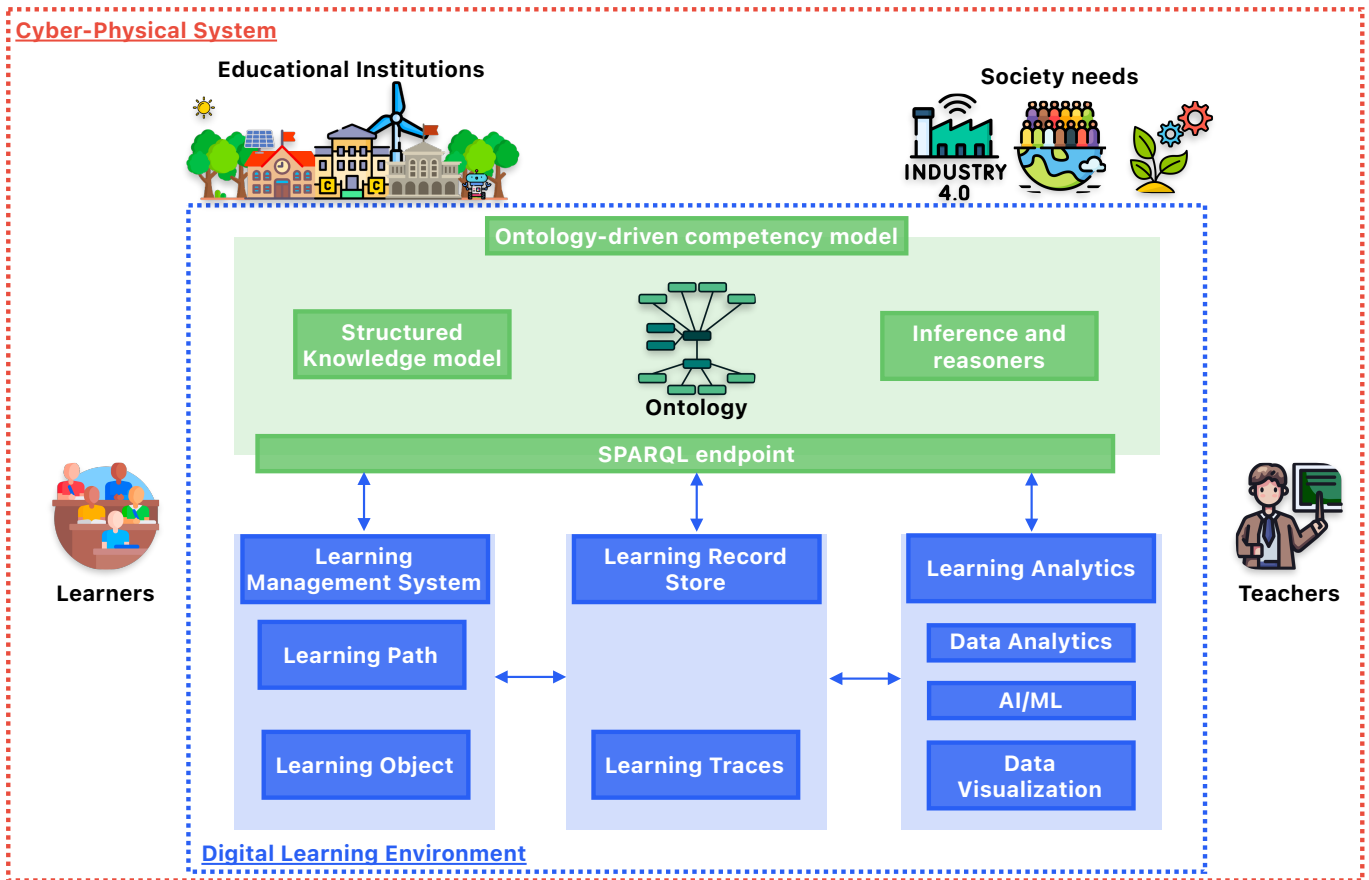


Fig. 2. Cyber-physical system architecture

### C. Solution design and architecture

Flexible, dynamic, and adaptive learning must empower learners to become architects of their training through the customization of learning paths. Implementing mechanisms for learners to customize their learning paths while ensuring adaptability to diverse learning paces, styles, and providing real-time feedback to learners on the impact of their customization is crucial.

The solution needs to find a way to be assessed and validated by users over time to facilitate continuous evolution and innovation in response to societal and technological changes. This involves establishing mechanisms for regular updates to the competency model based on industry feedback, implementing a feedback loop for educators and learners to propose improvements, and ensuring compatibility with emerging technologies and standards. These processes are required to interconnect learners, teachers, and society, ensuring sustainability (see Fig. 2). Ontology reasoners should check the ontology consistency during competency definition and enable the identification of all available learning paths for learners to acquire expected competencies. The SPARQL endpoint will facilitate ontology updates when students interact with the digital learning environment. It will also enable the automatic configuration of learning paths on the learning management

system and the implementation of learning analytics features for monitoring.

## IV. CASE STUDY

The research findings are actively contributing to the creation of the ISA NUM program, an innovative French computer engineering degree. This program is a response to the imperative need for a digital transformation in our society, marking a significant revolution on both national and international scales. This model is strategically designed to meet the current demands of our society, particularly in the dynamic field of computer science. Managed by an ontology-driven competency model, it lays the foundation for an intelligent cyber-physical education system. This system seamlessly integrates virtual learning environments and employs learning analytics, thereby fostering an educational experience characterized by flexibility, dynamism, and adaptability. It harmonizes the learning process with the ever-evolving digital landscape, catering to the specific needs of modern learners and society at large.

### A. Competency-based curricula approach

Thanks to the Association for Computing Machinery, we implemented their recommendations for computing curricula

using the CC2020: Paradigms for Global Computing Education [6]. The recommendation offers a perspective on the major computing disciplines as they currently exist and how they might exist in the future. It helps guide students, industry, and academia in the preparation of future professionals on computing discipline. CC2020 represents the society needs in the field of computing to shape the future of computing education [6].

In computing field, CC2020 identifies 34 elements of Computing Knowledge (CK), 13 Foundational and Professional Knowledge (skills: FPK) and 11 Dispositions (D) that ensure the alignment with industry demands and societal trend (**Req 1.3.**). To measure the level of knowledge acquisition, we decided to map the Bloom's taxonomy to a A1...C2 levels (A1: Remembering, A2: Understanding, B1: Applying, B2: Analyzing, C1: Evaluation, C2: Creating, **Req 1.2.**). Meanwhile, disposition prescribe a temperament, a quality of character in the performance of a learner's tasks (e.g., proactive, self-directer, inventive...). These qualities can be represented as a boolean value, true or false (e.g. the learner's project is inventive).

A Competency is defined as a set of knowledge, skill and disposition elements that learners has to acquire with a determined level (**Req 1.1.**). We define  $L = \{N/A, A1, A2, B1, B2, C1, C2\}$ , the set of all taxonomy levels and  $R = \{not\ required, required\}$ . Note that CK and FPK take values in  $L$  and that  $R$  specifies if the disposition of a given competency is required or not. Furthermore, we denote by  $J$  the total number of competencies, by  $n_{CK}$  the number of CK, by  $n_{FPK}$  the number of FPK, and by  $n_D$  the number of D. For every competence  $j = 1, \dots, J$  we define:

$$l_j^{CK}(i) = \{x \in L : \text{the learner has acquired level } x \text{ at } CK_i\},$$

for  $i = 1, \dots, n_{CK}$ ,

$$l_j^{FPK}(i) = \{x \in L : \text{the learner has acquired level } x \text{ at } FPK_i\},$$

for  $i = 1, \dots, n_{FPK}$ , and

$$r_j^D(i) = \{x \in R : \text{specifies if learner requires or not } D_i\},$$

for  $i = 1, \dots, n_D$ . Note that  $l_j^{CK}(i)$  is the taxonomy level that the learner has acquired for  $CK_i$  for competency  $j$  and  $i = 1, \dots, n_{CK}$ ,  $l_j^{FPK}(i)$  is the taxonomy level that the learner has acquired for  $FPK_i$  for competency  $j$  and  $i = 1, \dots, n_{FPK}$  and  $D_i$  specifies if that disposition is required or not for competency  $j$ . To design ISA NUM computing competency curricula, we defined 23 competencies using the following equation:

$$C_j = \sum_{i=1}^{n_{CK}} CK_i \cdot l_j^{CK}(i) + \sum_{i=1}^{n_{FPK}} FPK_i \cdot l_j^{FPK}(i) + \sum_{i=1}^{n_D} D_i \cdot r_j^D(i)$$

The result can be visualized as a matrix in which every competency is a composition of CK, FPK and D (see Table. IV).

TABLE IV  
COMPETENCY CURRICULA APPROACH

	CK1	...	CK34	FPK1	...	FPK13	D1	...	D11
C1	A2	...	C1	B1	...	B2	R	...	N/A
...	...	...	...	...	...	...	...	...	...
Cj	N/A	...	C2	A1	...	A1	N/A	...	N/A

The same approach could be used to design curricula in every field in condition to identifies the knowledge elements related to the domain.

For instance, ISA NUM competence 1.1. "Design and develop software solutions and IT systems that meet the functional needs of users and organizations, and take into account the constraints or non-functional requirements of the deployment context or environment" is acquired when :

$$C1.1 = CK2 \cdot B2 + CK6 \cdot C1 + CK8 \cdot C1 + CK9 \cdot C1 + CK22 \cdot B2 + CK31 \cdot B1 + FPK2 \cdot C1 + FPK3 \cdot C1 + D7 \cdot R + D8 \cdot R$$

We repeated the same process to define the 23 competencies and ensured that the curriculum includes at least a C1 level in each CK and FPK. This approach aims to build a comprehensive program that ensures mastery of each knowledge element. The ISA NUM engineering program aims to graduate computer engineers within 5 years with an experiential learning orientation. Throughout the learning process, learners need to master every competency, thereby acquiring a computing graduates who shape the industry and meet societal needs for the future. However, learners have the possibility to specialize in the last 2 years (software engineering, data engineering, information technology engineering), allowing them to master specific knowledge elements, fostered by an internship, and providing them with the full requirements to enter the jobs of the future in the computing field. Each graduate will be able to build a personalized learning path and exhibit potentially different competencies level acquisition.

### B. Ontology driven approach

An ontology has been designed through a collaborative effort involving educators, and IT specialists to create a robust ontology. This ontology defines relationships among competencies, learning resources, and individual learners (**Req 2.1.**) and serve as the foundational knowledge structure for the Education 4.0 program, the main concept of this ontology is simplified and represented in Fig. 3.

We propose to use semantic search and reasoning capabilities to ensure ontology consistency and facilitate dynamic adaptation and discovery of learning paths. These capabilities enable real-time adjustments, allowing the ontology to evolve in response to changing educational landscapes and learner needs (**Req 2.2.**). Our goal is to permit the competency model to evolve over time, facilitating flexible learning paths and enhancing adaptability to ensure the system remains responsive.

Meanwhile, SPARQL statements will facilitate real-time data collection, analysis, and visualization. This will enable



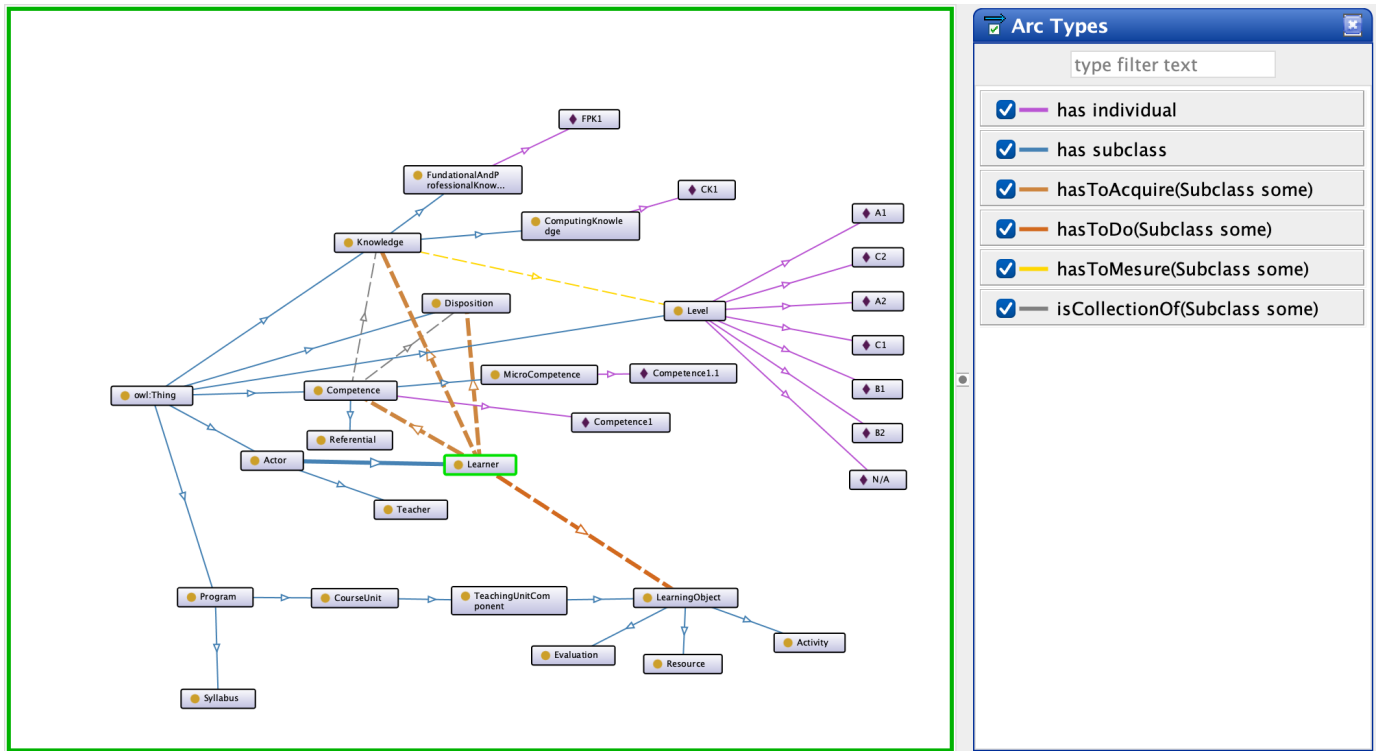


Fig. 3. Ontology-driven competency model

the system to gather insights into learner interactions, competencies achieved, and resource utilization (**Req 2.3.**). Moreover, ontology-driven framework improves interoperability to seamlessly integrate with existing educational systems and adhere to established standards. Collaborate with educational institutions and industry stakeholders to align the framework with widely accepted norms, ensuring smooth integration into diverse educational environments (**Req 2.4.**).

### C. Learning analytics

The Education 4.0 program requires a robust monitoring and analytics framework to empower educators and institutions with real-time insights into learner progress, behavior, and needs. The idea is to create learning paths to acquire competencies and collect learning traces when learners interact with the cyber-physical educational ecosystem, such as completing a course on the learning management system (LMS) or practicing on a virtual lab environment. To gather meaningful traces, we designed learning objects (LO) that integrate learning resources, activities, and assessments. Each LO includes learning incomes (CK or FPK or D) and learning outcomes (CK or FPK or D), specifying the level of knowledge acquisition using Bloom's taxonomy. Examples of interactive LOs are H5P objects that integrate resources, activities and quizzes [31]. Once deployed on the LMS, we can collect traces (every click and quiz result) using the xAPI standard (**Req 3.1.**). The learning traces are stored in a learning record store following a specific format (including who, what, when, and where) while triggering the ontology update and reasoning.

This data collection process provides numerous opportunities to integrate learning analytics (see Fig. 4).

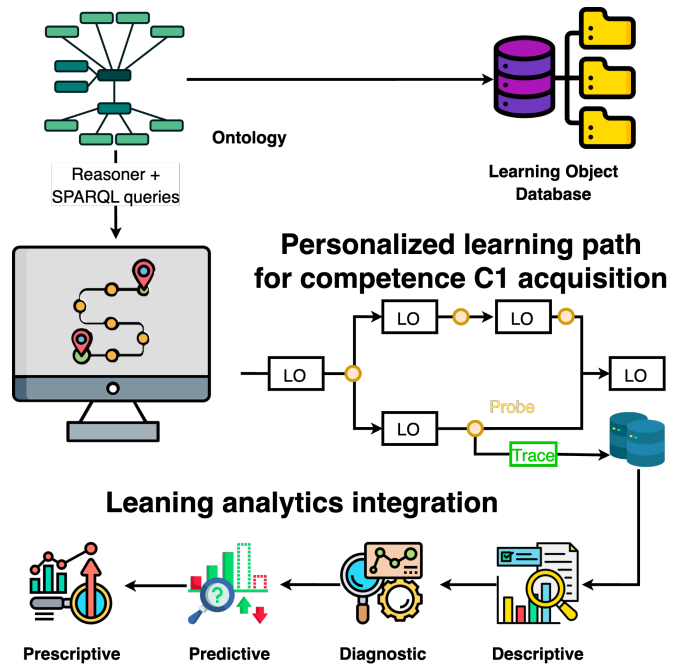


Fig. 4. Learning Path implementation

This approach allowed to develop a dashboard for descriptive and diagnostic analysis, showcasing what learners need to

do to acquire competencies and tracking their progress during the learning process. The visualisation tool incorporates color indicators to assist learners in understanding their position and alerts them, while also providing teachers with insights to support the learners (**Req 3.2. and 3.3.**). We employed process mining techniques offered by Celonis platform [32] to explore the learning paths taken by 21 computer science master students at UPPA enrolled to the data integration course (see Fig. 5). Additionally, we plan to leverage big data, considering multiple iterations of learners, to create learning path recommendations based on collaborative filtering. This aims to propose the most likely-to-succeed learning paths for competency mastery (**Req 3.4. and 3.5.**).

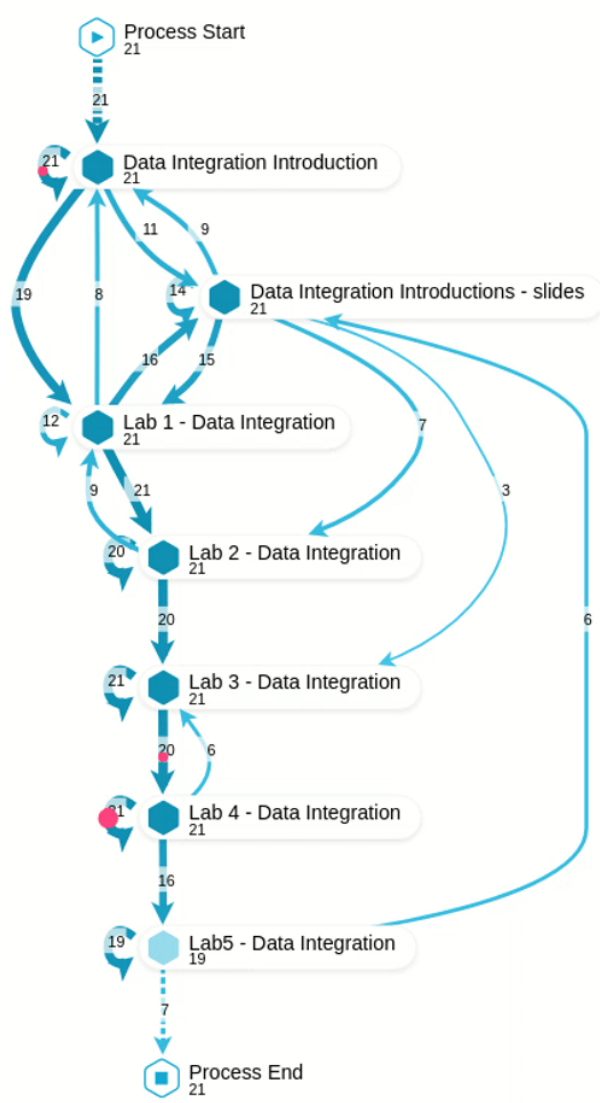


Fig. 5. Process mining to explore learning paths

#### D. Cyber-Physical System

To effectively navigate this diversity, the system must possess the capability to discern its configuration. It achieves this by collecting data from various sensors and autonomously

configuring itself. This configuration encompasses monitoring, analyzing, planning, and executing actions based on an established knowledge base for autonomic computing (**Req 4.2.**).

The critical aspect lies in the adaptability of data collection methods tailored to specific configurations outlined in the knowledge base. These adaptive mechanisms are indispensable to facilitate real-time adjustments and monitoring for learners and teachers across all configurations (**Req 4.3.**). This approach not only ensures efficient functioning within various educational scenarios but also empowers the system to autonomously transition from one configuration to another, while ensuring interoperability with existing educational technologies (**Req 4.4.**).

Furthermore, this adaptive capability opens the door for translating a traditional physical course into a virtual format using artificial intelligence for augmented capabilities. This transition not only accommodates diverse learning preferences but also contributes significantly to fostering inclusion for every learner, addressing the evolving landscape of educational needs.

## V. CONCLUSION AND PERSPECTIVES

Learners should not be overwhelmed or feel obligated to learn everything. Instead, they should have a vision for what they want to achieve and how they intend to shape their learning processes. Then, they can acquire the necessary competencies needed to pursue their goals and expand their opportunities, promoting inclusion within our modern society. We are convinced that the future of education lays in a student-centered education program. In this paper, we have presented our contribution to cope with these needs based on ontology-driven competency model as an implementation of the Computing Curricula 2020: Paradigms for Global Computing Education provided by the ACM that represent the current society need in computer science field. This model is the foundation for designing of an intelligent cyber-physical education system capable of managing flexible, dynamic and adaptive learning paths while integrating virtual learning environment and learning analytics. The outcomes of our research are being applied to the creation of a new French computer engineering training program called ISA NUM. Although ISA NUM is a project scheduled to start in 2024, our initiative has already been audited, evaluated and validated by the CTI (French Engineering Qualifications Commission). Our following steps involve implementation, deployment and evaluation of our solution by designing validation scenarios and collect feedback during the first class of trainees.

Future work is oriented to design an autonomic, agile and scalable Cyber-Physical System (CPS) to bridge the gap between physical and digital learning environments. The system must be capable of adapting to multiple configurations. Our goal is to eliminate temporal, spatial, and linguistic barriers with a system that autonomously adapts to various teaching methods (**Req 4.1.**).

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