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The foundation for future education, teaching, training, learning, and performing infrastructure - The open interoperability conceptual framework approach

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ABSTRACT

The proliferation of Information and Communication Technologies (ICT) in Education, Teaching, Training, Learning, and the operational application (Performing) of acquired knowledge, skills, and competencies in contemporary social environments has directly influenced the transformation of early Networked Learning (NL) concepts into a Global Learning Infrastructure. Creating cooperative/collaborative stakeholders networks composed of learning subjects, objects, and competencies consumers, exposes the significant potential for gaining overall social progress. The main challenging obstacles of such globalization are: embedding semantics into the competence credentials carriers, trusted dissemination of verifiable competence tokens, the heterogeneous ontologies mapping, and sustainable service delivery infrastructure.

The mainstream motivation of our research is the specification and development of a conceptual framework that fosters the interoperability of different stakeholders, whether individual or institutional, to declare, share and maintain the representative collections of information resources related to the particular Education, Learning, Teaching, Training, and Performing (Research, Development, Production, and Service) endeavors.

In this article, we have specified an open, heterogeneous, interoperable conceptual framework capable of orchestrating past, current, and future paradigms to foster building the foundations for comparative analysis and evaluation of traditional and nontraditional competency-building processes, joined with students' portfolio creation, dissemination, and management. It is a starting specification that would serve for the future: open, heterogeneous, cooperative/collaborative, service-oriented software framework specification and development.

1. Introduction

The contemporary development in science and engineering dominantly focuses on human and machine intelligence integration endeavors that tend to hybridize physical space, social space, and cyberspace [1] and thereby create a highly interconnected hyper-ecosystem of the near future. The high simulation potential of these systems enables model-driven simulation approaches to

Abbreviations: ADL, Advanced distributed learning; CBE, Competence-based education; CBL, Competence-based learning; ETLI, Education teaching and learning infrastructure; CF, Conceptual frameworks; SwFI, Software framework interoperability.

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complex systems engineering and helps mitigate risks that usually appear in the early development phases. System-of-Systems (SoS) Engineering faces the interoperability of heterogeneous Domain-specific Meta-Verses challenges that bring the development of suitable and sustainable conceptual and operational supportive frameworks in front of future research activities. Situation awareness is a fundamental aspect of the application usability of these frameworks and emerges from the intelligent fusing of data, information, and knowledge embedded in orchestrated systems [2,3]. Such a fusion builds the SoS overall context that preserves its current state. The integration of Artificial Intelligence mechanisms and tools, like Generative pre-trained transformers (GPT) [4], and the movement from algorithmic to linguistic intelligence [5] favoring machine learning through human-in-the-loop training, open a new paradigm in human assisting systems development.

In this context, the organized acquisition of knowledge, skills, values, competencies, and preferences (Education 4.0, Education 5.0, and Education 6.0) is one of the most influential driving forces that direct human society's development through different epochs, currently usually referenced as the industrial revolutions (Industry 4.0, Industry 5.0, and Industry 6.0), that directly drive contemporary and future Cyber-physical-social Systems (4.0, 5.0, and 6.0), as shown in a coarse-grained domains 7-Helix Model (Fig. 1).

Industry 5.0 technology (Fig. 2) Helix Model forms the context of digital transformation activities, initially declared challenging in Industry 4.0, tends to migrate to the future Industry 6.0 milieu due to the rapid shrinking of contemporary time gaps between industrial revolutions. Effective integration of the core Education (4.0, 5.0, and emerging 6.0) components with the core Industry (4.0, 5.0, and emerging 6.0) [6] counterparts is the root of all modeling and framing efforts, aimed to efficiently and effectively correlate different stakeholders (institutional or personal), methods, methodologies, and tools involved or affected by such integration. This integration, according to Ref. [7], addresses the technology that supports learning, connectivity, storage infrastructure, guidelines, organizational processes, and practices that promote innovation, digital transformation, and skills development that fosters educator's, teacher's, and trainer's ability to cope with learners and performers that are, now, natively digitally skilled.

In [8], the authors elaborate on a wide range of cognitive, social, and emotional competencies that all involved parties need to retain and sustainably develop aligned with the technology progress, with particular emphasis on creativity in the criticality approach as an effective cognitive tool within the Education 4.0 framework. The role of competencies in education and engineering 5.0 contexts, with the claim that still, there is no suitable theory of systematic competence development to date, directed the authors to discuss aspects of lifelong learning and the individualization of life paths concerning competence-oriented vocational tertiary education and training [9].

Education is dominantly institutional, process-oriented [10], and relies on systematic and formal instructions delivery, dominantly performed at schools or universities [11–15]. Its mission is to create universal and extendible mindset foundations capable of withstanding life-long or career-long maturity upgrades. In our opinion, time and context-based adaptability of the formed mindset leads to sustainability fostering and represents a proper validity measure of the formal education ecosystem's success.

Teaching and Training, although sometimes treated differently in particular contexts, share the fundamental mission of possibly noninvasive actions application that aids in learning a selected topic, with a deep understanding of individual learner's needs, experiences, and emotional states, and stimulate them to go far beyond the expected outcomes through problem-solving endeavors. The challenging aspects of educating, teaching, and training the educators, teachers, and trainers [16] fundamentally influence the direct or indirect interdependencies of the Education, Teaching, and Training dimensions of a 7-Helix Model (Fig. 3).

Learning is a personal and inherently informal life-long activity that may occur through Education, Training, personal development, practice, or experience [17]. The proliferation of Information and Communication Technologies (ICT) in Education, Teaching, Training, and Learning processes has directly influenced the transformation of early Networked Learning (NL) concepts into a promising global learning infrastructure. A comprehensive reference to Network Learning Principles [18] links former, current, and future network roles.

Creating a contemporary cooperative/collaborative learners network, composed of learning subjects and objects, has exposed the significant potential for the overall progression. There is a rapid growth of Learning Management Systems (LMSs), Massive Open Online Courses (MOOCs) [19], and Single Private Online Courses (SPOCs) [20]. LMSs are usually considered supplementary software technologies that are the extension (plug-in) components of the Education or Training provider's Integrated Information Systems (IIS) or Enterprise Management Information Systems (EMIS). Although MOOCs focus on the training-based development of new skills in the

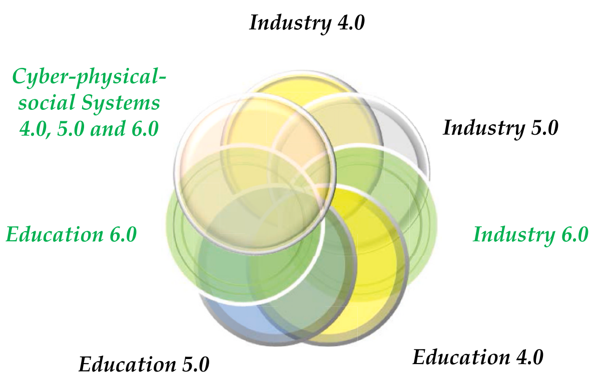

Fig. 1. Coarse-grained domains - a 7-helix model.

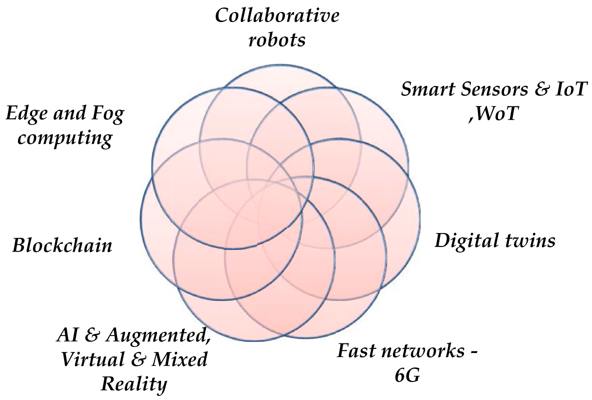

Fig. 2. Industry 5.0 technologies.

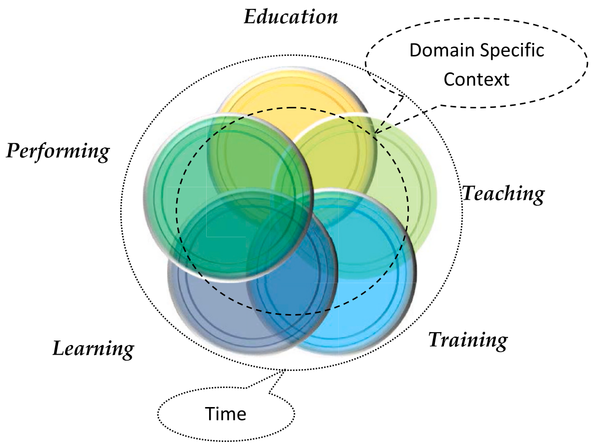

Fig. 3. Problem domain - a 7-helix model.

lifelong learning paradigm, they are often considered a promising alternative to the traditional education discipline. Although MOOCs have a high impact on the contemporary learning processes education discipline still successfully resists the potential threats [21]. SPOCSs, on the other hand, represent a form of Adaptive Learning infrastructure. It exists within the scope of associated LMS, which preferably enables real-time tailoring of the learning content to the learners' abilities (profile). In our opinion, Blended Learning (BL) appears as a promising synergic approach. Digital transformation of complex real-world systems is generally a business process transformation endeavor performed in the context of an enterprise architecture and powered by the appropriate framework, like the one presented in Ref. [22]. According to Ref. [23], the digital transformation of various higher education areas will experience radical changes due to advances in artificial intelligence and massive dataset-handling technologies. The author claims that a shift into the digital sphere will not eliminate the university infrastructure but will significantly change its purpose.

Performing is a composite dimension encapsulating specific job, occupational, research and development, innovating, mediation and regulative, and monitoring and control activities. It mainly affects the future Cyber-physical-social Systems (4.0, 5.0. And 6.0) structure and behavior (Fig. 1) and represents the context in which the final evaluation of other main dimensions occurs in a domain-specific and timed manner (Fig. 3). The importance of competency profile related to Industry 5.0 vocational education and training activities [24] establishes an example of a measurable dynamic container for individual competencies evaluation.

The role of semantic technology that enables machines to understand data when joined with creating trusted cyberspace and the irrevocability of disseminated artifacts' origin and content represents focal research and development direction in building trustable global information infrastructure as an essential feature for new-coming endeavors. Semantic Web and Blockchain are the most referenced and promising technologies ranging from early publications [25,26] to more recent ones [27–30] correlating the main dimensions of the conceptual framework approach proposed in this article.

Considering the entire previous elaboration, in our opinion, there are three generic research motivation questions deserving suitable and sustainable answers.

- How to create an Education, Teaching, Training, Learning, and Performing ecosystem that successfully and sustainably integrates the overall heterogeneous scene?

- How to support the creation, evaluation, and acceptance of trusted credentials in compliance with the quality assurance principles embedded in the national and international accreditation standards and procedures?
- How to support future learners (students) in individual competence portfolio building and stay compliant with the contemporary skills and knowledge market demands and the distributed learning infrastructure challenges?

One of the many possible approaches may be cooperation and collaboration through an open interoperability conceptual framework that supports the orchestration of all promising paradigms and builds the foundation for comparative analysis and evaluation of traditional and nontraditional competency-building processes and students' portfolio creation and management.

The proposed model is a starting specification for the future: open, heterogeneous, cooperative/collaborative, service-oriented software framework that may be tailored, according to the education and learning providers and consumer's needs, over the entire education, teaching, training, learning and performing systems.

2. The problem domain - the related work analysis and foundations

Throughout the new social development epoch, launched at the end of the 20th century, all relevant influencers (researchers, educators, policymakers, and business leaders) constantly repeat a well-known mantra of 21st-century knowledge and skills compliance validation only at the operational or job level. A particular theory, concept, idea, or product justification assumes the elaboration of impacts that the three upper layers of Bloom's taxonomy of education (analysis, synthesis, and evaluation) usually introduce [31]. The collision of problem solvers' current competencies with a previously unknown or unsolved problem(s) induces the analysis activities. Synthesis assumes the development of a novel product(s) from the specifications gained in an analytical phase or procedure. The evaluation is the expert judgment that aids the decision-making process when comparing and classifying independently developed product(s) or procedure(s) belonging to the same problem domain.

Why a framework-based approach? - a framework may be defined as a tangible or conceptual foundation that supports or guides building a particular artifact or performing a particular activity. Frameworks favor reusability by managing overall control flow and orchestration of dynamically configured components in an inversion of control manner. In Ref. [32], the elaboration of generative aspects of a conceptual framework ends up with the specification of seven interrelated components (architecture, governance, community, fit, combinatorial innovation, outcomes, and feedback) that define the ability to produce something in a quality manner.

In [33], the authors analyze several articles, addressing the conceptual and theoretical framework with the international education context understanding mission. Teaching and learning frameworks may have different granularity levels ranging from the higher granularity models, like: [34–36], to lower granularity models that serve as conceptual maps for planning or revising the particular course, syllabus, or lesson [37]. Stating that the quality of producing or creating is an essential part of the booth, the creational process, and the product, at arbitrary granularity level, the generatively appears as a desirable feature of any sustainable conceptual framework. A limited number of commercially developed software solutions designed to support the entire education, teaching, and learning processes and technologies in an integrated manner, like [38] distributed learning Enterprise Solutions or [39] Enterprise Learning solutions, exists. A substantially large number of commercial Learning Management Systems software solutions are currently available in the software market. In Ref. [40], the author systematizes, from his perspective, a representative selection and evaluation of the most relevant LMSs that may serve as an appropriate hub for future blended learning ventures.

In general, the interoperability framework development requires a multi-stakeholder process and the long-term vision of a highly reusable generic solution. The current ventures of this kind are directly associated with some high-level government institutions, usually through dedicated projects and portfolios. The highest possible granularity level of global initiatives in Education, Teaching, Training, and Learning domains are The European Higher Education Area (EHEA) Initiative (established by the Bologna declaration in 1999) (EU Commission) [41]; US Advanced Distributed Learning (ADL) Initiative (US Department of Defense (DoD))) [42]; BRICS (Brazil, Russia, India, China, and South Africa) Education Interoperability Initiative - 5 member states with great diversity and development potentials (BRICS Forum) [43]; Commonwealth Education Policy Framework (CEPF) - 50 member states with the broad differences (Commonwealth of Learning (COL)) [44]; and United Kingdom SFIA, the global skills and competency framework for the digital world with almost 200 participating countries (United Kingdom SFIA Foundation) [45].

The Organization for Economic Co-operation and Development (OECD) "Future of Education and Skills Education 2030″ document [46] has been selected as the most suitable reference to start with the related work analysis and discussion section. The corresponding conceptual framework introduces A holistic learning support environment (Learners agency); A specification of a broad set of operational Knowledge, Skills, Attitudes, and Values; Transformation competencies; and Design principles that influence the ecosystem change. Combined with the assessment mechanisms supported by the OECD's Program for International Student Assessment (PISA) Competence Framework [47], they enable the creation of Education, Teaching, Training, and Learning infrastructure as a starting point of any sustainable open interoperability conceptual framework (OICF) specification and development.

The broad area of education in the EU is, generally, a national question and responsibility. Over time, there has been a convergence of policy across the nations [48], influencing the need for reshaping the EU education governing by the concept of a "delivery chain" based on regular, reliable, and real-time data exchanged between all of the related stakeholders in an interoperable manner. In the context of the European Higher Education Area (EHEA) initiative, the interoperability issue emerges through the initial version of the European Interoperability Framework (EIF), primarily developed to support the digital transformation of public services and data at the EU or national levels. In the current revision of EIF [49], the specification consists of three main framework segments: the group segment, the interoperability model, and the interoperability-by-design conceptual model.

European Interoperability Reference Architecture (EIRA) appears in the context of the Interoperability Solutions for European

Public Administrations (ISA2) program. It represents a Service Oriented Architecture content metamodel that, via ArchiMate modeling notation, defines the most salient architectural building blocks (ABBs) needed to build interoperable e-Government systems [50], with current status elaboration in Ref. [51]. Among referent EU education activities, the Eurydice Network [52] is concerned with understanding and explaining the organization and operation of Europe's education systems at an arbitrary level. The network describes national education systems and the results of comparative studies of specific topics, indicators, and statistics delivered as different reports, for example, [53,54]. They form the organizational and operational foundation for future interoperability activities.

The European Learning Model (ELM) aims to capture the results of any non-formal, informal, and formal learning across Europe. The EDCI Data Model is an extension of the W3C Verifiable Credentials Data Model, expressed as XML/XSD [55]. It consists of the following web services: EDCI Issuer - which allows users to issue digital credentials; EDCI Wallet - which stores and shares the credentials; EDCI Viewer - which allows users to view, export, and verify the credentials; and EDCI Accreditation Database - which stores the institutions' accreditation records for the institutions.

The accreditation process and Quality assurance in higher education are the next challenging dimension of the OIF integration model. From the EU perspective, these dimensions have gradually evolved from initial education-oriented into currently learning-oriented specifications. There are two EU institutions covering accreditation and Quality assurance concerns: the European Accreditation Board of Higher Education Schools [56] and the European Association for Quality Assurance in Higher Education (ENQA) [57].

In favor of the interoperability issues, the credentials dimension of the EU education and learning ecosystem interconnects the European Qualification Framework (EQF) [58] and the European Digital Credentials for Learning (EDCL) [59]. Due to its diversity, substantial regulations, and the number of project initiatives, the EU education, teaching, and learning area is a relevant set of related work documents that have inspired the diversification attributes of the proposed OICF integration model.

On the other hand, US Advanced Distributed Learning (ADL) Initiative is a non-traditional dynamic initiative and the most comprehensive approach to competency-based learning that joins the fundamental education and learning perspectives in establishing the ecosystem. In Ref. [60], the authors elaborate on four ADL-based learning ecosystem tenets (lifelong; holistic, ubiquitous; and asset-focused), with a particular accent on the usability and trustworthiness of independently developed heterogeneous frameworks supporting mechanisms (personalization, security, and privacy protection). In Ref. [61], a current list of ADL Products&Services, supported by xAPI (learning experiences data collecting support specification) and Apache Kafka (distributed message-oriented middleware that supports partitioning, replication, and fault-tolerance while handling massive datasets) establish a starting infrastructure. Joining ADL, as a dominantly learning-oriented framework, with the ETLE, as a dominantly education-oriented framework, covers the ultimate dimensions of the future sustainable environment.

Skills, competencies, qualifications, and occupations' role in the overall ecosystem is the next important aspect elaborated in at least two referent documents the European Skills Competences Qualifications and Occupations (ESCO) [62] and the Skills Framework for the Information Age (SFIA) [63]. The ESCO multilingual classification identifies and categorizes skills, competencies, qualifications, and occupations relevant to the EU labor market, education, and training, while SFIA has become the globally accepted common language for the skills and competencies for the digital world. SFIA 8, as the last available version, represents a reference model that addresses a set of the world's most attractive occupations in several high-ranking professional areas. It defines a set of generic attributes over seven proposed responsibility and accountability levels that, joined together, facilitate the recognition of particular career improvements. Besides that, these levels establish a universal interface through which other frameworks or Corporate Information Systems may map to SFIA. In Table 1, mapping SFIA levels of responsibility and generic attribute collection [64] form combinatorial two-dimensional classification that aids competency validation activities.

Although SFIA is closely related to a dynamic and proliferating segment, of the broad professional occupations domain, it is well structured and suitable for creative inclusion in OICF model.

The additional related work elaborates on the selected references concerning fundamental aspects of the specified OICF model (OICFM), presented in Table 2. They are cross-referenced and grouped over the OICF fundamental concepts: framework and interoperability in education, learning, and teaching domains.

Table 1
SFIA responsibility levels and generic attributes map (refined from Ref. [64]).

		Generic Attributes				
Level	Determination	Autonomy	Influence	Complexity	Business skills	*Knowledge*
1	Follow	directed	minimal	routine	moderated	basic
2	Assist	routine directed	internal	ranged	sufficient	basic domain
3	Apply	general directed	internal, external	ranged, creative	effective	balanced generic and domain- specific
4	Enable	framed	external, manage internal	broad ranged	fluent, aware	body of knowledge
5	Ensure, advise	broad directions	overall, managed	policy, strategic	leadreship, operational management	fully familiar
6	Initiate, influence	authority, accountability	policy and strategy formation	policy, strategic development, and implementation	risks mitigation	Executive leadership
7	Set strategy, inspire, mobilize	highest authority	Industry or higher level	highest strategic	leadership, and strategic management	fosters culture

The related work analysis shows the documents, studies, standards, procedures, and scientific articles that dominantly address particular aspects of current and future Education, Teaching, Training, Learning, and Performing ecosystems. These documents need the exact augmentation via performing the competence-based professional tasks and activities related to a person's current occupation strategies. On the other hand, there is a lack of research concerning the interoperability framework approach with the integration mission. In this stage of development, the proposed solution focuses on the large picture, the Generic Ecosystem that sustainably orchestrates: Education, Teaching, Training, Learning, and Performing (industrial arena that blenders competencies, as emergent properties, in the context of the professional occupation) domain-specific eco-subsystems.

3. The Open Interoperability Conceptual Framework Model (OICFM) - the dimensionality and architecture foundations

The integration of Education, Teaching, Training, Learning and Performing strategies through an Open Interoperability Conceptual Framework (OICF), proposed in this article, is based on the extendible set of dimensions that dynamically map different contexts. Two essential concepts and one principle had a crucial impact on the approach adopted in this article: the context and the dimensions as concepts; and the openness (extendibility) as a principle. The stakeholders' view determines context and dimensions and directs the initial approach to gain a sustainable solution for an arbitrary real-world problem. The openness principle states that any solution component has to be opened for extensions and closed for changes (meaning that any new extension does not affect any existing part of the overall solution).

To support the comparative analysis of any phenomenon from Education, Teaching, Training, Learning and Performing environments assumes the existence of a comprehensive, open, multi-dimensional, and multilevel classification system that minimally includes: occupations, science, knowledge, understanding, skills, competencies, and credentials dimensions (Fig. 4).

Occupations - The standardized Classification of Occupations is a starting point for a global framework that may support internationally comparable occupational data collection, processing, and dissemination. In the recent decade, at the national or international level, there have been several occupation classification systems proposed, revised, and accepted, like the EU [106], Australia and New Zeeland [107], Canada [108], and the Republic of Singapore [109]. Industry 4.0. Has established challenging research towards the revolution in the democratization of education through suitable framework specification [110,111].

Although they have a similar hierarchical structure, the different coding and classification principles open two possible interoperability approaches: adopting or creating an overall worldwide acceptable classification or developing a universal mapping mechanism of the heterogeneous representatives. To support the interoperability of future learning strategies throughout the entire education and learning environment, following the openness principle, it is more likely that a mapping approach would be a reasonable solution.

Science - The open set of standardized and classified scientific Bodies of Knowledge (BoKs) for particular scientific fields is a design challenge of an arbitrary interoperability framework. The mission of technical and technology-based scientific disciplines is to preserve the creative balance between knowledge, understanding, and skills. Scientific research is a robust and dynamic practice using multiple methods of systems or phenomena investigation (experimentation, description, comparison, and modeling). According to Ref. [112], science consists of two elements: a Body of Knowledge (BoK) and the process of producing it. Different scientific disciplines typically use specific methods and approaches to investigate the natural world, but testing lies at the core of scientific inquiry for all scientists.

Knowledge - is usually defined as a collection of facts, principles, and beliefs expressed through formal declarations. Technical knowledge is significantly more technology-dependent and may radically change the underlining BoK and associated skills and virtues

Table 2
Additional, individually originated, references.

Related to	Description and reference	OIFSM Impact
Ontology	The ontology involvement ranges from competence management [65], portfolio modeling [66], contemporary personalization issues [67], and personal learning and semantic web ontology [68].	high
Education and teaching	The topics ranged from bridging the gap between traditional and innovative education and teaching [69], curriculum development aspects [70], simulation of computational thinking in engineering education [71], and development of the collaborative culture [72]	high
Learning	Related references range from challenging learning strategies [73] and the semantic web approach [74], continuous game-based adaptive learning [75], learning management support [76,77], learning process improvement through interactive teaching applications [78], and aspects of life-long learning [79].	very high
Competences	Related references range from competency-based e-assessment [80], competency model for Industry 4.0 compliance [81,82], curriculum analysis based on embedded competences [83], competence aspects for a set of domain-specific engineering disciplines [84,85], general themes concerning the future competence-based education and learning [86–88], and open innovations competence framework [89].	very high
Credentials	Digital transformation in the domain of the credential favors the orientation to Micro-credentials with a focus on the global micro-credential landscape [90], specific overview [91], learner value micro-credential framework [92], and the significance of learning profiles in the evaluation process [93].	very high
Artificial intelligence	Swarm [94], and Artificial intelligence in education [95].	high
Smart technologies and Blockchain	Semantic web approaches to improving the adaptation quality of virtual learning environments [96–98], pedagogic framework for semantic web [99], assessing approach to learning [100], adaptive learning [101], design representation [102], AI and blockchain integration [103], adaptation factor for blockchain [104], and blockchain public sector implementation [105].	very high

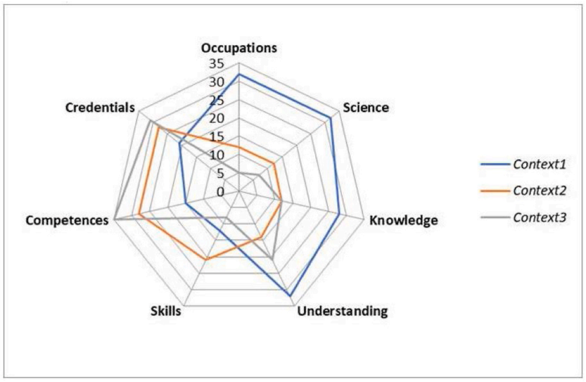

Fig. 4. Open Interoperability Software Framework Fundamental Dimensions in different contexts.

that are dominantly tool-dependent in a short time frame. In Ref. [113], there is the representative list of currently existing BoKs presented. Combinatorial structure and context-dependent nature of curriculum development, even in the same scientific field, cause significant variations. These are the challenging aspects of formal evaluation, comparison, and quality assurance models and procedures. According to the contemporary interdisciplinary and multidisciplinary education and learning trends, an opened multidimensional classification system that supports the exact mapping of technical and technology science BoKs is essential when specifying and developing a sustainable interoperability framework. Domain-specific BoKs, powered by the tailorable curriculum templates (dominantly characterized by social, cultural, administrative, and legislative constraints), aid their customization abilities. They generally serve for Quality Assurance metrics and evaluation purposes [114], assuming that the agreed definition of Quality is the level of compliance with the specification. The BoK-based approach to education and learning is usually curriculum-oriented, where the curriculum is a compound structure that, in major and minor streams, joins the subsets of several knowledge areas from interrelated or closely related scientific disciplines. The inherent combinatorial structure and context-dependent nature of curriculums, even in the same scientific field, causes significant variations in structure and learning outcomes. This makes formal evaluation, comparison, and quality assurance a challenging endeavor. The process of curriculum change management dominantly constrains its real-time applicability and usefulness.

According to the contemporary interdisciplinary and multidisciplinary education and learning trends, an open multidimensional classification mechanism that fully supports the mapping of technical and technology science BoKs is essential for the specification and development of a sustainable interoperability framework.

Understanding - Engineering education and learning are dominantly problem-solving-oriented. In Ref. [115], regarding the facts that some knowledge is not a cognitive achievement, some achievements do not constitute knowledge, and some go beyond, the author concludes that understanding has to become a central epistemological concept in the future. From that perspective, the understanding hierarchical layer is placed directly above the knowledge by narrowing it through: facts interpreting; information understanding; meaning capturing; transferring knowledge into different contexts; differentiation between causes and effects; sorting; grouping; and the anticipation of consequences. The differences between understanding and knowledge are systematized in Table 3. Although the primary focus of the mentioned article was on art and art-related artifacts' role in cognitive processes, it has directly promoted the understanding as one of the basic OIF dimensions that emerge from the interaction of knowledge and practicing skills.

Skills-represent the capacity to effectively apply knowledge and abilities to perform physical or mental tasks. Although academic knowledge is still essential, professional and personal contexts demand additional skills and dispositions. They are beyond the pure domain-specific BoKs. According to Bloom's taxonomy [116,117], the third level of problem-oriented education is concerned with practicing already learned and ultimately understood knowledge. Skills development, education, and learning programs became integral parts of formal accreditation documents and standards at national or international levels. The concept of short programs is emerging as a formal answer to non-formal educational challenges and tends to establish a mediation between contemporary education and learning mainstreams.

Competency-belongs to two major groups: generic (holistically developed with generic applicability in any education and learning

Table 3
Differences between understanding and knowledge (reworked from Ref. [115]).

Understanding	Knowledge
not belief-based	belief based
unstructured	structured
completely holistic	partly holistic
non-propositional	propositional
gradual	non-gradual
not facts oriented	facts oriented
is related to a plurality of epistemic goals	is related to truth as a unique or the highest epistemic goal

context or real-life activity) and domain-specific (intentionally developed and applied in single or multiple closely related scientific domains). Competency-based education (CBE) and Competency-based learning (CBL) emerged as promising solutions to the rigidity and real-time inapplicability of the traditional curriculum approaches. The future CBL frameworks are intelligent supporting tools if empowered by the integration of augmented and virtual reality platforms in the context base training environment.

In the Open Interoperability Conceptual Framework, the achieved competencies represent an emergent property of synergic interactions between science, knowledge, understanding, and skills developed within the educational scope, through learning processes and time-directed successful application, in the context of current occupation tasks. The competency is represented by the five-dimensional helix model composed of knowledge, skills, attitude, ability, and time dimensions, with parametric-driven interdependencies (Fig. 5). The combinatorial impact of different dimension resultants causes significant variations of a single instance structure and aids the responsiveness of particular competency in different stages derived from the concrete dimension tensors (relative strength). In Fig. 5, a representative set of competency configurations expose knowledge-intensive, skills-intensive, attitude-intensive, ability-intensive, time-intensive, and proportional competency variations.

A network of competencies typically has varying mastery levels as a part of its credentialing model. Introducing the time-dependent variations of particular competency assumes the existence of a suitable version control system that supports forward chaining of competency structure growth and enables backward tracking issues for context-dependent consistency evaluation.

Credentials - are authorized trusted artifacts encapsulating a single or a set of competencies. They represent a certification mechanism to certify that a particular stakeholder (person or an institution) has achieved qualification or competence, in the related subject/field, in a proper way. The main problem associated with contemporary credentials (although some of them encapsulate data about the curricula or associated experience) is that they do not provide much detail on the performance capabilities of awarded person or institution. The granularity level of a particular credential significantly varies regarding the granularity of embedded competencies. The credential types range from ones designed to motivate behavior, recognize achievement, and establish credibility (badges and micro-credentials) through formally non-mandatory to formally mandatory licensure. In the Open Interoperability Conceptual Framework, credentials represent tokens that flow throughout the education and learning multidimensional and multilevel network that occasionally enable the network state transitions. Digital representation of competence models and associated credentials that supports tokenization in a trusted manner has to preserve the raw elements of individual experiences embedded in particular tokens. The token implementation through Blockchain technology opens challenging implementation perspectives. The Open Interoperability Conceptual Framework Model (OICFM) is a first step toward the established goal.

The complex system's collaboration generally faces interoperability issues that may result in a dynamic set of emergent behaviors or properties. In this context, the emergent property/behavior represents a property/behavior or set of properties/behaviors the individual participating systems do not individually exhibit. They exist only in the current configuration of engaged participants. In Fig. 6, the OICF core dimensions, credential, and competency token object-oriented meta-model summarize previous dimensionality-based elaboration, with details in Fig. 7.

Individual dimensions are potentially structurally reflexive (*StructuralReflexive* aggregation) and serve as building blocks of complex configurations (*Configuration*) that are time reflexive (*TimeReflexive*) structures. Due to the potential complexity of individual dimensions, the meta-model supports a construction delegation mechanism (*DimensionCreation* with concrete creators *ConcreteDimensionCreator*) that forms Abstract Fabric or Template creation mechanisms. The Structural aspects of configuration types constitute the extendible set of structures (CompetenceStructrure, BodyofKnowledgeStructure, CredentialStructure, and EducationStructure). The configurations' behavior is delegated to the GenericBehavior interface that hides the operational details of the extendible set of implementers (Teaching, Learning, Performing, and Evaluating). From the extended ontology aspect, it is necessary to standardize every potential ontology branch. From the typology aspect, according to the background and related work analysis (Section 2), the different Framework Type Objects and a sample of possible Configuration Type Objects are listed in Table 4.

According to the related work and the analyzed mainstream approaches, the OICFM represents a Hyper Framework (A Framework of Frameworks) as a System-of-Systems paradigm representative example. It has to enable the application of a lightweight interoperability approach that supports dynamic ad-libitum interoperability of all relevant concepts contributing gradual transition to future Education, Teaching, Learning, and Performing ecosystems (ETLPE).

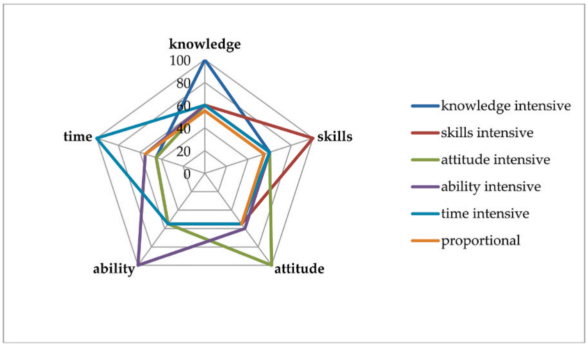

Fig. 5. Competency related dimensions.

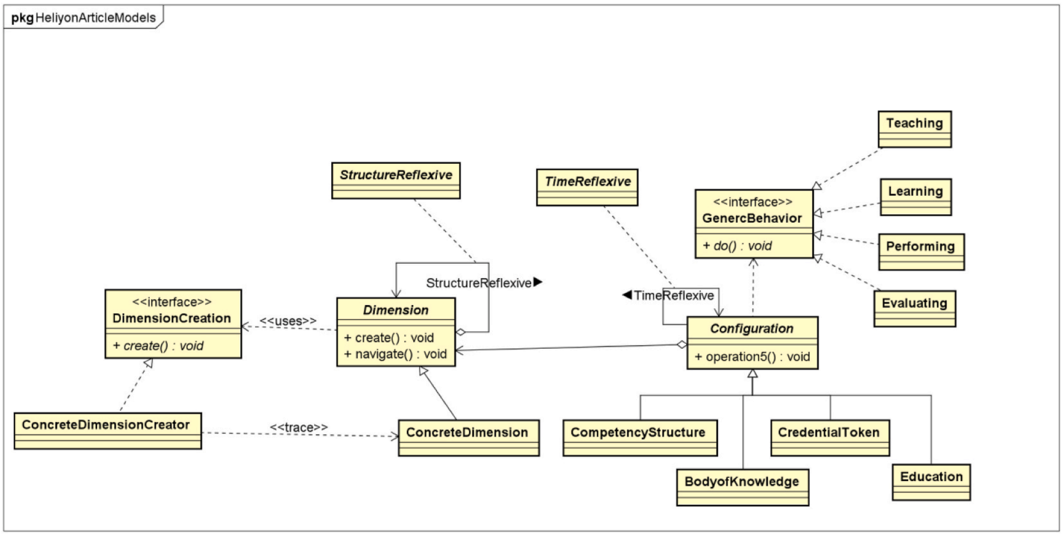

Fig. 6. Object oriented meta-model of OICF core dimensions.

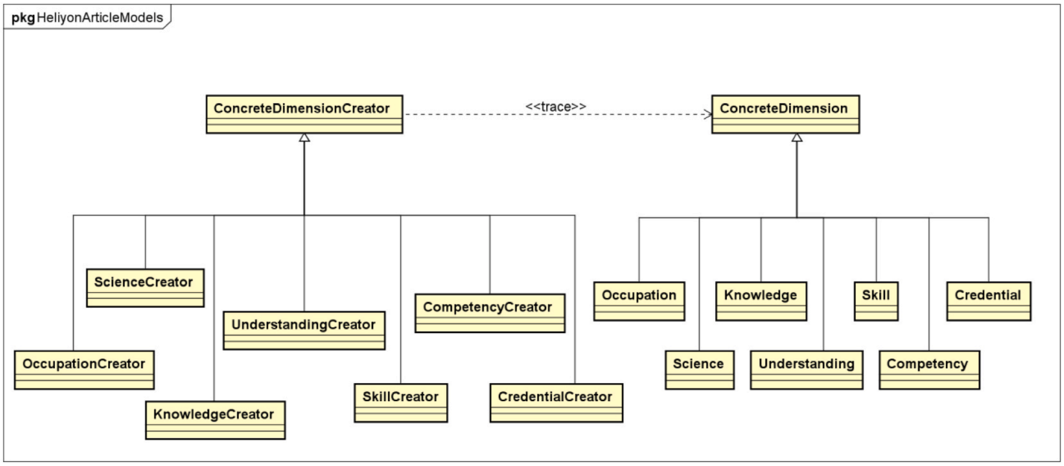

Fig. 7. Object oriented meta-model of OICF core dimensions - details.

Table 4
Framework type (a) and Configuration type objects (b).

a. Framework Type Objects		b. ConfigurationType Objects	
Type	Sub-Type	Type	Sub-Type
General Ontology		Accreditation	International, Multinational, and National Framework
General Taxonomy			
Science	Scientific BoK	Quality Assurance	International, Multinational, and National Framework
Knowledge	Domain-Specific BoK	Educational	Curriculum Development
Skills	Generic		Artificial Intelligence
	Domain-Specific	Teaching and Coaching	Package Development
Understanding			Course Development
Competencies	Generic	Learning	Personalization
	Domain-Specific		Privacy Management
Credentials	Macro, Micro, and Nano		Security Management
	Non-credential based		Learning Management
Occupations	International, Multinational, and National		Activity Tracking
General Ontology			Session Handling
		Employing	National

The Enterprise Architecture Model (EAM) at the highest abstraction level of the OICFM, differentiate two general stakeholders groups (Personal and Institutional) clustered in two architecture areas: Institutional Area and Personal Area (Fig. 8).

The *InstitutionalArea* hides the complexity of embedded multidimensional dynamic hyper framework (a contextual temporal configuration of arbitrary Institutions' internal frameworks). The Institution is an abstract stakeholder representing a physical or a virtual organizational system registered as an institutional actor. It is an abstract factory with an extendible set of concrete specializations that form a context-relative institutional hyper framework responsible for the institution's relative structures and behaviors

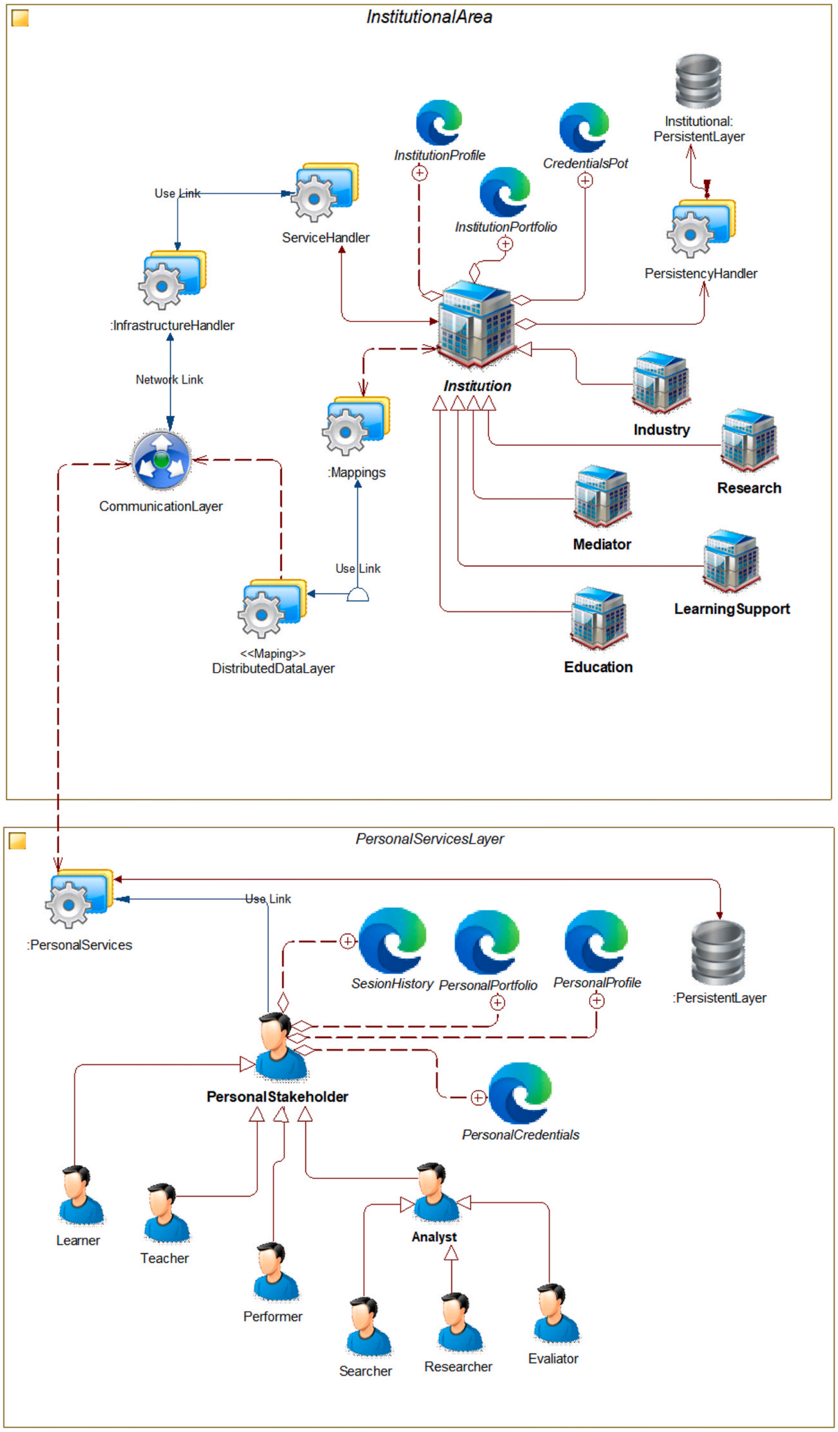

Fig. 8. Framework Enterprise Architecture Model - the first Integration Shell.

and may produce, consume or maintain credentials and competencies tokens. Institution posses the extendible set of abstract data collections encapsulating The InstitutionProfile (the expandable collection of offered, mediated, participated, or consumed competence packages); The InstitutionPortfolio (dynamic set of domain-specific set of preferences); and The CredentialsPot (the expandable collection of issued or consumed credential tokens), and three delegated handlers ServiceHandler (institutional service broker), PersistencyHandler (hosts persistent data/information/knowledge layer services that encapsulate handling of heterogeneous information resources), and InteroperabilityHandler (a communication middleware - Master Broker that orchestrates all activities, supporting direct mapping of arbitrary ontology, structure, form, and types, and is extendible over configuration maps and associated services).

According to the ontology and taxonomy aspects of OICFM, supporting the whole spectrum of multidimensionality for an arbitrary model instance is essential. Framework, via an extendible set of domain-specific primary stakeholders, defines the Education, Learning Support, Industry, Research, and Mediator specializations.

- The Education institution usually represents a physical organization with Educational, Learning, and Teaching capabilities;
- The LearningSupport institution is a physical or virtual organization with Learning and Teaching supportive capabilities;
- The Mediator is usually a physical organization and encapsulates an extendible set of secondary stakeholders responsible for the organization, accreditation, quality insurance, standardization, and arbitrary evaluation activities related to the ETLPE;
- The Industry is a physical or virtual organization that is the generic consumer of occupation-related competencies and credentials and establishes performing-related contexts with competency token upgrading capabilities through innovative activities; and

The Research is a physical or virtual organization that is the generic consumer of research-and-development-related competencies and credentials tokens with the ability to create specific scientific or innovative upgrades of existing or the creation of new ones.

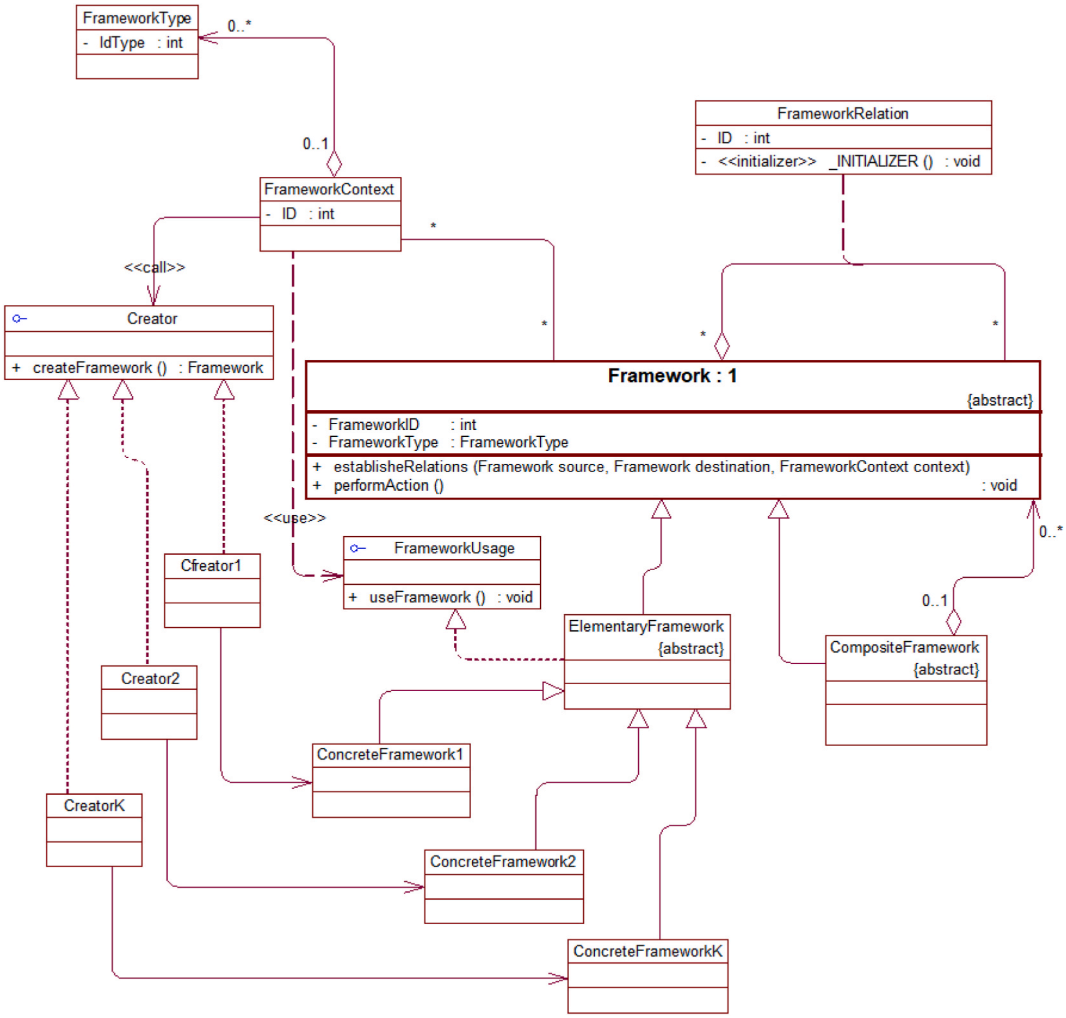

Fig. 9. Hyper Framework Factory - Conceptual model.

The CommunicationLayer hosts an open, extendible set of services and is responsible for establishing, monitoring, and controlling communication infrastructure. Due to the openness principle, the collection of available services is extendible through orchestration (micro-services) or composition (macro-services) operations. The infrastructure repository stores and retrieves the dynamic infrastructure instances, the context-created composite, and multidimensional entities associated with temporal attributes that correlate the infrastructure configuration items in time.

The PersonalArea is an Architectural Area that hides the complexity of a proposed framework from the PersonalStakeholder hosting an extendible set of PersonalServices and is directly responsible for PersonalPersistnetLayer and ProfileInstances handling. Due to the openness principle, the specified set of services is extendible either through the orchestration (micro-services) or composition (macro-services).

From the personal perspective, PersonalStakeholder is an abstract role accompanied by the extendible set of abstract data collections that minimally describe PersonalProfile (a dynamic, context-created, composite, and multidimensional object associated with temporal attributes that form the expandable set of acquired competencies), PersonalCredetials (the expandable collection of acquired credential tokens), PersonalPortfolio (education, learning, teaching or performing current intentions set), and SessionHistory (infrastructure service log). PersonalStakeholder specializations Learner, Teacher, Performer, and Mediator (Analyzer, Researcher, Evaluator) enable further differentiation of layers' roles. An arbitrary Learner may establish learning sessions only. A Teacher may establish either learning or teaching sessions. The Performer role is a hybrid role that encapsulates performing credentials related to professional issues different from education or teaching. The Performer may establish performing, training, and development sessions that may, occasionally, evolve into learning or even teaching counterparts. The Mediator is an abstract role activated in the context of PersonalStakeholder enlarging its specializations by profile-dependent search and analytic services. It may exist as a standalone instance of a Mediator role with an open set of specialized ones like an Analyzer, Researcher, or Evaluator.

For the OICFM, as a hyper framework, the specification of an open meta-framework model that may serve as a generative template for concrete configurations building support is a necessity. The Meta-Framework (MF) conceptual model, as a static object-oriented model (class diagram), represents the overall instantiation support (Fig. 9). It is an Abstract Fabric creational pattern based and explicitly separates the process of arbitrary framework creation (interoperability critical complex action, rarely repeatable on small-scale timeframes) and its' operational usage (framework-long activities through the entire framework's life cycle).

Concrete frameworks are complex, context-dependent dynamic constructs. They may appear in different framework forms (FrameworkType) and different framework contexts (Framework-Context) and represent single mission-oriented (Elementary-Framework) or multiple mission-oriented (CompositeFramework) frameworks. The reflexive many-to-many aggregation over Framework instances enables hyper-framework creation under the control of the FrameworkRelation associative meta-class (See Fig. 9.).

Fig. 10 presents The Internal Framework Architecture model as a generic Model View Controller (MVC) architecture pattern.

The FrameworkModel is a complex, composite, dynamic object encapsulating, in an arbitrary context, the underlining data/information/knowledge structure. It has to be constructed during Framework initialization and maintained during the entire life cycle of the constructed framework. Certain parts of the Framework model instances may emerge from the Analytic services that, due to the extendible set of simulations, may be internally or externally orchestrated via the FrameworkControler.

The FrameworkControler encapsulates all Framework activities over the extendible set of dedicated Interfaces that hide the complexity of Framework internal or external services and follow applied orchestration principles.

FrameworkView is one of the most challenging and demanding components set of any particular Framework. It is responsible for the visualization of arbitrary Framework-Model component instances.

The basic dimensions (occupations, science, knowledge, understanding, skills, competencies, and credentials), through arbitrary configuration activities, form dynamic, time-dependent, associative semantic networks.

According to the personal and institutional data collection instances (See Fig. 8.), it is possible to analyze a variety of paths through the created and interconnected semantic networks based on the extendible set of rule-based token-passing mechanisms. Some trajectories are simulations based, dominantly on Personal or institutional intentions. For example: Where can I find suitable educational, learning, teaching, and performing configurations that match the desired one? Is it achievable due to the current Portfolio and Credentials Status?

4. The discussion and concluding remarks

Considering the inherent complexity of the System of Systems Approach to Open Interoperability Conceptual Framework (OICF) based integration of future Education, Teaching, Training, Learning, and Performing ecosystem (ETTLPE), the majority of this article is devoted to clarifying potential problem-domain-related obstacles. The introductory and related work analysis shows documents, studies, standards, procedures, and scientific articles that dominantly address particular aspects of current and future Education, Teaching, Training, Learning, and Performing ecosystems. These documents need the exact augmentation via performing the competence-based professional tasks and activities related to a person's current occupation strategies. On the other hand, there is a lack of research concerning the interoperability framework approach with the integration mission. The proposed solution, elaborated in Section 3, focus on the large picture, the Generic Ecosystem that sustainably orchestrates: Education, Teaching, Training, Learning, and Performing (industrial arena that blenders competencies, as emergent properties, in the context of the professional occupation) domain-specific eco-subsystems. The entire elaboration has stated the following generic research motivation questions.

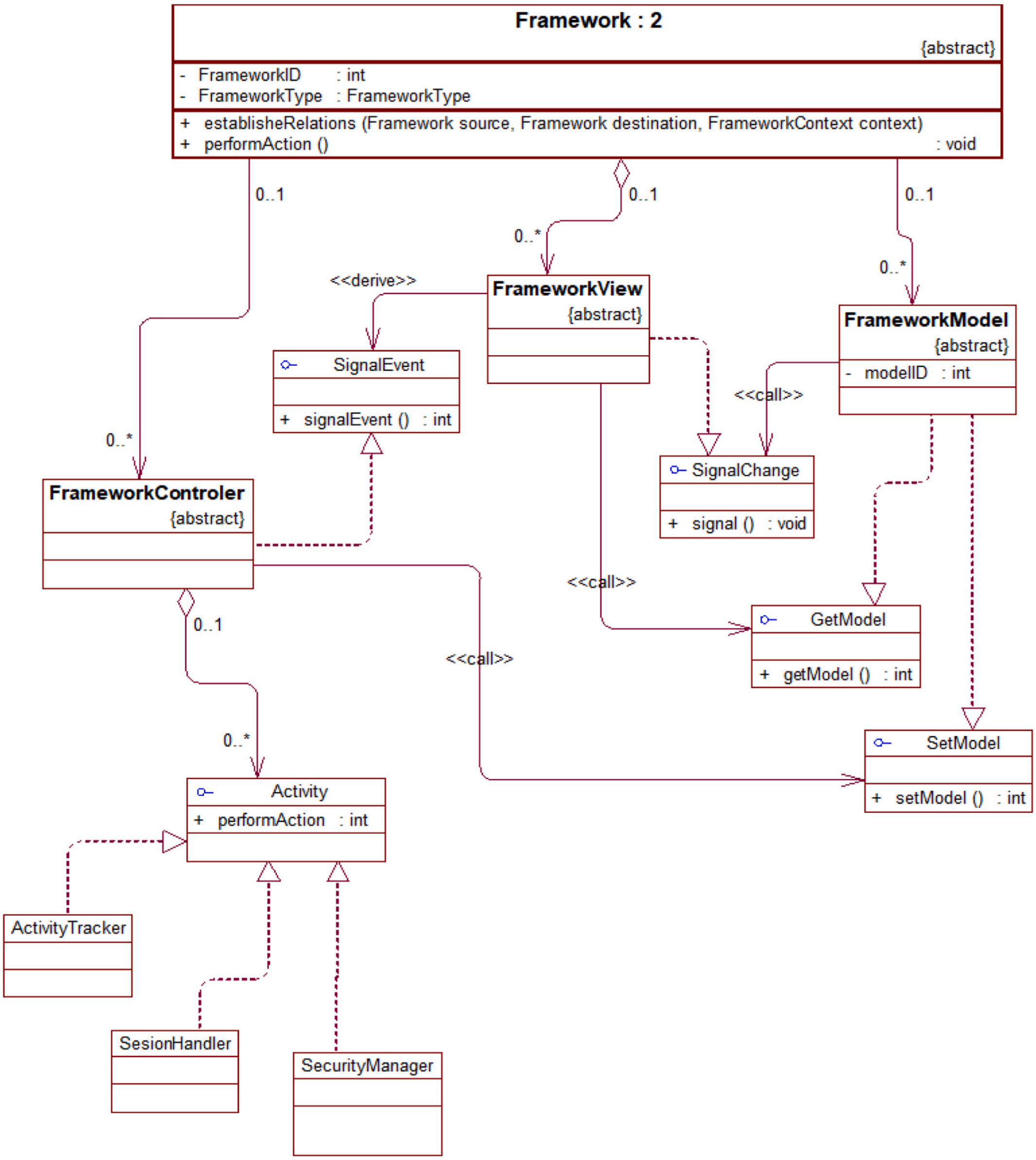

Fig. 10. Internal framework architecture meta-model.

- How to create an Education, Teaching, Training, Learning, and Performing ecosystem that successfully and sustainably integrates the overall heterogeneous scene?
- How to support the creation, evaluation, and acceptance of trusted credentials in compliance with the quality assurance principles embedded in the national and international accreditation standards and procedures?
- How to support future learners (students) in individual competence portfolio building and stay compliant with the contemporary skills and knowledge market demands and the distributed learning infrastructure challenges?

The cooperation and collaboration through the specified Open Interoperability Conceptual Framework (OICF) that, while supporting the orchestration of all of the valuable paradigms (former, current, or future), forms the foundation for comparative analysis and evaluation of traditional or nontraditional competency-building processes and all the relevant stakeholders' portfolio, credential, and competency tokens creation and management.

The comparative analysis of any phenomenon from the ETTLPE environment has influenced the creation of a multidimensional, comprehensive, open classification system and the related architectural, hyper-framework model with configuration-based semantic network creation ability.

From the semantic clarification of individual dimensions the OICF has inherited the set of major features: from occupations - the need for opened mapping mechanisms for different existing classifications systems; from science - the opened set of standardized scientific Body of Knowledge (BoK) composites; from knowledge - interdisciplinary and multidisciplinary classifications systems that support full mapping technical and technology science BoKs; from understanding - the inclusion of domain knowledge and practicing skills operational synergy; from skills - the transformation from time-framed academic education for the whole life to the life-long learning with continuous personal carrier improvement based on personal education, teaching, learning and performing portfolios management; from competences - viewing competency as the most challenging dimension that emerges from the synergic interactions between: science, knowledge, understanding and skills developed within educational scope, through learning processes and successful application, in context of current occupation tasks, with varying mastery levels as a part of its credentialing model; from credentials - being trusted tokens that flow throughout the ETTLPE space and occasionally enable the state transitions.

The proposed model is a starting specification for the future: open, heterogeneous, cooperative/collaborative, service-oriented software framework that may be tailored, according to the education and learning providers and consumer's needs, over the hyper-software-framework supported Education, Teaching, Training, Learning, and Performing ecosystems. The specification and development of such software framework is the main direction of future research endeavors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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