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BRIDGING COMPUTER SCIENCE EDUCATION AND INDUSTRY: A COMPETENCY-BASED ARCHITECTURE USING E-CF

The rapid growth of the information technology (IT) sector has made the existing gap between university training and industry requirements even more noticeable. As a result, many graduates feel the need to pursue additional qualifications to stay competitive in the job market. This paper suggests a recommendation system that connects academic results with professional expectations by using competency-based learning principles and the European e-Competence Framework (e-CF). Competency-based learning shifts the focus from traditional knowledge assessments to skills and real-world outcomes. The e-CF offers a standardized and internationally recognized way to describe IT roles, skills, and proficiency levels. Based on previous research in personalized learning and curriculum changes, the proposed system identifies gaps between competencies gained in a student's university program and those needed for specific IT roles. Using course similarity measures, the system maps both academic disciplines and job profiles, finds missing competencies, and calculates a personalized learning path that includes the minimum number of extra courses needed to fill these gaps. The architecture uses the IDEF0 functional modeling method, which clearly shows key processes such as analyzing competency gaps, and optimizing course paths. Preliminary evaluations suggest that this approach can reduce the time and effort needed for aligning competencies while improving the accuracy of skill gap detection. The findings are useful for universities looking to update their curricula, individuals aiming to develop specific skills, and employers wanting clearer and more comparable candidate profiles. By combining competency-based learning with a standardized European framework, this system provides a flexible and scalable solution for enhancing the connection between higher education and the changing demands of the IT job market. It can also be applied to other fields with established competency models.

Keywords: competency-based learning, recommendation system, knowledge gap, European e-Competence Framework, personalized learning paths, education labor market alignment.

Introduction. The information technology sector has a long history and is very developed. Its rapid growth is clear in the overall industry expansion and the increased demand for skilled professionals [1]. At the same time, the tools and technologies that support IT practices are evolving quickly.

This fast pace of change has created gaps between what universities teach and what employers need. Academic programs can't always be updated quickly or thoroughly because of limited resources. As a result, candidates often need additional coursework to fill these gaps.

Therefore, we need a recommendation system that matches a graduate's knowledge from their university studies with the skill requirements of specific roles in the job market. By identifying these gaps, the system could suggest courses or modules, possibly from different institutions, that could effectively close those gaps.

Literature review. Traditional education often struggles to keep pace with the fast-changing demands of the technology sector, leaving many graduates requiring additional training or certifications. This gap raises concerns about the relevance of academic curricula to industry needs. Especially in software engineering researchers stress the value of interactive learning environments for applying theoretical knowledge in real-world contexts [2]. Regular curriculum updates and project-based learning further promote hands-on experience and help close knowledge gaps, aligning education with labor market expectations [3].

Incorporating open-source software projects into coursework strengthens this alignment by exposing students to collaborative workflows and industry tools [4]. However, barriers such as outdated materials, limited access to technology, and a lack of industry-experienced instructors persist. Addressing these resource gaps is crucial for preparing graduates to meet the demands of today's tech-driven work-place [5].

Another area of research highlights the importance of personalized learning paths for professional development. These strategies effectively address individual needs by supporting psychological factors such as competence, autonomy, and connectedness are key drivers of intrinsic motivation, engagement, and sustained learning. Personalized learning fosters self-regulation by allowing students to set goals and progress at their own pace, strengthening autonomy and responsibility for academic outcomes [6–7].

Tailored instruction also improves performance and knowledge retention by offering feedback and appropriately challenging tasks, minimizing both overload and disengagement [8]. By adapting content to varying competency levels, personalized systems reduce cognitive load and promote equity. Aligning instruction with individual preferences increases satisfaction and supports a more inclusive, learner-centered environment [9]. Building on these findings, the proposed framework aims to reduce the need for extra training by recommending the fewest disciplines necessary to bridge competency gaps.

Framework basis. Competency-based learning focuses on measurable, real-world outcomes rather than traditional academic metrics. It is increasingly adopted in U.S. universities to align graduate skills with labor market needs [10–11].

The European e-Competence Framework (e-CF), developed by the CEN ICT Skills Workshop, standardizes IT competences across Europe, ensuring consistent interpretation among educators and employers. It supports initiatives like the Grand Coalition for Digital Jobs [12–13].

Structured into four dimensions, the e-CF's competences and proficiency levels as core elements are central to curriculum mapping [14]. Fig. 1 shows how the e-CF Explorer maps the Developer role to relevant competences and levels in the "Build" and "Run" domains, facilitating curriculum alignment.

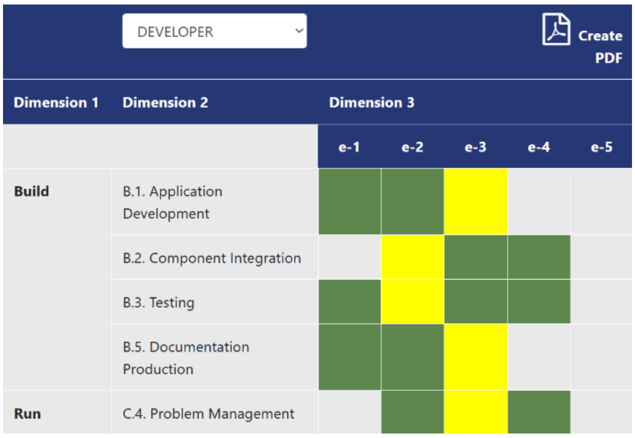

Fig. 1. e-CF competency mapping for the Developer profile, showing relevant competencies across the Build and Run domains, along with their corresponding proficiency levels (e-1 to e-5)

The e-CF fosters unified competence development and supports workforce planning and career growth [15]. However, implementation remains challenging due to limited resources and unfamiliarity with its concepts, requiring adaptable program design and supportive digital tools [12, 14].

In summary, the e-CF provides a solid foundation for IT competence development and mobility across Europe.

Proposed architecture. The proposed architecture in Fig. 2 is built using the IDEF0 functional modeling methodology. It allows to describe the architecture in the most complete way by representing it in the form of processes. The architecture describes the main components of the system: similarities of courses, identify gaps in student knowledge, find the minimum number of courses to fill the gaps.

The main inputs come from three sources. Program syllabuses provide the academic component. Diploma supplements show evidence of what learners have achieved. Job descriptions outline what the labor market expects. Above these inputs, the top control band sets limits and common language. Higher education standards outline what constitutes an outcome in a curricular context. The e-Competence Framework (e-CF) offers a broad classification of digital skills. A set of processing rules guides how activities operate, like the detail level at which skills are recognized or the criteria that trigger a "match". At the bottom of the diagram, AI processing methods are the main mechanism, indicating that techniques such as natural language processing, ontology engineering, and similarity search implement the transformations described in the boxes. The single output on the right is a curated list of courses. Its singular focus shows that the model aims to help decide which minimal set of courses a learner should take to be job-ready.

The upper stream of activities converts academic content into a meaning that supports comparison and reasoning. The first transformation, "Map courses into competencies" takes program syllabuses and translates their learning objectives and results into a shared skills space defined by the standards and e-CF. This process has two roles. It aligns the diverse language of course documents with an external skills vocabulary. It also creates a reusable layer of "competencies" that serves as a common language for the next steps. The presence of control arrows from higher education standards, e-CF, and processing rules to this box highlights the need to harmonize differences in wording, scope, and detail across institutions and decide how detailed the mapping should be for future optimization.

From this common skills layer, the system moves to "Build ontologies of courses". Here, the mapped competencies are enhanced with structured knowledge taken from courses' metadata and stated learning objectives and results. The ontology creates a graph-like representation where courses, competencies, prerequisites, and topic relationships are clearly shown. By making these relationships machine-readable, the model does more than just identify keyword similarities. It supports inferential tasks such as subsumption (when one course's outcomes include another's) and partial coverage (when two courses together cover a competency that neither covers fully). This activity is controlled by the same set of standards and rules that guide decisions about what entities to model, which relationships to allow, and how to manage ambiguous outcomes.

The next activity, "Comparing syllabuses" uses program syllabuses to align and contrast different courses or curricula. Its output, "comparison results" measures overlaps, gaps, and unique focuses across offerings. The model sets up this comparison as a precursor to "Find similarities between courses" where it distills the rich comparison into similarity assertions that can be applied across the course set. These similarities are essential constraints for the optimization step. Highly similar courses can be seen as substitutes, while complementary courses may be bundled for efficient competence coverage. Control arrows indicate that the standards govern the thresholds for declaring similarity and the weighting of various factors topic closeness, competency coverage, or mastery levels.

Parallel to this curricular stream is the learner- and job-centered stream at the bottom of the diagram. The activity "Identify student competencies" analyzes the diploma supplement to pull out verified outcomes and translate them into the same skills space. This ensures that the learner's profile can be compared with course representations and job expectations. The corresponding activity "Convert job description into competencies" translates labor-market language into competency terms, resulting in "job competencies". Together, these two processes allow "Identify gaps in student knowledge"

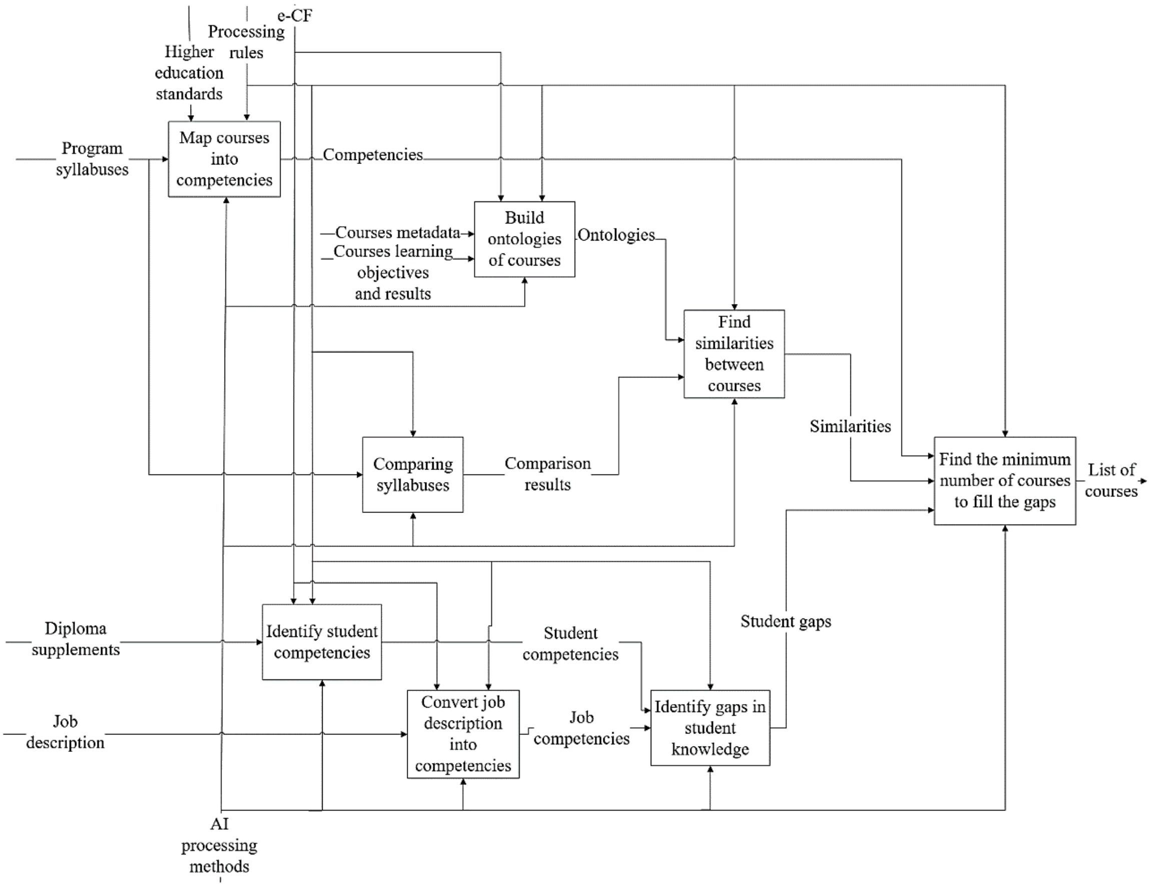

Fig. 2. IDEF0 Diagram of the Recommendation System

which calculates the difference between job requirements and what the student has shown. The output, "student gaps" is crucial for the final recommendation: fill this gap with as few courses as possible while considering the constraints related to similarity and equivalence.

These two streams connect in the activity "Find the minimum number of courses to fill the gaps". This stage conceptually addresses a constrained covering problem. The universe is the set of required competencies, each course covers a subset, and similarities and comparisons provide additional information that allows for substitutions, reduces redundancy, or imposes prerequisite structures shaped by the ontology. While the diagram does not specify an exact algorithm, it suggests that the system uses a form of combinatorial optimization aiming to balance complete coverage against efficiency. Control inputs play a significant role here. Processing rules may impose limits on course loads, place weights on required versus optional competencies, or set precedence constraints. The standards and e-CF ensure coverage is evaluated against an accepted classification rather than random descriptors, making the recommendations justifiable to academic and industry stakeholders.

The meaning of the arrows clarifies the logic of the architecture. The competency stream from "Map courses into competencies" feeds both the ontology builder and the comparison engine, showing that all higher-level reasoning relies on a normalized competency view rather than raw text. The "comparison results" and "ontologies" together inform similarity detection, which then influences the minimization activity alongside "student gaps". The bottom stream directs "student competencies" into gap identification and also contributes to the overall system's landscape by preventing recommendations for courses that mainly cover already achieved competencies. The translation from job requirements to competencies is equally important: without this, the model would not be able to identify gaps or justify specific course selections. Finally, the arrows from AI processing methods to nearly all activities indicate that these transformations are automated and repeatable rather than based on individual human assessments.

Choosing e-CF and higher education standards as controls rather than inputs is methodologically important. As controls, they do not get transformed, they shape how other changes occur. This design choice makes it so updates to standards directly readjust mappings, ontologies, and similarity judgments without altering the system's logic. It also fosters interoperability: curricula from various institutions and job descriptions from different employers become comparable when projected into the same skills ontology. Mentioning "processing rules" alongside the standards highlights that operational details like tokenization methods, similarity measures, or acceptance thresholds need to be adjustable and documented, which is vital for reproducibility and auditing in critical advising situations.

The diagram's final output, a "List of courses". It solves a formally structured problem framed by recognized competency frameworks and shaped by a series of semantic transformations. Because earlier activities capture course similarities and potential equivalences, the final list can focus on non-overlapping coverage, reducing unnecessary repetition and offering justified alternatives when institutional constraints or scheduling issues occur. The inclusion of ontological knowledge allows for more informed choices. For example, if a single advanced course covers two intermediate ones, the minimization stage can acknowledge this and suggest a more efficient option, assuming the student's prior skills meet the prerequisites.

Conclusions. This study highlights the pressing need to bridge the gap between university education and the dynamic demands of the IT sector. By leveraging competency-based learning principles and the European Competence Framework (e-CF), the proposed recommendation system architecture provides a systematic and efficient approach to aligning educational outcomes with industry requirements.

The architecture identifies individual skill gaps by analyzing the competencies gained through formal education and the demands of specific IT roles. It then recommends a tailored learning path comprising the minimum number of additional courses needed to address these gaps. Preliminary results demonstrate significant time and effort savings in competency alignment, as well as enhanced accuracy in identifying skill discrepancies.

The broader implications of this research are profound. For educational institutions, the system enables better alignment of curricula with market trends, fostering more relevant and effective learning experiences. For individuals, it facilitates targeted upskilling, empowering them to meet job requirements more efficiently. For employers, it provides a mechanism to identify and develop talent with near-complete skill sets.

By promoting competency-based learning and aligning educational practices with international standards, this research offers a scalable and adaptable framework with the potential to transform how educational systems and labor markets interact. Future work may explore the application of this architecture in other fields beyond IT, further solidifying its utility in addressing the pervasive issue of knowledge gaps in professional development.

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ПОЄДНАННЯ ОСВІТИ З КОМП'ЮТЕРНИХ НАУК ТА ІНДУСТРІЇ: КОМПЕТЕНТІСТНО ОРІЄНТОВАНА АРХІТЕКТУРА З ВИКОРИСТАННЯМ E-CF

Швидке зростання сектору інформаційних технологій (ІТ) ще більше посилило існуючий розрив між університетською підготовкою та вимогами галузі. Як наслідок, багато випускників відчувають потребу в отриманні додаткової кваліфікації, щоб залишатися конкурентоспроможними на ринку праці. У цій статті пропонується система рекомендацій, яка пов'язує академічні результати з професійними очікуваннями, використовуючи принципи навчання на основі компетенцій та Європейську рамку е-компетенцій (e-CF). Навчання на основі компетенцій зміщує фокус з традиційних оцінок знань на навички та реальні результати. e-CF пропонує стандартизований та міжнародно визнаний спосіб опису ІТ-ролей, навичок та рівнів володіння. На основі попередніх досліджень персоналізованого навчання та змін у навчальних програмах запропонована система визначає розриви між компетенціями, отриманими студентом в університетській програмі, та тими, що необхідні для конкретних ІТ-ролей. Використовуючи онтології та показники подібності курсів, система відображає як академічні дисципліни, так і профілі посад, знаходить відсутні компетенції та розраховує персоналізований шлях навчання, який включає мінімальну кількість додаткових курсів, необхідних для заповнення цих прогалин. Архітектура використовує метод функціонального моделювання IDEF0, який чітко показує ключові процеси, такі як побудова онтологій, аналіз прогалин у компетенціях та оптимізація шляхів навчання. Попередні оцінки показують, що цей підхід може скоротити час і зусилля, необхідні для узгодження компетенцій, одночасно підвищуючи точність виявлення прогалин у навичках. Результати дослідження корисні для університетів, які прагнуть оновити свої навчальні програми, для осіб, які прагнуть розвинути певні навички, та для роботодавців, які бажають мати чіткіші та більш порівнянні профілі кандидатів. Поєднуючи навчання на основі компетенцій зі стандартизованою Європейською рамкою, ця система забезпечує гнучке та масштабоване рішення для посилення зв'язку між вищою освітою та мінливими вимогами ринку праці в галузі ІТ. Її також можна застосовувати до інших галузей з усталеними моделями компетенцій.

Ключові слова: компетентнісне навчання, система рекомендацій, прогалини в знаннях, Європейська рамка е-компетенцій, персоналізований навчальний шлях, узгодження освіти та ринку праці.

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