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Instructional Design as a Key Factor for Industry 5.0 Engineering Education

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Abstract

The rapid advancement of Industry 4.0 and the emerging concept of Industry 5.0 are revolutionising the manufacturing landscape, demanding a paradigm shift in engineering education. There is a critical need to develop learning concepts for engineering education that will play a pivotal role in bridging the gap between academia and industry, ensuring that engineering graduates are equipped to spearhead sustainable and intelligent operations management practices in the automotive sector. The European project EE4M-CoVE is focused on that need. In the context of the project, this paper analyses the development of an educational concept for Industry 5.0 education. It proposes an instructional design (ID) model that has been designed, developed, and validated by a panel of experts to ensure its alignment with industry standards and best educational practices. The project's ultimate goal is to empower future engineers with the skills and knowledge necessary to thrive in the Industry 5.0 era. This will be achieved by developing and implementing learning concepts focused on operation management within the mobility value chain, considering both digital and green transitions. The instructional design model serves as a key tool to ensure the quality, standardisation, and scalability of this educational approach along all project members.

Keywords: Industry 5.0, Instructional Design, Engineering Education

1. Introduction

Industrial enterprises within the mobility value chain are currently confronting a confluence of external pressures driven by the dual imperatives of digitalisation and ecological transformation. These challenges are well documented

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in various studies and proposals and supported by government policies and plans. In 2020, the European Commission laid the foundation for an industrial strategy, which was updated in 2021 [1], to drive the dual transition to a green and digital economy. This strategy aims to strengthen the European Union's global industrial competitiveness while fostering its strategic autonomy. Furthermore, within this evolving industrial context, human capital and talent will be one of the competitive keys for many companies. The talent and capabilities of the workforce present both opportunities and constraints for navigating this transformative period [2]. The success of these sociotechnical transition's hinges on the development of core competences and skills within the workforce, extending beyond technological advancements to encompass organisational structures and human decision-making processes [3]. This context leads to the need for the continuous realignment of engineers for the long-term success of the companies affected by this transformation of the future. Reinforcing the operation management competences and skills of engineers is critical for manufacturing companies in the mobility value chain. This focus will ensure a talent pool with the expertise to handle the complexities of modern production [1].

With the ultimate aim of strengthening the competitiveness of industrial entities within the European Union, the EE4M-CoVE project aims to develop the competences and skills of people who will be part of the future operations management of mobility manufacturing companies. To ensure the competitiveness of the European economy for the digital and ecological transformations of the present and the future, companies must develop innovative products and improve external processes to meet the evolving needs of global markets.

With a focus on smarter manufacturing, recent studies emphasise the need to develop the skills of future engineers who will be crucial for transforming operations. The transition to the work of the future implies a modification of current tasks, forcing a readjustment and realignment of the skills, competences, and qualifications of tomorrow's engineers [1], [4]. For example, some of these authors emphasised that employee education and training are increasingly considered innovative forces and are therefore key competitive criteria. Following this thread, the entire VET education sector is particularly challenged to drive sustainable and digital transformations in terms of skills development and labour market trends, thus ensuring the training of the next generation of professionals in line with the times.

In the context of Industry 4.0, education is technology-oriented; however, with the advent of Industry 5.0, a need is created to create a synergy between machines, robots, and humans. This is why engineering education faces an urgent transformation to train a new generation of Industry 5.0 engineers [5], [6]. This technological revolution implies advancing in teaching towards engineering education for Industry 5.0, transcending the development and application of technology and entering the field of ethics and humanism and sustainability. For Industry 5.0 to be more sustainable, resilient, and human-centric, university and study programmes should be redesigned for the engineers of the future [7]. Engineering education for Industry 5.0 will be influenced and driven by technological advances based on the improvement of Industry 5.0 concepts and models that will permanently change traditional work processes, generating new professional fields [8]. Therefore, beyond technical training, future industrial engineering and management professionals will need to be equipped to adapt to the new professional action competences, and the educational processes will have to transform not only the teaching and learning methods but also the contents and competences taught.

This paper emphasises the need for innovative learning concepts in engineering education for Industry 5.0. These concepts aim to address the transformation of manufacturing operations towards a smarter and more sustainable future. To develop these learning concepts, an instructional design (ID) model is proposed to promote commonality and rigour in the development process among the learning concepts for operation management in the mobility value chain.

The remainder of this work is organised as follows. Section 2 outlines the rationale behind the new learning concepts and the authors' interpretation of the term. Section 3 explores the relevant ID literature, specifically the ADDIE model. Section 4 details the research methodology, followed by Section 5, which presents the results, including the developed ID model with each template for the development of the learning concepts, a proposal for an *instructional design for Industry 5.0 engineering education*, and its validation by experts. Section 6 concludes the paper and outlines potential directions for future research.

2. Learning Concepts for Engineering Education in Industry 5.0

In the previously mentioned context, a European project for ERASMUS EDU, EE4M-CoVE, was born to respond to the growing needs for training, reformulation, and improvement of the qualifications of engineers in the mobility value chain, starting from raw material to recycling and back to the circuit. The project marks an innovative educational approach for the development of learning concepts. The programme architecture should use a competency-based approach with a modular structure, leveraging digital teaching and learning formats to equip students with the skills needed for smart and sustainable operations management. The concepts developed throughout the project should be easy to integrate into the existing and regular curricula of vocational training centres, continuing education and universities, thus adapting to current challenges and problems through dynamic reflection and permanent feedback.

Within operations management, three main areas of focus are identified to which the learning concepts will have to respond:

- Logistics and supply management.
- Product development and manufacturing.
- Entrepreneurship and industrial marketing management.

To develop new and innovative competency-based teaching and learning concepts, it will be necessary to define and identify the necessary competences to be developed, depending on the degree of study. The concepts will be designed according to current pedagogical principles and will apply Biggs' theory of constructive alignment theory [9], a pedagogical approach that focuses on aligning learning objectives or outcomes, learning activities, and assessments in education. This alignment between learning objectives, activities, and assessment guarantees that the intended learning outcomes are demonstrably achieved by students.

We understand a learning concept to be the result of the alignment between learning outcomes, assessments, and learning activities leading to certain skills (Fig. 1). Therefore, different versions of the learning concept may be obtained based on the skills aimed to be developed, the different levels to be achieved on those skills, the methods and tools used to build them, and the content used for them. The development of skills and competences will determine the content, resources, and learning outcomes for a particular level of study.

Sustainable competences, as defined by several authors [10], [11], refer to the skills, motives, and attitudes that enable students to address and manage the complexity and uncertainty of sustainability issues in society, advancing toward sustainable development. Digital competences, characterized by cognitive, attitudinal, and technical skills, consist of abilities that enable the effective use of technology to help mitigate challenges in contemporary society

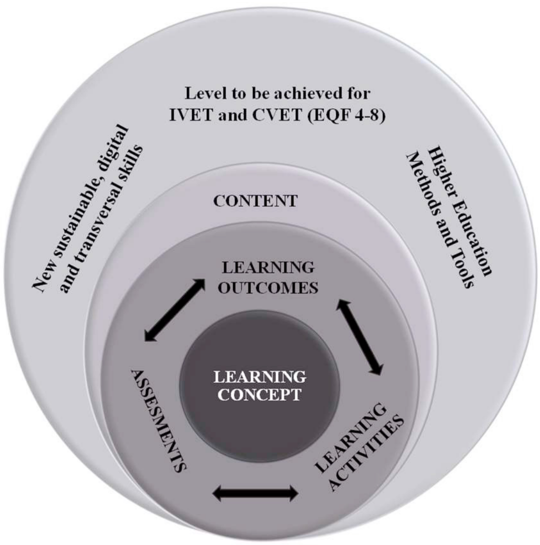

Fig. 1: Learning concept framework

[12], with some of these competences being defined by [13]. Critical or transversal competences [13], [14] must also be considered. Once these competences are established, learning activities and assessment methods can be used to design the learning concept. The research focuses on the development of learning concepts that will help develop skills. Engineering education programmes should equip students with a strong foundation of skills and knowledge that will remain relevant throughout their careers. This applies to entry-level programmes (EQF levels 4–8) and all the way to continuing education programmes designed for experienced professionals who want to update their skillsets and stay competitive in the evolving engineering landscape. By focusing on these future-proof competences, we can ensure a high-quality engineering workforce with strong employability prospects at all levels. Learning concepts should, in turn, incorporate methods and tools aligned with the latest trends in engineering education for Industry 5.0. Pacher [8] provides a summary of innovative approaches to industrial engineering management educational methods, which concludes with the need to use practical, interdisciplinary, and problem-based methods. It also emphasises that these educational trends are incorporating industry collaboration, sustainability principles, and tools based on new technologies.

Finally, an adequate template that will guide and give structure to the learning concept is crucial for the final result.

3. ID Models in Higher Education

3.1. The Importance of Instructional Design

The development of learning concepts is a challenge that requires the use of instruments that will help to develop each learning concept and define a standardised way to develop them to fulfil the quality criteria of participants in the project and the common expectations of all. In this context, the ID approach is a key instrument used in higher education as a useful tool to design and build a learning concept. ID is a systematic process used to develop education and training programmes in a consistent and reliable manner [15]. It is an essential aspect of creating effective and enriching learning environments, and its importance cannot be underestimated. Accordingly, ID provides a theoretical basis for the selection of instructional strategies and guides the development of appropriate cognitive processes to ultimately achieve effective learning outcomes [16]. ID can be used to guide the integration of information and communication technologies into the teaching and learning process . This can improve the quality of education by providing new opportunities for interactive and flexible learning. Therefore, ID can also be used to develop effective online learning environments [17]. This is particularly relevant in the context of distance education, where ID can help overcome the challenges associated with adopting new pedagogies and creating effective online learning environments [18].

Further, from a learning perspective, ID can be used to develop learning environments that foster collaborative learning and knowledge construction [19]. This can improve the quality of learning by enabling students to learn from each other and build knowledge together. However, other authors have highlighted the role of ID and its use in developing learning environments that foster autonomous learning [20], [21]. This can improve the quality of learning by enabling students to take control of their own learning processes and develop self-learning skills. Other scholars have also highlighted the role of ID and its use as a mechanism to enhance student motivation and engagement [22].

3.2. Instructional Design Models

As discussed above, ID models are tools that guide the practice of instructional designers and facilitate the creation of quality teaching and learning materials. They can be used to guide the integration of information and communication technologies, enhance student motivation and engagement, foster collaborative and autonomous learning, and develop effective online learning environments [17]. ID models are a source of theoretical and practical reference for educators and instructional designers, especially in the field of higher education, where a high level of quality and effectiveness is required in teaching and learning processes [17], [23], [24]. In the context of higher education, ID models help improve student learning outcomes and integrate emerging technologies into educational environments [16], [17]. There are different types of ID models, each with unique characteristics, principles, and processes [24]. Some models are based on learning theories, such as constructivism or cognitivism, while others focus on pedagogical, technological, or contextual aspects [25], [26]. The selection of an appropriate ID model for a teaching and learning situation depends on several factors, such as the type of content, learning objectives, learner characteristics, available resources, and environmental constraints [27].

As there are no one-size-fits-all models, it is necessary to assess the advantages and disadvantages of each and adapt them accordingly [28]. Among the ID models, one of the most widespread is the ADDIE model. This ID model is a framework used to guide the process of developing educational and training programmes in a consistent and reliable manner [22], [29], [30]. This ADDIE model is compared by some authors [24] in a study on ID models, where they identify seven ID models in current practice, and ten new models developed according to the specific needs of the learning concepts. The study evaluates the impact of each model in terms of learning outcomes, such as academic performance, satisfaction, and student and teacher perceptions. The ADDIE model is widely used in ID and has proven to be effective in guiding the process of developing learning concepts and educational programmes [24].

3.3. The ADDIE Model

The ADDIE model consists of five phases: analysis, design, development, implementation, and evaluation. In the analysis phase, information is collected and analysed regarding the needs of the learners, the learning objectives, and the content of the learning concept. In the design phase, the structure and organisation of the learning concept is planned, teaching strategies are selected, and assessments are designed. In the development phase, learning concept materials and resources are created. In the implementation phase, the learning concept is delivered, and teaching is carried out. Finally, in the evaluation phase, the success of the learning concept is evaluated, and adjustments are made to improve the learning concept. However, some instructors still find ID challenging, and there are information gaps regarding ID models, categories, educational contexts, and recommendations for future work [31]. Despite these challenges, the ADDIE model remains a valuable tool for instructional designers, as it provides a structured framework to guide the process of developing learning concepts and educational programmes. Furthermore, the ADDIE model can be adapted and customised to meet the specific needs of different educational and training contexts [27]. Thus, some authors have highlighted the potential of the ADDIE model in its application to different learning contexts, including blended, online, and project based learning (PBL) training.

4. Methodology

For the development of this project, the Design Science Research methodology (DSR) has been adopted, which seeks to generate scientific knowledge on how to plan and design the necessary steps to achieve the objectives. According to Brocke [32], DSR is useful in areas such as engineering, architecture, economics and information technology to create innovative solutions to relevant problems. The methodology consists of five phases adapted from [33]: problem identification and goal definition, design and development, demonstration, evaluation and communication. These phases can start from different approaches (problem, objective, design or context).

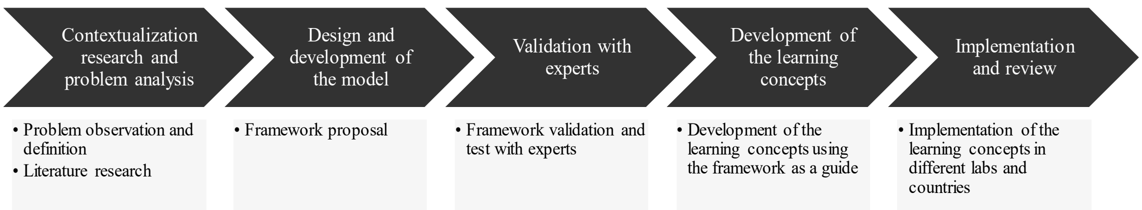

Fig. 2. Methodology followed in this study based on DSR paradigm [32]

The research methodology followed a five phase approach. The first phase, called contextualisation research and problem analysis, began by defining the research problems related to current engineering education practices. It then justified the importance of the proposed solution, an ID model for developing learning concepts. Essentially, this phase established the need for the ID model. The second phase was based on designing and developing the model. Building upon the identified needs, this phase focused on designing and developing the ID model and templates that would work as a guided structure to develop each learning concept in later phases. The third stage was validation. Once the template was designed, it was subjected to a validation process involving a panel of educational experts. Following the validation and incorporation of expert feedback, the template guided the development of learning concepts in three key focus areas. The template ensured standardisation and consistency across these areas. The final phase involved implementing the learning concepts in engineering labs across different countries. This allows for further evaluation and refinement based on real-world applications (Fig. 2).

5. Results

This section presents the findings from the first three stages of the research methodology: contextualisation and problem analysis (described in previous sections), the newly developed ID model for Industry 5.0 engineering education, and the validation process and results obtained from expert evaluation. Building upon these results, the next steps involved utilising the validated ID model to develop learning concepts for Industry 5.0 engineering education, followed by their implementation and evaluation in various educational areas and levels.

5.1. Instructional Design for Engineering Education for Industry 5.0

To respond to the needs previously presented, the development of a proper ID model is proposed to facilitate the standardisation of the method of development of learning concepts for the three previously defined areas of focus (logistics and supply management, product development and manufacturing, and entrepreneurship and industrial marketing management).

In line with the ADDIE reference model, we developed a comprehensive ID model for the development of the learning concepts. The ID model is an adaptation of the model proposed by Lasher [34]. Based on the five core elements of ADDIE, Lasher advocated placing the evaluation component at the centre of the design process. This central positioning of evaluation requires continuous evaluation throughout all phases of the design process. By adopting this evaluation-centric approach, our ID model seeks to foster a dynamic, iterative design process that ensures the development of effective, high-quality learning concepts (Fig. 3). To further enhance the learning concept design model, we propose adopting a constructive alignment approach. Pioneered by John Biggs, this approach advocates a clear articulation of intended learning outcomes as the basis for designing effective teaching and learning activities and assessment tasks.

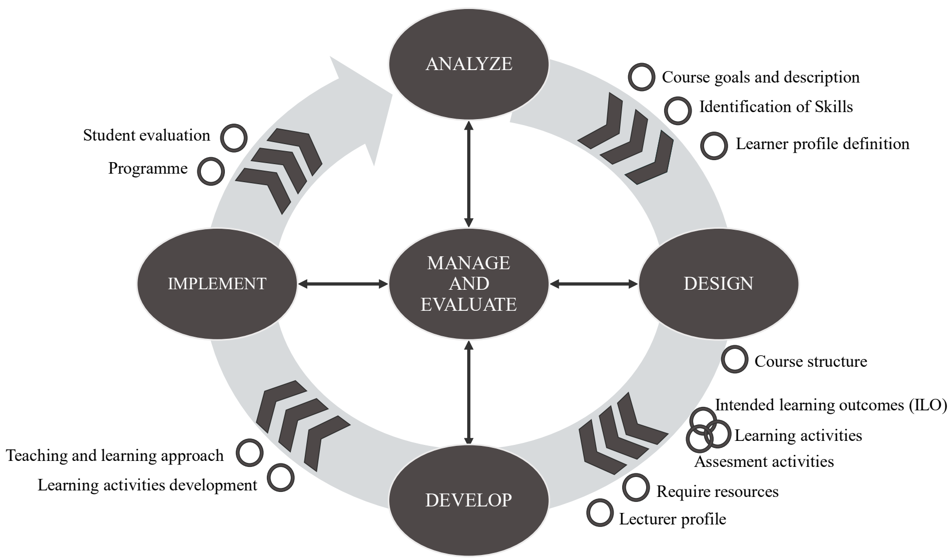

Fig. 3. Instructional design model for engineering education for Industry 5.0, based on [34].

In the context of the European project EE4M-Cove, we developed an explanation of each stage for the ID model and a template for guidance.

5.1.1. Stage 1: Analyse

In the analysis phase, skills and learning needs should be clearly defined. This will require a specific definition of the objectives of the learning concept, identifying the skills that the learning concept will be based on, as well as a description of the targeted group of the analyses (learner profile).

Table 1. Analyse stage

Section	Sub-Section	Description
General information	-	General information regarding the learning concept, title, duration, requirements, participants, as well as theoretical and practical percentages of the learning concept.
Learning concept description	Need for training	Learning concept brief description, goals of the learning concept, and list of skills to be developed.
	Learner profile	Description and characteristics of the profile, previous skills, and motivations.

5.1.2. Stage 2: Design

In the design stage, intended learning outcomes should be clearly defined and derived from the skills and learner profile identified in the analysis phase. The objective is to create a learning environment in which learners can leverage their existing knowledge to effectively master new concepts. This involves defining study and learning activities, as well as assessment activities that build one upon each other. Completing this phase requires specifying the necessary resources and determining the profile of an appropriate teacher.

Table 2. Design stage

Section	Description
Learning concept structure plan	The learning concept is going to be divided in lessons which are specific units focused to respond to a specific learning objective. The plan includes the lesson name or title, general objective of that lesson and the specific intended learning outcome that lesson will be answering to.
Teaching and Learning activities	In this section, the lesson needs to be related to a certain teaching and learning activity, specifying the hours, methods used, the require resources and bibliography.
Performance measures	This last section on the design stage is about assessments tasks definition or criteria. The table consists of the relation between the learning concept's general objective, the intended learning outcomes defined for that learning concept, the learning activity, and the assessment task.

5.1.3. Stage 3: Develop

The development stage encompasses the actual creation of the learning concept. This phase is the determination of the details about the elements that have been designed in the previous phase. The development strategy should prioritise the organisation and delivery of learning materials, methods, and activities to create a cohesive and effective learning journey for students. This phase prioritises the development of two key elements: engaging learning activities and a comprehensive teaching and learning methodology. These elements work together to ensure that the intended audience successfully achieves the established learning objectives.

Table 3. Develop stage

Section	Description
Learning activities development	This template has a preliminary description of the activity content, including duration, format, which training material will be used, media need it, and material for the validation.
Teaching and learning approach (Methodology)	This part consists of the description of the detailed methodology that will be used in the learning concept, as well as the relationship between lesson, lecturer training need, and specific resources and facilities.
Assessment development	This involves the development of the assessment task method, related learning activities, and materials used for the assessment.

5.1.4. Stage 4: Implement

In the implementation stage, the teaching and learning activity is defined. Once the unit training product is designed and developed and the validation activities are completed, the training is implemented. The purpose of the implementation phase is to prepare the learning environment and engage the learners. Common procedures associated with the implementation phase are to prepare the teacher and the learner. Implementation should prepare and involve learners. The two activities to be developed in this phase are programme development and summative and formative evaluations of the training results.

Table 4. Implement stage

Section	Description
Learning concept schedule	Detailed description of the learning concept schedule, including day, lecturer, lesson, and activities to implement
Distribute material	Detailed description of the learning concept material, including lesson, activities, related material, and format to use.
Student evaluation	Detailed description of the assessment test related to the lesson, material and students result.

5.1.5. Manage and evaluate

Evaluation is a continuous process that begins during the analysis phase and continues throughout the life cycle of the training learning concept. In this phase, there are two activities to be developed: First, the management activity of the whole ID process development in which the processes and activities of each phase of the ID should be continuously managed and monitored. Second, process evaluations should also be performed. The multifaceted evaluation approach leverages observations, lessons learned, identified best practices, insights from after-action reviews and reports, and feedback gathered during unit observation sessions. Evaluations are conducted through both student and teacher satisfaction surveys to identify opportunities for improvement. This stage will include one template for management that specifies the management procedure for each stage. Further, examples of feedback questionnaires for students and lecturers are given.

5.2. Validation of the ID Model

5.2.1. Validation process

After the initial development and refinement of the model, the validation process of the ID developed was carried out by a panel of experts in the field composed of an expert in educational innovation and the development of training models and two professors in the field of undergraduate and master's degrees with extensive experience in the application of instructional models. For this purpose, a validation process was designed based on the one developed by Tracey and Richey [35]. We based the validation method on guided interviews previously arranged between the researchers and the experts. For this purpose, the experts were sent information on the ID model developed and some questions that would be asked later in the interview. These questions were classified into three blocks: the first block involved a thorough analysis of the relevant procedures; the second block focused on analysing the most crucial aspects of the ID; and the third block aimed to determine the expert's agreement with the proposed model.

5.2.2. Validation results

Following the validation method described earlier, the experts provided valuable feedback on the ID model and generated templates. Their comments were categorised by development phase. For the analysis phase, a crucial point raised by the experts was a proper analysis of the gap and identification of the skills. In the design phase, they emphasised the need to clearly define the learning outcomes. In terms of methods and tools, which are related to the development phase, all the experts agreed on the need for pre-defined methods and tools for engineering education that can be applied and used by the instructors in this phase. Regarding the implementation phase, they considered the development of pilots as key for the validation of the developed learning concepts. The panel unanimously identified a need for clearer instructions and examples within the templates to facilitate their use and reduce interpretation variations. Additionally, the templates should explicitly define the target group (including levels and characteristics). The experts also suggested reducing the table size to avoid concept repetition.

The expert feedback reaffirmed the model's effectiveness. They found that it encompasses key learning concepts design and offers a systematic approach to learning concept analysis, design, and development. They also evaluated and tested the model-derived templates, which provide essential guidelines for standardising the proposed instructional design.

6. Conclusions and Further Steps

Engineering education is facing a need to regenerate itself in order to address the new paradigm of Industry 5.0, which requires a transformation in how engineers are trained. Engineers must be equipped with the necessary skills to meet the challenges of this disruptive environment. In this context, education programs that bridge the gap between Industry 5.0 and engineers' competences should be created [36]. The proposed new learning concepts approach developed, can be a fundamental tool in closing this gap by providing future engineers with lessons in sustainability, resilience, and a human-centerer perspective, while also nurturing their digital tools and skills.

To achieve this, we designed an instructional design (ID) model for developing these learning concepts, offering a guide for the creation of effective learning materials. We also developed templates that were evaluated by a panel of experts, who confirmed their usefulness and potential to facilitate the learning concept development process. The proposed ID model will promote consistency and rigor in the development of learning concepts across all focus areas and projects. The challenge we may face lies in creating new materials, implement the learning concept in different laboratories and regions and evaluate the effectiveness of the learning concepts developed to truly transform engineering education and prepare the engineers of the future [37]. Further research should focus on validating the findings in a broader context, which would enhance the generalizability of the results and provide a deeper understanding of training approaches across diverse regions.

Acknowledgements

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