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PLM Education: The Role of Engineering Management Study Programs

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Abstract: *Due to its ability to support the achievement of operational and strategic business excellence despite complex business conditions, growing globalization, demanding customers, and shorter product lifecycles, the Product Lifecycle Management concept (PLM concept) is becoming the most significant industry initiative today, while PLM education is becoming an essential strategy in the education of future engineers. The paper emphasized the necessity for the promotion of PLM education by academic communities, discussed PLM education issues, and identified key PLM competencies. It also explores the role of Engineering Management study programs in educating professionals with comprehensive PLM competencies.*

Keywords: PLM education; PLM concept; Engineering Management study programs

1. INTRODUCTION

Increasingly intense globalization, growing competition, demanding customers, shorter life cycles, and increasing complexity of products necessitate stronger control over the product life cycle in order to reduce costs, accelerate innovation processes, and enhance product quality.

These circumstances give product information the status of a strategic corporate resource, while the effective management of such information over the entire product life cycle becomes essential for overcoming the aforementioned challenges.

The combination of all of the previously mentioned factors and the development of information technologies has resulted in the emergence of a new, IT-based business paradigm for the integrated management of product information from product conception to its disposal, so-called Product Lifecycle Management (PLM). The PLM is considered a business model based on a strategic approach to managing processes, information, and resources to support a dynamic configuration of the product lifecycle [1]. According to Lee et al. [2], PLM is a strategically oriented approach that provides a complete product lifecycle definition, including all information and processes required to plan, develop, manufacture, and operationally support a product from conception to the end of its lifecycle, integrating people, processes, business systems, and information. Ming et al. [3] define PLM as a business model that supports the collaborative creation, management, dissemination, and use of intellectual capital related to a product, including data, information, knowledge, etc. PLM is interpreted as a specialized information system that supports all product-related processes, from their development to disposal.

In recent years, there has been a surge in interest in the adoption of the PLM concept. Attracted by PLM's ability to contribute to the attainment of operational and strategic business excellence despite complex business conditions, an increasing number of companies are launching the PLM initiative. PLM transcends traditional application boundaries such as aviation, automotive, and general processing industries, penetrating into other sectors such as fashion or the food industry.

According to the reports of the CIMdata company [4], the global leader in the field of PLM consulting, PLM software market is the fastest growing IT market today with a total investment value of $57,51 billion in 2021 and an estimated growth rate of 8.5% for the next five years.

However, despite significant investments in PLM technologies, many businesses are still struggling to adopt a PLM philosophy and reach higher levels of PLM maturity.

The successful implementation and consistent application of the PLM approach are mostly determined by the human factor. According to Ameri & Dutta [5], the implementation of PLM does not begin with the introduction of PLM software solutions, but rather with the development and adoption of the PLM vision by people involved in PLM-oriented processes.

Given that PLM is a rapidly growing business paradigm, driven by its strong influence on improving the management of business systems, incorporating all relevant PLM topics into educational processes is imperative in the education of the so-called engineers of the future. These educational processes must go beyond simply the processing of PLM theoretical assumptions and principles. Namely, the consistent application and control of the PLM approach requires extensive analysis and understanding of information flows, business activities, specific methods, and concepts used in different phases of the product life cycle.

This necessitates the education of engineers with sophisticated and multidisciplinary competencies pertinent to the various stages of the product life cycle.

Given their multidisciplinary nature, Engineering Management study programs appear to be the most pertinent for educating experts capable of implementing and coordinating the application of the PLM approach and successfully working in a PLM environment. However, there is a scarcity of considerable discussion in the literature about how the existing Engineering Management study programs' curriculums are aligned with this vision. This paper attempts to fill this gap in the literature and make a certain contribution to the development of an appropriate education strategy for producing engineers with advanced PLM competencies.

The paper first discusses the main issues in PLM education, then it investigates the key PLM topics that must be included in curriculums for the education of future engineers capable of implementing and coordinating the PLM approach, and finally, it discusses the role of PLM academic platforms in the education of future engineers. The last section examines the extent to which PLM topics are covered in Engineering Management bachelor's study programs. The research looked at 19 study programs in Engineering Management from technical and polytechnic universities.

2. PLM EDUCATION ISSUES

In the absence of a systematic, well-organized, and well-conceived PLM education, industry PLM competencies are being developed through long-term employment in various positions throughout the product lifecycle, which is actually the process of absorption and learning about products and operational strategies through experience [5]. This is a fairly drawn-out process and delays the attainment of higher levels of maturity in PLM adoption.

This necessitates the strong promotion of PLM education by academic communities. Additionally, by incorporating PLM education into the university education processes, the academic community might significantly accelerate the process of increasing industry comprehension of the significance of the PLM concept through newly educated staff.

According to the findings of several significant studies in this area [5, 6, 7], several strategic issues must be considered when designing PLM-oriented educational programs in order to close the gap between the industry's true requirements and the student competencies that educational institutions provide:

- It is essential to educate professionals in engineering and business who are aware of the significance of the PLM concept in driving new economies, markets, and technologies.
- It is critical to raise awareness that PLM is more than just an engineering-focused approach; as a result, PLM education must include business and operational strategies that use product and related process information.
- Specific topics must be integrated into the curriculum to promote an understanding of how PLM influences areas outside of product engineering, such as marketing, procurement, product support, project management, costing, manufacturing, supply chain processes, etc.
- PLM education must provide an understanding of how PLM impacts a company's ability to support the use of new initiatives in product engineering, such as model-based approaches. (Model Based Systems Engineering - MBSE, Model Based Enterprise - MBE)
- The emphasis should be on preparing students for tomorrow's business reality through training in a real PLM environment.

The current priority is expanding PLM education beyond a purely engineering focus to include other areas of business where the PLM approach has a significant influence, as well as enhancing students' PLM digital competencies. This will be discussed in more detail in the sections that follow.

2.1. The PLM competences

According to an extensive survey conducted by the CIMdata [6] consulting group, which included a large number of universities, the scope of topics covered in the PLM courses implemented by these institutions is mainly focused on the product engineering and production areas, including topics such as mechanical CAD, documentation, and product design, etc., indicating that this education has not progressed beyond Product Data Management (PDM) focused topics. More precisely, it is mainly focused on the management of information about product definition for the needs of engineering processes and does not enable the preparation of future engineers for all the challenges of product realization and optimization.

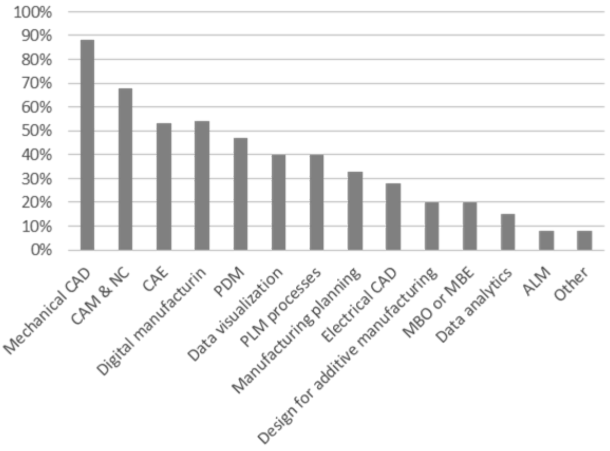


Figure 1. *Topics covered in PLM related curriculums [6]*

From an educational point of view, PLM technologies have long been viewed as sophisticated analytical and visualization tools, helping engineering students to improve their problem-solving and design skills, but more importantly, to better understand the behavior of engineering systems [7].

Companies, on the other hand, demand students to grasp industrial practice beyond the technical focus, as well as how PLM integrates different aspects of the product life cycle and to be able to effectively perform tasks in a self-sufficient manner in a real business environment; in other words, to possess comprehensive PLM competencies. In the matter of engineering education, educational programs must evolve to meet these demands.

Several studies deal with the issue of defining omprehensive PLM competencies [8, 9, 10, 11].

For example, Tamaki et al. [11] are dealing with the development of educational programs aimed at developing the competencies required for the cultivation of the so-called "global-PLM producer." The definition of the comprehensive competencies required for cultivating such an expert is illustrated by a matrix (Table 1) consisting of six phases of the product life cycle (product strategy, business model, global market sensing and the new product plan, product architecture strategy, supply chain management, manufacturing, and quality control, global marketing channels, sales, and maintenance service), and four levels of business administration (global business environment, business creation, customer creation, and product development and operational management). This matrix can be used as a guideline for educational institutions when developing PLM-focused curricula, indicating that competencies such as marketing research, system architecture design, competitive strategy, manufacturing process planning, and so on must be the outcomes of these educational processes.

Table 1. *Educational goals corresponding to whole "competency" required for cultivating Global-PLM producer [11]*

Product lifecycle phase

PLM level

	Product strategy	Business model	Global market sensing	Product architecture strategy	SCM, manufacturing and QC	Global marketing channel, sale and maintenance
LEVEL 1 Global business environment	Product line-up strategy Platform strategy Product line strategy Variation management					
LEVEL 2 Business creation		Analysis of business environment New business concept Global business model Competitive strategy				
LEVEL 3 Customer creation			Marketing research Market segment positioning Customer behavior analysis New product planning			Global logistic strategy Local market cultivation Local market promotion Local service promotion
LEVEL 4 Product development and Operational management				Technological benchmark Product specification Concept development System architecture design Integrated PLM business process model	Global framework building of production and SCM strategy Mass production planning Manufacturing process planning	

- Design and methods of industrial engineering
- Technologies and production systems
- Industrial plants
- Economics and management Engineering
- Information elaboration systems

- Computer science

In order to connect industrial realities with the widely acknowledged PLM theory, it is essential to develop an educational model that demonstrates how the PLM theory operates in practice in a way that is comprehensible to students. For this purpose, Fradl et al. [9] developed a scenario around the product in its eco-system in classroom conditions, namely, the product was physically made using easy-to-use technologies, where all relevant organizational aspects, processes, and IT tools from the real PLM environment are present. Through this educational model, students gain competencies in five areas that are considered critical for preparing future engineers for the PLM reality. These competencies include:

PLM basic:

- Product structure vs MCAD structure
- Collaboration
- Change management

PLM advanced:

- Product structure with modular product architecture
- Engineering change management
- End-to-end PLM processes

PLM system:

- Configuration of a PLM-system
- Realisation of connectors
- IoT and cloud data pipeline

Series manufacturing:

- CAD to BOM to release
- Engineering change management
- Production management
- Supply chain management
- Service

Mechanical CAD/CAE:

- Managing files
- Checkin / checkout
- Update properties vom PLM

2.1. PLM digital competences and the role of PLM academic platforms

PLM is a strategic business approach and a product management paradigm, as well as a technological concept supported by advanced ICT technologies. The totality of the IT infrastructure that supports the PLM strategy is most often defined as a PLM solution or a PLM system. It is a complex technological solution that supports a wide range of PLM-oriented processes, enabling a PLM strategy, which is defined as a consistent set of business solutions to support the collaborative creation, management, sharing and use of product information across the enterprise, integrating people, processes, business systems and information [12]. Considering its functionalities, according to dos Santos et al. [13] PLM system could be defined as:

- Infrastructure for information management, i.e. modeling, centralization, manipulation and sharing of product life cycle data;
- A set of business applications to support the use of data and knowledge about the life cycle of products in different organizations and at different stages of the life cycle;
- A knowledge management system for generating and disseminating knowledge about the product life cycle;
- A collaborative environment for integrating business units across the value chain network.

Acquiring digital competencies for dealing with such technologies is an essential aspect of PLM educational procedures that contributes considerably to preparing students for tomorrow's business reality and working in a real PLM environment. However, the technology employed in educational processes by universities today has long been technologically and functionally incompatible with that used in industry. Actually, education is most often carried out on technology solutions that cover only the domain of PDM functions; nevertheless, PLM has long outgrown the engineering focus. Namely, at the current stage in its technological evolution, PLM systems are viewed as comprehensive business solutions whose functionalities span all aspects of the product lifecycle, including integration along the entire supply chain.

A substantial barrier for educational institutions trying to simulate a real PLM environment is the high cost of these technologies. This is the stage where the PLM vendors are anticipated to give major assistance. Namely, via so-called PLM academic platforms, PLM vendors provide educational institutions with comprehensive PLM systems tailored to the demands of educational processes for a fairly low price.

Some of them even went a step further. Siemens PLM Software, for example, is developing curriculum and specialized software support to help universities build qualified PLM enablers to participate and thrive in the evolving digital future.

As part of its education program, Aras Academic also offers online learning courses in the hottest PLM topics, including: Component Engineering, Manufacturing Process Planning, Quality Planning Essentials, Product Engineering Essentials, Program Management Essentials, Visual Collaboration, Self Service Reporting, and Technical Documentation.

Also, Dassault System Company provides various services that are available for institutions, educators and students to increase learning efficiency and improve education process including:

- 3DS academy website
- Peer Learning EXPERIENCE
- Project-centric learning
- Dassault Systèmes Certification Program

In addition, Dassault Systemes Company is constantly striving to contribute to the creation of educational innovation. As a result of these aspirations, it arises Edu Hub, which conducts educational research by global collaboration to envision future trends in engineering education.

It is inevitable that engineering education must take a step forward using advanced educational models based on students' work in a real-world PLM environment. A good way to achieve such an educational model is through the use of PLM academic platforms, which have become an indispensable part of PLM educational processes. According to a survey conducted by Bedolla et al. [10], 62.5% of European educational institutions that have implemented PLM education use such software support in their educational activities.

The use of PLM academic platforms is aimed at supporting the education of future engineers by providing students with a comprehensive PLM experience and advanced digital competencies. PLM platforms intended for educational processes deliver a multitude of commercial PLM solutions' capabilities, covering the gamut from planning to engineering design to manufacturing. Namely, they provide IT support for major PLM aspects through a variety of commercial applications integrated into a single platform that spans the entire product lifecycle.

By introducing PLM academic platforms into the classrooms, students are enabled to acquire skills, knowledge, and advanced digital competencies by working in a real PLM environment. It also enables the preparation of future engineers for PLM roles beyond engineering, leading to a comprehensive understanding of the PLM concept and how it could be used to establish integrated management of product data throughout the entire product lifecycle or to drive company growth.

That way, students can transition to the professional workforce, which will be competent to implement and enforce PLM concepts within companies.

It is also important to note that the use of the PLM academic platform during the educational process supports the implementation of the project and problem-based educational learning models. These pedagogical strategies are widely accepted in various fields in educational contexts to promote critical thinking and problem-solving skills, so they play an important role in educating engineers in line with contemporary industry requirements.

Some of the most commonly used PLM academic platforms in educational institutions with PLM-oriented courses are platforms provided by PLM software vendors such as Aras, Siemens, and Dassault System. Figure 2 presents the functionalities that the Aras PLM academic platform spans.

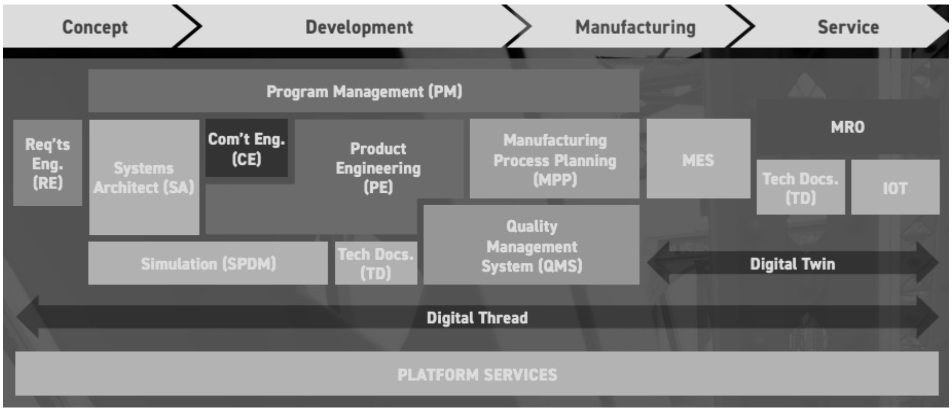


Figure 2. *Aras PLM Platform [14]*

Engineering Management graduates are competent to support a variety of innovative industrial initiatives, and it is believed that they play a crucial part in the consistent application and control of the PLM approach. The research question addressed in this section is: to what extent may Engineering Management study programs contribute to the education of professionals with comprehensive PLM competencies?

Engineering Management, according to the Missouri S&T [15], is a discipline that prepares professionals to successfully combine engineering and management expertise while optimizing the utilization of people, equipment, material resources, energy, and information.

This study program has received significant attention in recent years owing to its potential to educate professionals for today's industrial reality who will be able to effectively respond to the demands of technical progress, an increasingly complex business environment, and new industrial initiatives.

The pertinence of Engineering Management study programs stems from the necessity to consider the business unit as a complete, technology-driven organization and to successfully integrate system components, guaranteeing that the company succeeds in a competitive environment.

The Study program supports the STEM concept in education. STEM refers to educational institutions that prioritize education, which is essential for scientific and technological sphere of development, through offered educational programs. STEM refers to several academic disciplines: S – Science, T – Technology, E – Engineering and M – Mathematics. This also strengthens the connection between engineering management as a discipline and the PLM concept.

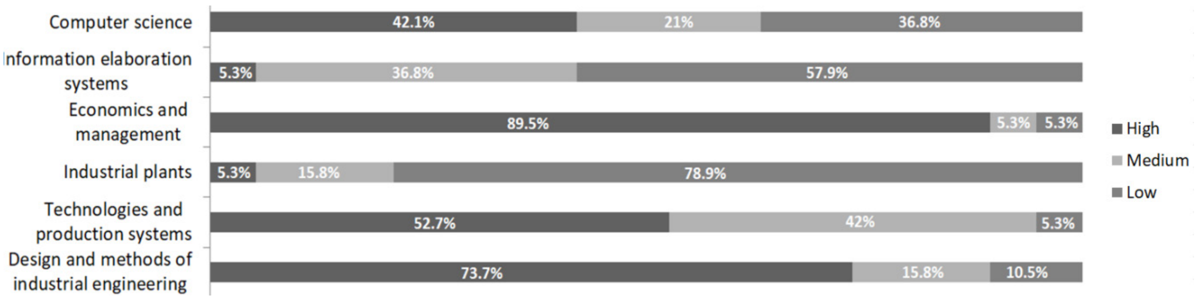
The analysis included Engineering Management study programs from 19 universities. The list is presented below.

- University of Groningen, Netherlands
- University of Lincoln, United Kingdom
- WSB University, Poland
- University of Perugia, Italy
- Sirindhorn International Institute of Technology -Thammasat University, Thailand
- Poznan University of Technology, Poland
- Stevens Institute of Technology, New Jersey
- Missouri University of Science and Technology, Missouri
- University of Maryland, Baltimore County, Maryland
- Massachusetts Institute of Technology, Cambridge, United Kingdom
- University of Illinois Chicago, Illinois
- Michigan Technological University, Michigan
- Southern Methodist University, Texas
- Loughborough University, United Kingdom
- Clarkson University, New York
- Illinois Institute of Technology, Illinois
- Faculty of Technical Sciences Cacak, Serbia
- Faculty of Technical Science Novi Sad, Serbia
- Faculty of Mechanical Engineering Nis, Serbia

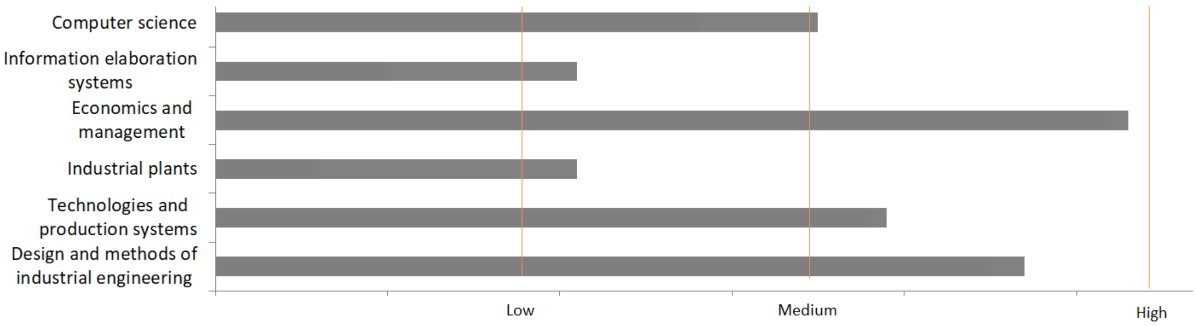
This research question was considered based on an empirical screening of these programs' curriculum structures. The aim was to identify courses through which students could acquire some of the core PLM competencies and also assess the acquired competency level based on the analysis of the predicted outcomes of these courses. The analysis made use of the PLM competencies concept established by Bedolla et al. [10], which covers the following areas:

- Design and methods of industrial engineering
- Technologies and production systems
- Industrial plants
- Economics and management Engineering
- Information elaboration systems
- Computer science

Figure 3 depicts the representation of competencies from these areas by study programs (a. by categorization of the *high, medium, and low*, and b. by the total strength).



a.



b.

Figure 3. *PLM competency representation in Engineering Management study programs' outcomes*

These competencies are highly represented in almost 90% of the analyzed study programs. The situation is comparable to competencies in the field of design and methods of industrial engineering (74% - high represented). This discipline also strongly emphasizes competencies in technologies, production systems, and computer science. On the other hand, these programs somewhat underrepresent the competencies related to industrial plants and information elaboration systems.

This indicates that Engineering Management programs provide multidisciplinary competencies, enabling understanding of information flows, business and engineering activities, specific methods, technologies, and concepts used in different phases of the product life cycle, and also provide education beyond a purely engineering focus, including other areas of business where the PLM approach has a significant influence.

This undoubtedly supports the hypothesis that Engineering Management study programs are among the most pertinent for educating experts capable of implementing and coordinating the application of the PLM approach.

4. CONCLUSION

The research findings provide proof that Engineering Management study programs have a significant role in educating engineers with comprehensive PLM competencies, providing education beyond a purely engineering focus, including other areas of business where the PLM approach has a significant influence.

Thus, more emphasis should be placed on promoting these study programs as the main generators of engineers with advanced PLM competencies. The introduction of courses that will more intensively study the theoretical settings and practical implications of PLM is also necessary in order to develop students' awareness of the importance of the PLM concept in achieving operational and strategic business excellence.

However, there is currently no evidence that students can acquire digital competencies for work in a real PLM environment through the analyzed study programs. This could be an important direction for future research, which also should highlight the importance of PLM academic platforms in the education of future engineers.

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