Systematic Mapping Study on Collaborative Curriculum Development on e-Learning Platforms for PLM Master Courses

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Abstract:

Engineering education is facing new social requirements demanding enhanced skills in cross-disciplinary competencies. Universities should incorporate Industry 4.0 and the support of computers both to cover these requirements and to teach them. In the future of the manufacturing discipline, it will be critical to use product lifecycle management (PLM) computer platforms. Therefore, it is necessary to define and design a new master's degree program that could enhance these capabilities for professionals.

In this paper, we have constructed a collaborative systematic mapping study to discover the critical things to achieve an interdisciplinary curriculum focused on PLM. The study's main topics of interest have disparate importance across the scientific community that a joint search with all items drastically limits the number of results. To solve this problem and to be able to review a large number of papers in a short time without being restricted by the criteria of a single reviewer, we propose a collaborative algorithm that includes a scoring method to accept or reject articles. This new systematic mapping study methodology allows reviewers to accept vaguely related papers that include relevant information that would have otherwise been rejected.

A systematic mapping study concluded, among other things, that the most important challenge in collaborative curriculum development is to choose the right methodology. We have detected that the outcomes of a master's degree program in product life cycle management are very little publicized, so analyzing the outcomes achieved is a relevant topic to deepen.

Keywords:

Collaborative Review, Systematic Mapping Study, Score-based Review, Building Research Questions, Computer-Supported Learning

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1. Introduction.

Product design and manufacturing companies are in continuous improvement in their authoring activities. By covering the entire product lifecycle management process, new computer and collaborative platforms can improve efficiency and, therefore, aid in obtaining parts and products with higher quality. However, these processes are difficult to improve since they require the latest information and communication technologies and paradigmatic changes in the way that tasks are accomplished and controlled. Such improvements can only be realized by formulating new methodologies (Burchardt, 2016).

Since the early 1990s, new work philosophies such as Concurrent Engineering (CE), Collaborative Engineering (CoE), and Integrated Product, Processes, and Resources Development (IPPRD) have been topics of interest. Conversely, many corporations have found these integrated and cooperative ways of working to be very complicated to implement, and often do not know how to handle the new tools for this shift. Moreover, this transformation requires the workforce to adapt to using these new tools.

The paradigm of Industry 4.0 requires new skills for new tools, especially in product engineering and information management engineering. The new product life cycle management (PLM) computer platforms include a huge number of applications that serve a variety of purposes during product design and manufacturing. Therefore, these new skills necessitate a new way of learning that, at the same time, can be accomplished using a collaborative e-learning platform that supposes the beginning of recent education trends (Johnson & Ramadas, 2020). Moreover, there must be interoperability between e-learning and PLM platforms (Bygstad, Øvrelid, Ludvigsen, & Dæhlen, 2022).

E-learning platforms are undergoing rapid change due to technological advances. At their inception, e-learning platforms offered learning services on a main computer using internet resources (Anjana, 2018). Their aim was to support face-to-face classes and leverage digital resources and applications to serve the needs of students, such as providing study material, supplemental resources, and tutorials, facilitating individual work and necessary group work (Damsa, 2014), and conducting assessments. After this initial stage, the natural evolution of the e-learning platforms focused on improving the use of (information and communication technology (ICT) resources and keeping the students engaged (Tautz, Sprenger, & Schwaninger, 2021), (Nasir, Kothiyal, Bruno & Dillenbourg, 2022).

To achieve both targets, the e-learning process is adapted according to the students' learning preferences: active, sensory, visual, or sequential (Zlatkovic et al., 2020) and according to the level of knowledge of the students and their evolution in the subjects. Finally, we could say that there are Adaptive Platforms, where the student's interest is maintained since they work on what they do not know or have less mastered.

Another important issue is that one of the keys to having a successful e-learning environment is to have a good collaborative working curriculum. To obtain this, the participation of experts in the field is compulsory. The set of experts should be made up of not only instructors but also administrators and ICT technicians. Their collaboration is important to choose and structure the content of the curriculum, to consider management requirements and environmental control, and to use available media and digital resources.

Despite the real and effective collaboration needs, time and involvement of the participants, as some authors state, collaborative curriculum development is the best way to successfully achieve this goal (Jonker, März, & Voogt, 2019).

E-learning platforms have been used in all scenarios, including in primary education (So, Chen, & Wan, 2019), high schools (Dhika, Destiawati, Sonny, & Surajiyo, 2019), (Hu, Ng & Chu, 2022), universities (Violante & Vezzetti, 2014) and even business training (Kaizer, Sanches da Silva, Zerbini, & Paiva, 2020). However, perhaps one of the best scenarios for e-learning are master's degree courses in which the level of students' interest and prior knowledge can be especially beneficial in enriching the learning environment. Additionally, these students have gone through important periods of learning in their life and have likely used some of the computer tools involved in the e-learning process. This makes students' motivation and involvement high. The use of an e-learning platform allows collaboration with experts, including those in industrial engineering, from around the world, thus optimizing the use of time required for master's degree courses. These platforms allow the confluence of students from different countries, which, when combined with teamwork, greatly enrich the training process.

Currently, the operation of a medium and large production company without the support of ICT involved in managing every stage of the production cycle is unthinkable. Even small companies use specific parts of a PLM computer tool, which is more affordable and focused on everyday production tasks such as preparing the process plan, managing resources and materials, and controlling stocks and orders.

Learning how to practically manage the necessary tools in the different stages of the production cycle is a necessity. A PLM computer platform enables integrating these tools in a multidisciplinary environment, sharing all types of data (costs, stocks, drawings, planes, programs, or timetables), and controlling the users' roles and access permissions to make a company effective and competitive.

The scope of PLM computer platforms necessitates a wide range of computer resources and excellent informatics support. PLM computer platforms are not user friendly software tools. Once the environment and the work procedure are known, the user requires knowledge of the task to execute designing, process planning, and production planning. The content of these tasks and the way to solve them are part of an industrial engineering curriculum.

It is necessary to have an intensive and controlled e-learning system to train users on how to manage and work in a PLM computer platform. There are many studies on e-learning, but their content should be complete, time-controlled, and focused on the critical factors that the collaborative team in charge of the design of the master's degree curriculum deems important (Peeraer & Van Petegem, 2012). Looking to prior research is one way to incorporate tools, methodologies, and experiences from similar projects to common mistakes and bad praxis. The goal is to create a cohesive, connected, and collaborative student learning experience. For the CONNECT4PLM Erasmus+ project, a systematic mapping study (SMS) was developed and followed to achieve this.

The focus of the project is preparing an e-learning-based curriculum that can be applied in all partner countries. With this aim, the project has five objectives: 1) developing an international curriculum, 2) creating e-learning content for a master's degree program in PLM, 3) building an e-learning module for this master's degree program, 4) practicing how to use this e-learning module for PLM practices, and 5) testing the outputs with a pilot group and course. The project outcomes could potentially be valuable to create an international master's degree program within an e-learning platform that will help professionals deal with a complex environment.

This work introduces the methodological research found in prior work on e-learning, methodologies, outcomes, and applications to engineering learning in master's degree programs.

The present paper reviews the related existing work in Section 2. In Section 3, we explain the steps followed in our SMS proposal. Section 4 presents the results and discussion. The main conclusions of our proposal and future work are detailed in Section 5.

2. Previous Works and the State of the Art of PLM in Graduate Engineering Curricula.

Currently, it is widely accepted to use a systematic search method that provides a wide description of a research topic. The results of this review allow us to identify and quantify the advancements in research in a specific field. There are several methodologies, but one of the most rigorous methods is systematic mapping study. Interesting research topics and tendencies in a specified field of knowledge can be identified through this method.

A good starting point for new research is understanding the work of other researchers and the advantages and drawbacks that they have found. Knowing this information allows for documenting mistakes and inefficient practices in advance.

The use of a SMS methodology enables researchers to approach a knowledge area with a large quantity of previous works and information using controlled criteria to guide the search in an ordered manner. Among the interesting examples of this technique in engineering, we found the work of Ambreen et al. (Ambreen et al., 2018), who focused on determining the most relevant topics and tendencies in requirements engineering. They used the results of a SMS to anticipate future needs in requirements engineering.

Moreover, an existing systematic mapping study can be updated with new search databases and works made after the initial study (Wortmann et al., 2020). Therefore, research gaps can be detected (Cedillo et al., 2013) for researchers to address.

In our research, we found that the application of SMS entailed incorporating several areas of knowledge which was the reason that no similar studies were found as a starting point. In this study, the issues of product life cycle management, e-learning platforms, and curriculum development need to be combined to formulate the research questions used to apply the SMS methodology.

While studies on each of our topics can be found in isolation, the final conclusions change radically when a SMS is used to properly combine research questions in the target topics.

Reviewing the topics of interest separately, we can find studies such as the one presented by Rivest et al. (Rivest et al., 2019), where the topic "PLM" was used as a search domain to know about the advances achieved in the last decade of research (from 2005 to 2015). The search was conducted using paired keywords from different authors. The study identifies four main research sets in PLM: '*Interoperability*,' '*Ontology*,' '*Product Data Management*,' and '*Lifecycle Assessment*.' This work uses clear rules to highlight the difficulty and importance of keyword normalization. The study concludes that PLM is a large research domain that is difficult to define with just a few terms.

Other authors used a SMS to focus on more specific parts of PLM, such as the work of Szejra et al. (Szejka et al., 2017) on the "integrated product development process." Some authors focused on particular uses of PLM, such as Jo Conlon (Conlon, 2020) who examined the level of implementation of a PLM system in the textile and apparel sector. All these types of studies highlight the real shortcomings and potential of PLM and were used as a starting point to find other studies and identify trends.

On the topic of "curriculum development," Quezada-Sarmiento et al. (Pablo-Alejandro Quezada-Sarmiento & Liliana-Elvira Enciso-Quispe, 2016) studied the use of Bodies of Knowledge (BOK) to perform a curriculum design. In their work, they also considered the context of the industry. Specifically, in the case of engineering, a general structure of a BOK was described in detail. This structure was made of a set of knowledge areas, units, and topics according to the research area.

Using the SMS methodology, Passow and Passow (Passow & Passow, 2017) looked for which competencies are most relevant to curriculum design and compared these competencies with the Accreditation Board for Engineering and Technology, Inc (ABET) accreditation requirements.

If the study focused on the topic of "e-learning platforms," then the SMS found pertained to their usability and methods for evaluation (Abuhlfaia & de Quincey, 2018), or the methodologies that they used.

For example, Valverde-Berrocoso et al. (Valverde-Berrocoso et al., 2020) performed a systematic literature review to analyze the evolution of educational research on e-learning. After the analysis, they found that the most relevant issues were online students, online teachers, and curriculum-interactive learning environments. The most pertinent theories revolve around the Community of Inquiry and Technological Acceptance Model. Regarding research modalities, massive open online courses (MOOCs) seem to be the most important. Finally, they detected the "*case study*" as the most used methodology.

Similarly, Gurcan et al. (Gurcan et al., 2021) used the latent Dirichlet allocation and data from 2000 to 2019 to identify 16 topics reflecting trends in e-learning. MOOCs, assessment, and e-learning systems were the most relevant among them. After the analysis, the authors concluded that there was a tendency to build individualized and adaptive e-learning environments.

As we have seen, several general or specific studies on e-learning can be found and we must consider all of them because the results of this study will be the starting point of a European project in charge of establishing an international master's degree program on PLM using an e-learning platform. We need a new way to perform a SMS that takes into account the guidelines for the search process from a group of experts. These guidelines enabled us to distribute the work of reviewing papers, which allowed us to cover as many papers as possible and establish criteria to accept or reject papers with a minimum and logical consensus between the involved experts.

3. Research Approach.

3.1. Systematic Mapping Study.

The systematic mapping study is a review methodology that can help to collect the related works during the first research step. It was first defined as "*the process of identifying, categorizing, analyzing existing literatures that are relevant to a certain research topic*" (Petersen et al., 2007). The key starting point is to define the right initial research questions that include the main topics of the research and apply to all the disciplines. This methodological research of the state of the art includes several steps and outcomes that are the inputs of the next step until reaching the final result, which is a conceptual map of all the previous works found (Fig. 1).

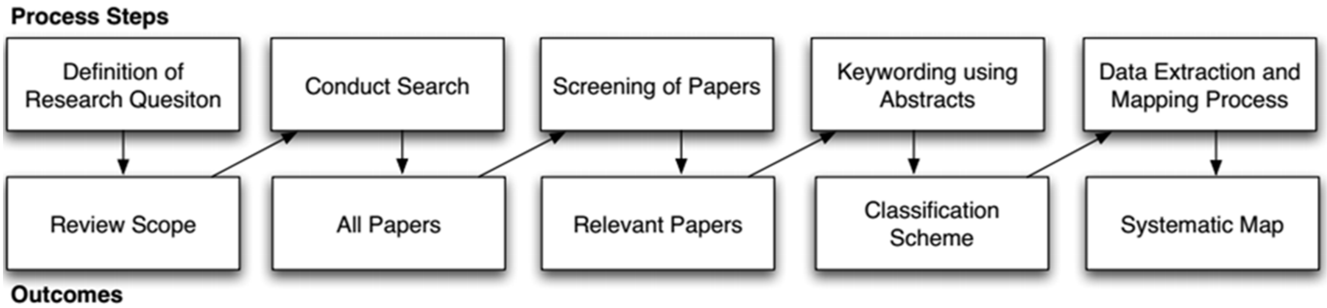


Fig. 1. Systematic Mapping Study Process Steps and Outcomes.

3.1.1. Formulate the Research Questions.

In the literature, selecting research questions pertaining to a "systematic mapping study" is a straightforward process. Based on the keywords extracted from the project proposal, the definition of the research questions aims to position the topics within the literature and to analyze the diversity and quality of research. Due to the multidisciplinary nature of the initiative that supports this research, we found some restrictions for the results for each research question while searching online libraries. As we search the literature for new SMS studies, we have only found a review addition to the traditional methodology (Caballero-Hernández, Palomo-Duarte, & Dodero, 2017). A new way to determine research questions for a systematic mapping study with diverse topics was proposed to overcome this problem (Fig. 2). This method starts with determining and grouping keywords to establish the research questions to obtain meaningful results from online libraries.

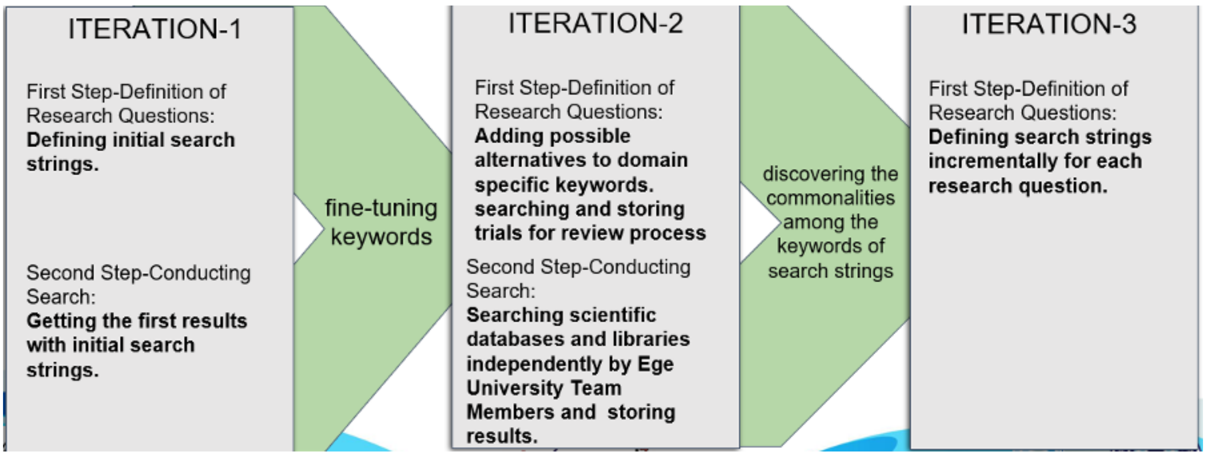


Fig. 2. Research Question Definition Process.

3.1.2. Constructing a decision graph for determining and grouping keywords.

Initially, we needed to determine the possible keywords for our project. Our project has three main pillars: *curriculum development*, *product life cycle management*, and *e-learning platforms*. These pillars and their synonyms are accepted as possible keywords. Moreover, project members have also defined candidate keywords from the project proposal. In this collaborative effort, we gathered two types of keywords: 1) metadata keywords (general), and 2) data keywords (project dependent), as shown in Fig. 3.

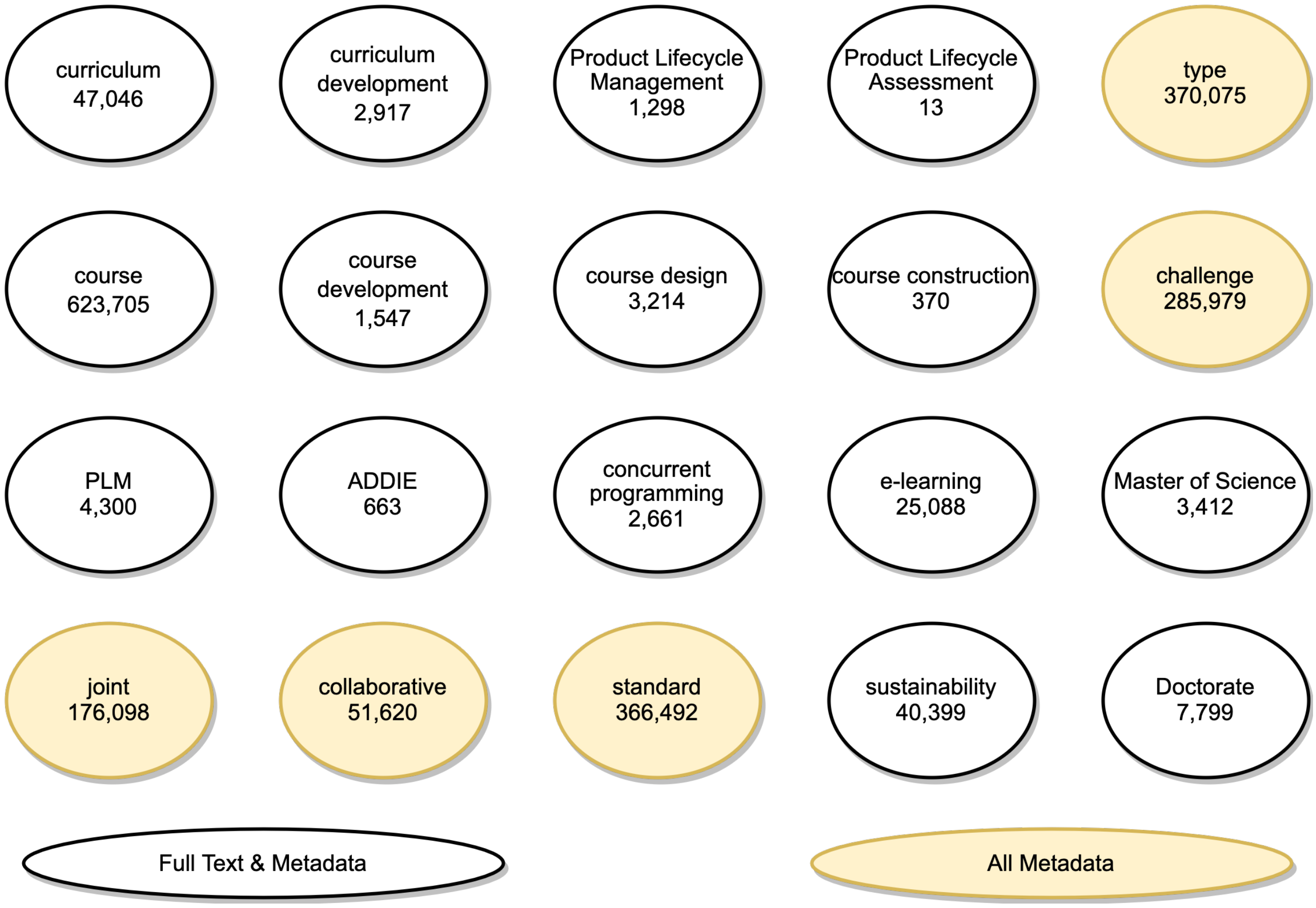


Fig. 3. Determined Keywords for the research.

Fig. 3 shows all the keywords that were considered for the systematic study in our project. Papers related to these keywords were searched inside the IEEE Xplore Online Library for testing purposes. The number of articles related to these keywords is shown at the bottom of every keyword. These numbers show the selectivity of the keywords. For example, a search with a combination of Analyze, Design, Develop, Implement, and Evaluate (ADDIE) and PLM keywords returns at most 663 possible articles. Thus, this search was restricted to the selectivity of the minor keyword in the sentence based on the number of related articles.

The first step of our proposal is to introduce how a decision graph can be constructed with the possible keywords and their connections. These connections are defined by the transformation of potential research questions into logical sentences linked with Boolean expressions, as shown in Fig. 4.

Three different topics were selected for this study (curriculum development, product life cycle management, and e-learning platforms). Different combinations of these keywords signify that the topics and related keywords are not always interconnected. For example, "curriculum development" and "collaborative keywords" are connected, but when "PLM" or "product life cycle management" keywords are added, the number of returned journal papers is reduced to very few articles. This disparity implies that the selection of keywords and search sentences must be altered accordingly to accomplish a useful systematic mapping study.

In the second step of our SMS, these keywords were grouped together to construct a decision graph. This grouping was conducted in two ways:

1. Definition of research questions by the domain experts.

2. Conducting the research questions from the most relevant keyword.

The first method is a top-down construction of research questions using the domain experts' candidate research questions. These candidate research questions reflect the actual goals to be searched in the literature. However, in a project with different topics, these kinds of questions must be optimized by the results from the online libraries selected. Each version of the keyword combinations extracted from the research question was used to query the online libraries. If the results from online libraries have enough papers to answer the research question, then this keyword combination will be selected for the library search. If there are not enough papers in the results, then the keyword combinations must be altered, Table 1. In our proposal, we defined three possible modifications for the keywords.

- Broadening: If the initial keyword combination does not produce enough literature results, then the keywords can be expanded and replaced with more general keywords in semantic taxonomy.
- Narrowing: This is the opposite of broadening; many available combinations can be restricted with more groupings or Boolean expressions.
- Alternating: Keywords in the combination are replaced with a synonym.

Table 1 shows examples of these modifications. A research question is determined by an expert to reflect the challenges of the project in which a SMS was applied. This question will then be broken down into its keywords, which are later combined to reflect the Boolean sentence of the research question. However, if the exact Boolean sentence of the research question has zero results from the literature, then the search sentence is useless in answering the related research question. To overcome this problem, we have altered this sentence by broadening the keywords, e.g., the question was broadened into the "*challenge AND curriculum AND e-learning*" sentence at the end of the process. One limitation of this process is that the number of results must be enough to answer the related research question. For each research question in our project, domain experts in the relevant subject were consulted.

Table 1. Research Question Adjustment Process

Research Question (Input)	**What are the research challenges of joint curriculum development for PLM master's degree courses in e-learning platforms?**
Keywords (Output)	Number of Results
challenge, research challenge, curriculum, curriculum development, joint curriculum development, PLM, Product Lifecycle Management, master degree course, PLM master degree course, e-learning, e-learning platform	
Search String (Output)	
"research challenge" AND "joint curriculum development" AND "PLM master degree course" AND "e-learning platform"	Ideal Search String → 0
challenge AND "joint curriculum development" AND "PLM master degree course" AND "e-learning platform"	Broadening Search String → 0
challenge AND "curriculum development" AND "PLM master degree course" AND "e-learning platform"	Broadening Search String → 0
challenge AND "curriculum development" AND PLM AND e-learning	Broadening Search String → 0
challenge AND curriculum AND PLM AND e-learning	Broadening Search String → 8
challenge AND curriculum AND PLM	Broadening Search String → 57
challenge AND curriculum AND e-learning	Broadening Search String → 2 913

The second method allows us to determine the research questions from the keywords with a bottom-up construction. In this method, there is no preliminary research question determined by an expert. Instead of the initial research questions, the keywords shown in Fig. 3 were used. The combinations of the keywords were gathered by an expert, and the results of this Boolean sentence from the online libraries were used to determine whether this search string was valid. If the domain experts think that the search string has enough results in online libraries, then a research question will be constructed using a combination of the keywords. This research question is then asked against the possible candidates from the online libraries by using the constructed Boolean sentence.

Table 2. Keyword combinations and an example of the constructed research question.

Research Question (Input)	**What are the research challenges of joint curriculum development for PLM master's degree courses in e-learning platforms?**	
Keywords (Input)		**Number of Results**
curriculum development, graduate course, e-learning		
Search String (Output)		
"curriculum development" AND "graduate course" AND e-learning		Ideal Search String → 6
curriculum AND "graduate course" AND e-learning		Broadening Search String → 40
curriculum AND graduate AND e-learning		Broadening Search String → 1,454
curriculum AND course AND e-learning		Broadening Search String → 4,519
Research Question (Output)	**What are the methodologies used for graduate course curriculum development in the context of e-learning?**	

Finally, research questions are merged into a graph structure by using their Boolean equivalents. In the decision graph, each Boolean sentence is represented within the chart. This transformation can be achieved by operators such as AND, OR, and NOT.

For our work, the selected Boolean sentences were merged into a decision graph with the picture shown in Fig. 4. The numbers inside the boxes represent the results of the Boolean sentences. The final decision graph shows the overall Boolean sentences of the systematic mapping study and helps reduce the number of keyword combinations.

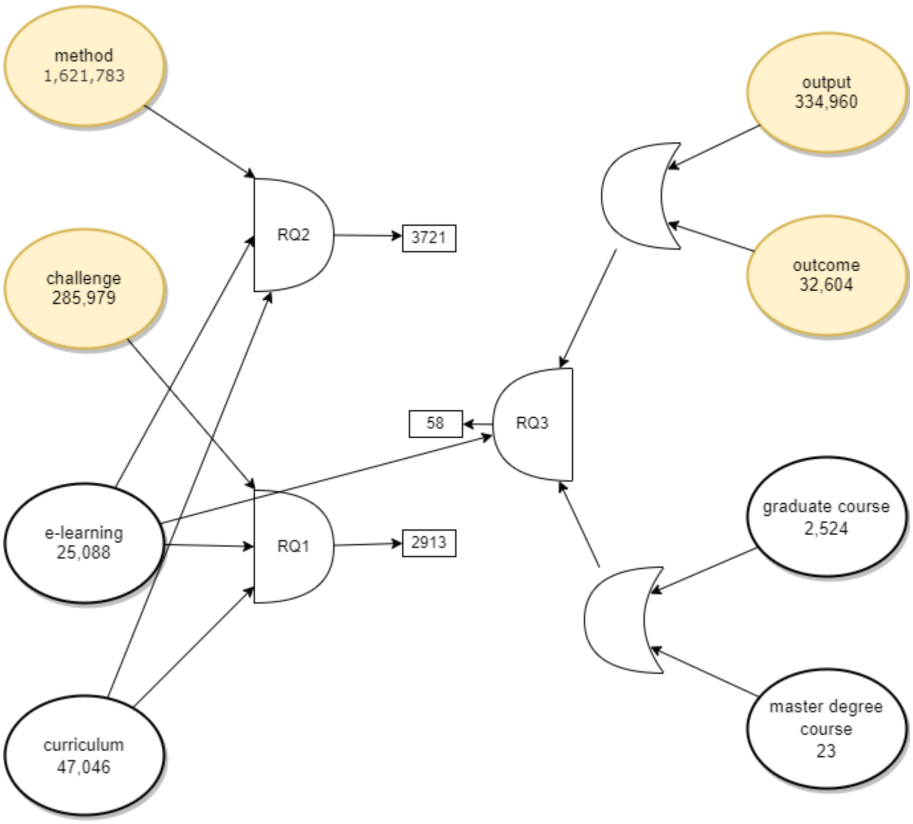


Fig. 4. All RQs in a Boolean Sentence Representation and Number of Results.

During the study, out of 35 research questions that were processed in this new methodology, only three research questions (RQs) remained in the final research question set. The elimination process was performed through two iterations. The reasons followed to eliminate RQs in the first iteration were ‘Ambiguous keyword’ (two repetitions in selected research questions), ‘Too general keyword’ (three repetitions), ‘Already included in another’ (five repetitions), ‘Included’ (seven repetitions) and ‘Unrelated question’ (eight repetitions). In the second iteration, the reasons were ‘Out of project scope’ (one instance), ‘Yes or no question’ (one instance), ‘Uncategorized’ (two instances) and ‘Included’ (three instances).

The three final defined questions were as follows:

- RQ1: ***What are the research challenges of joint curriculum development for master’s degree courses in PLM on e-learning platforms?***
- RQ2: ***What are the methods of joint curriculum development for master’s degrees on e-learning platforms?***
- RQ3: ***What are the outcomes of master’s degree courses in PLM on e-learning platforms?***

The result set from the online libraries for each research question is empty for the ideal Boolean search sentence. As described above, these Boolean search sentences were corrected with these sentences.

- RQ1: challenge AND curriculum AND e-learning
- RQ2: method AND curriculum AND e-learning
- RQ3: (outcome OR output) AND ("master degree course" OR "graduate course") AND e-learning

3.2. Searching.

Searching the selected online libraries with the defined search strings is not an easy task. This task was conducted with a collaborative effort of the Intellectual Output 1 (IO1) Working Group focused on the Systematic Mapping Study on e-learning platforms. The group members agreed to use five different online libraries for searching. The number of articles for this search achieved a total of 65,650 for RQ1, 89,524 for RQ2, and 2,443 for RQ3.

3.3. Screening.

A review of the search results was performed to complete the systematic mapping study. Although systematic mapping studies have been performed in the literature with a collaborative effort of two or three members, the review process in this research was conducted with a collaborative effort of five members. Thus, the distribution of the workload and management of the collaboration was handled well. To achieve this goal on time and complete the IO1 tasks, a new collaboration methodology was defined.

3.3.1. Inclusion/Exclusion Criteria.

The review process will start with the definition of inclusion and exclusion criteria. These criteria will be applied to the search results and used to narrow the search results for processing. Although these criteria mostly depend on the experts conducting systematic mapping studies, there are generally acknowledged criteria in the literature for systematic mapping studies. Criteria such as year and post type restrictions were used to limit search results. On the other hand, reviewing is a dynamic process. As seen in Fig. 5, the process is updated by the reviewers to reflect the selection criteria based on the followed “*think-aloud*” process among different universities.

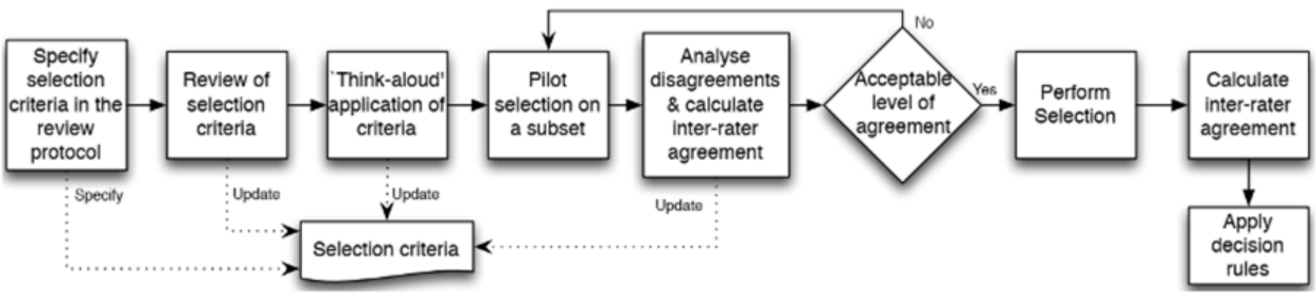


Fig. 5. Selection Process (source: Petersen, Vakkalanka, & Kuzniarz, 2015)

Based on the results of the preliminary study and discussion among the IO1 working group, we have accepted the following results from online libraries:

- Published in journals
- Published between 2012 and 2021 (ten years)
- Published in English

The results of each criterion can be seen in Table 3. The number of related articles for each research question and every criterion can be seen in each column. The "Total" column represents the numbers of articles matching all criteria.

In the next iteration of the reviewing process, IO1 working group members revised the elimination criteria and added two more criteria for reviewing:

- Published between 2016 and 2021 (5 years),
- First 5,000 most relevant results from the online libraries.

Although these criteria have lowered the number of results, they have covered the most relevant and popular articles from the literature for the reviewing process.

Table 3. Exclusion Criteria on Results

	Search Results	Date Exclusion Criteria	Language Exclusion Criteria	Article Type Exclusion Criteria	Total	Total with five-year Criteria
RQ1	65,650	41,529	23,319	29,821	19,319	7,890
RQ2	89,524	53,587	29,662	45,968	27,902	10,229
RQ3	2,443	1,375	784	1,310	728	524

3.3.2. Combining Review Results

Unlike the existing methodologies in the literature, combining the review results is not an easy task in the project. Partners of the project not only come from different research backgrounds but are also geographically separated from each other. To overcome these obstacles, we defined grouping techniques to apply a systematic mapping study review process, as seen in the algorithm in Fig. 6.

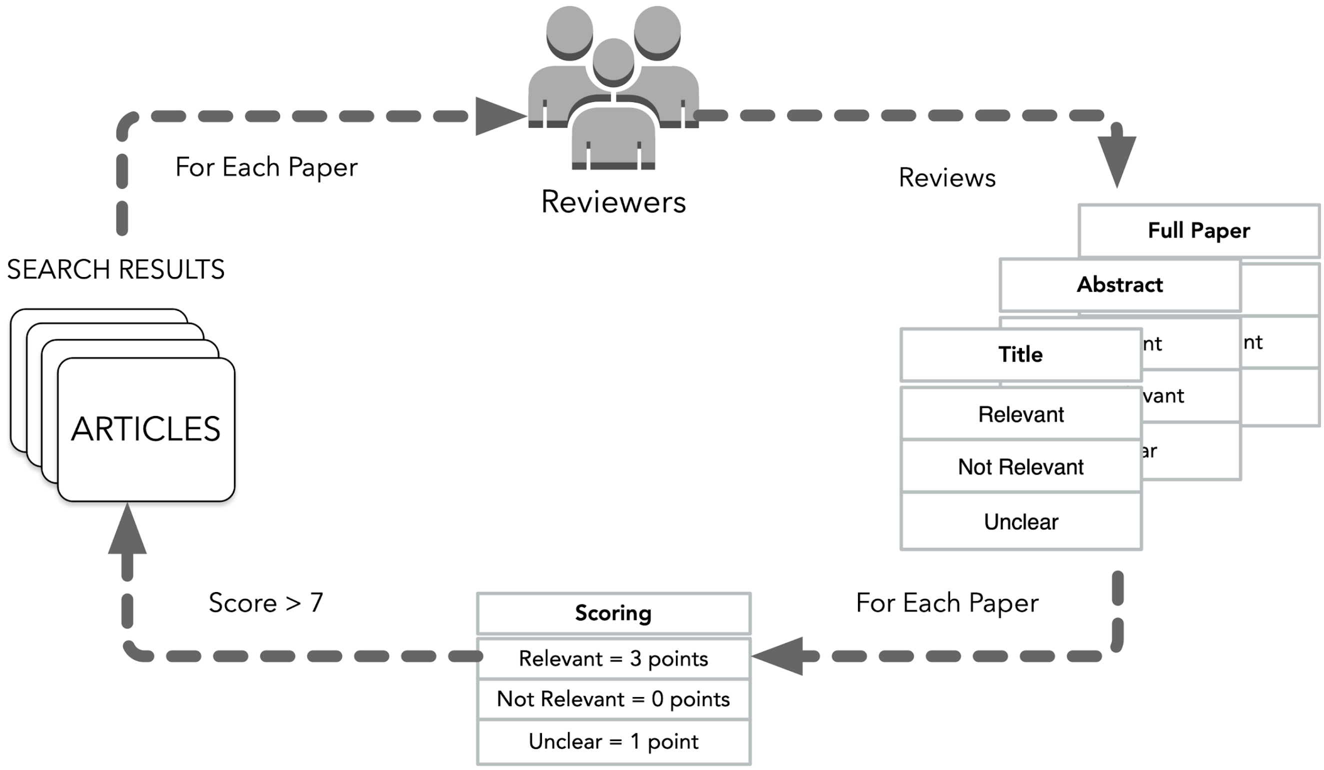


Fig. 6. Review Results Combination Algorithm

3.4. Review Results

All members of the IO1 working group reviewed all the relevant articles, and they have progressively eliminated these articles based on their title, abstract, and full content. As the reviewing process, even when reading just the title, took so much time, the IO1 working group decided to reduce the number of articles to be reviewed to just cover the literature for each research question:

- First 500 results from online libraries

The figures of each elimination for each online library can be seen in Table 4. For research question 1 (RQ1), 2,178 relevant articles were narrowed down to 25 articles based on their title and abstract. Similarly, for RQ2, 2,203 articles were narrowed down to ten articles, and for RQ3, 1,080 articles were narrowed down to only one article.

Table 4. Reviewing Results

	Number of Articles	Number of Articles with New Elimination Criteria	Review Results Based on Title	Review Results Based on Abstract	Review Results Based on Paper
RQ1	7,890	2,178	83	25	12
RQ2	10,229	2,203	27	10	4
RQ3	524	524	5	1	1

The abstract review results were split equally for each reviewer. Consequently, 36 papers were reviewed by reading the entire paper and summarized based on the template that the IO1 working group had agreed upon. This summarization template contains the following information: *keywords, main topic of the paper*, *key points regarding the research questions*, and some *technologies* that can be related to the project. At the end of this process, each paper was discussed among the IO1 group members, and in total, only 17 papers were selected to answer the research questions.

3.5. Data Extraction.

As the final set for each research question was determined in the screening step, keywording and categorization were considered to reveal the aspects of the topic and answer the research questions.

3.5.1. Keywording.

In this paper, keywording was not limited to only the author's keywords. In the summarization template, reviewers also define new keywords to describe each relevant paper in addition to the author's keywords. At the end of the reviewing process, in addition to 65 author keywords, reviewers also identified the papers in the RQ1 final set with 45 more keywords. Thus, in the keywording process, we used 110 keywords in total to reveal the most important keywords for each research question and topic. We categorized the most important keywords for each research question within the proposed systematic mapping study.

As seen in Figure 7, the most important keywords for RQ1 are *e-learning*, *learning objects*, and *project-based learning* keywords. This result shows that the keywords identified by the authors and reviewers are related to e-learning and e-learning objects mostly used in project-based learning. In addition to this statement, curriculum development and digitalization are also important features to describe the works in the final set of RQ1.

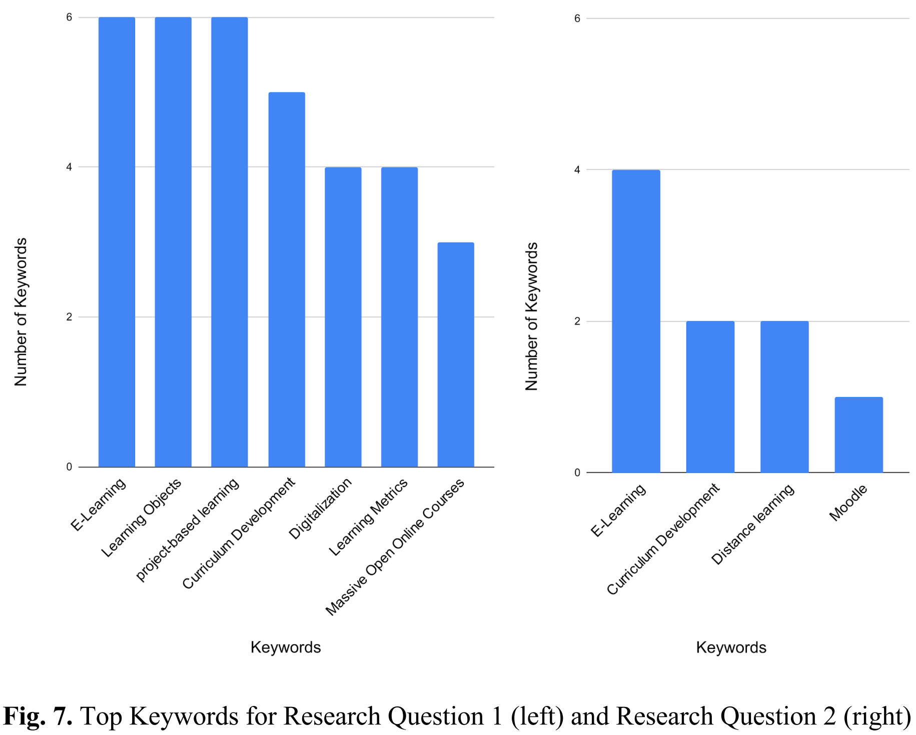


Fig. 7. Top Keywords for Research Question 1 (left) and Research Question 2 (right)

For RQ2, keywording was conducted for four articles in the final set. Reviewers decided to add ten more keywords to the set of 17 keywords that the authors were using to describe their own articles. From the final set of 27, the most common keywords were e-learning, curriculum development, and distance learning, although the keywords in the final set for RQ2 were very diverse.

Since there was only one article relevant to Research Question 3, its keywords were not used.

In conclusion, the keywording concluded with merging all keywords in each research question of the final set. The final set of keywords in Fig. 8 shows that e-learning is the most important keyword for describing ongoing project curriculum development and that learning objects are ranked third.

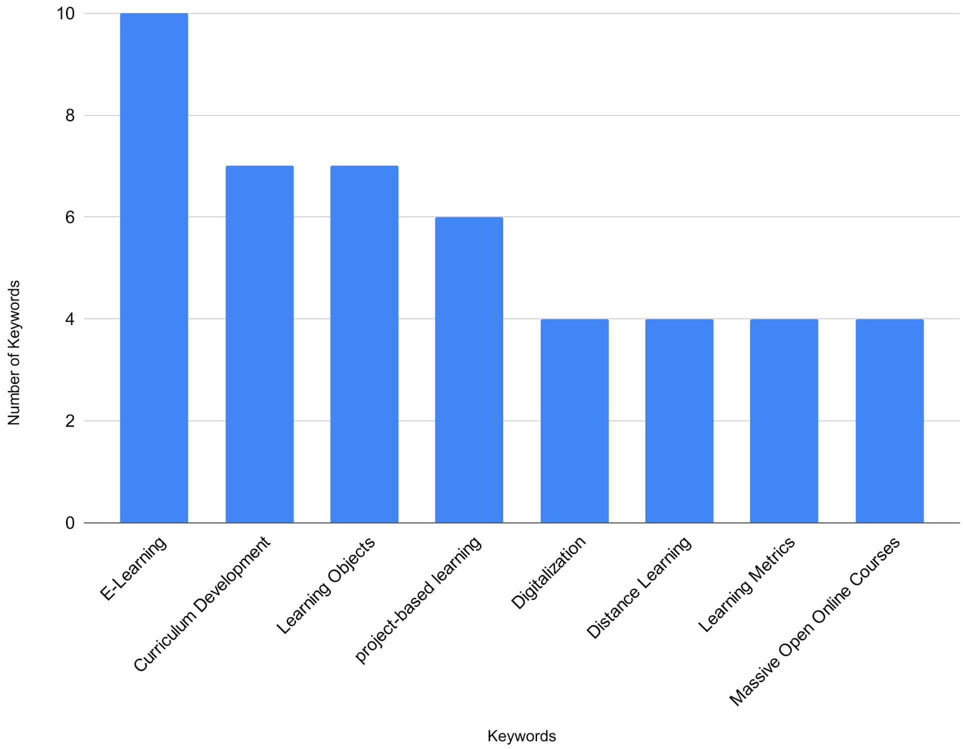
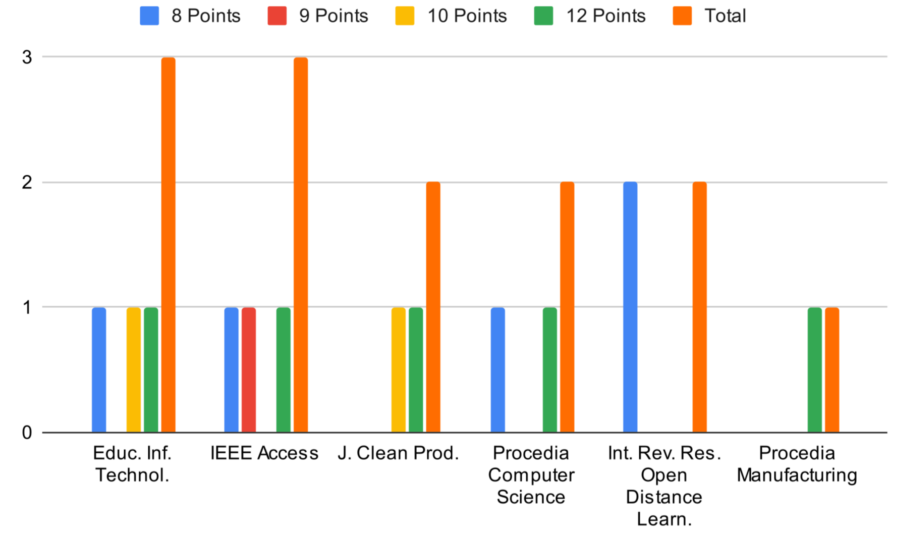


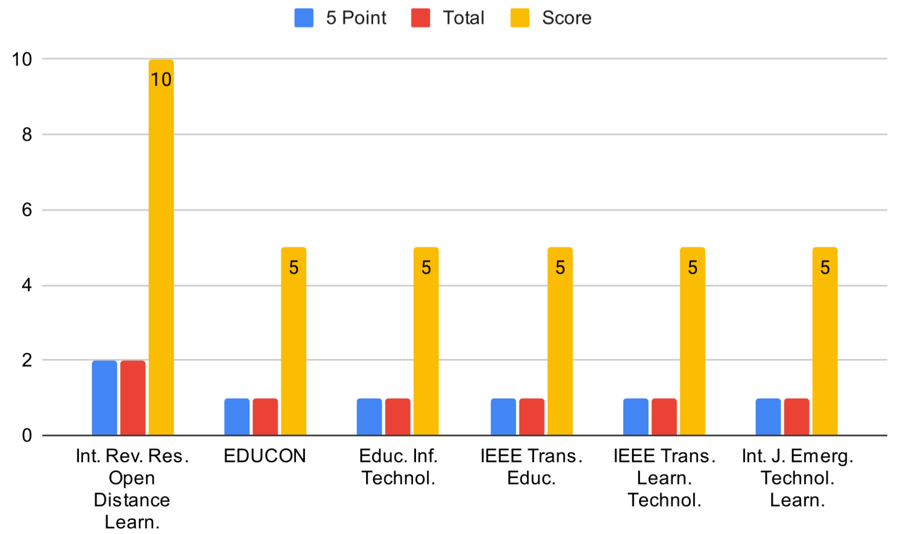
Fig. 8. Top Final Set Keywords

3.5.2. Categorization.

For the 17 papers in the final set, categorization was conducted with three aspects, where the first categorization metric is the venue. Categorization was altered with the help of the scores (see Fig. 9 Calculation of Article Score given by the reviewers in the reviewing process). Figure 9 and Figure 10 show the most selected venues and their review scores for abstract reviews and paper reviews.



a)Venues and Scores in Abstract Review

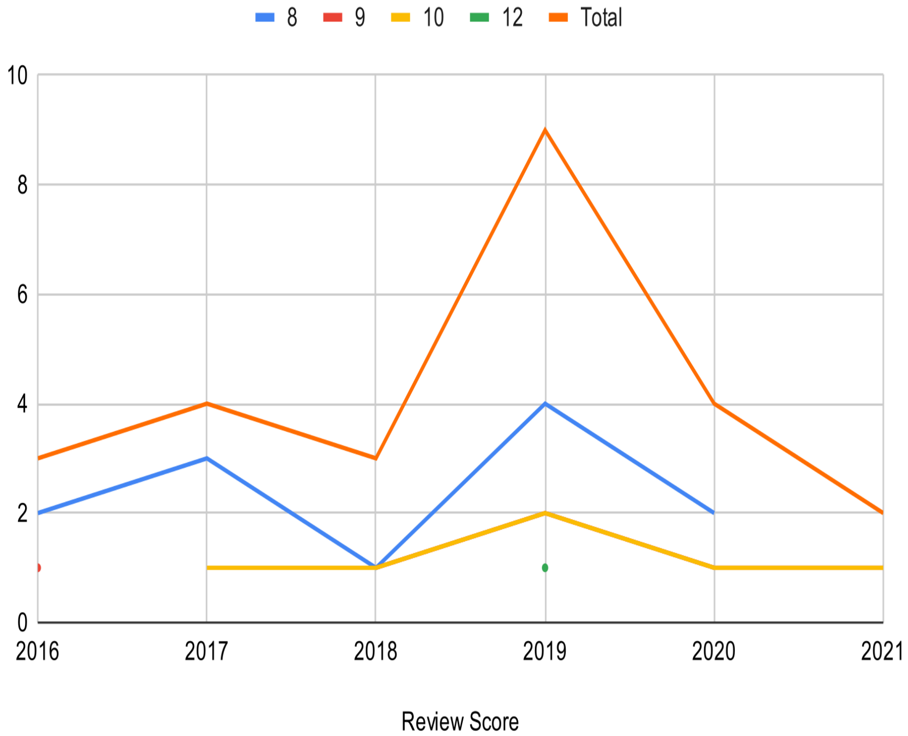


b)Venues and Scores in Final Review

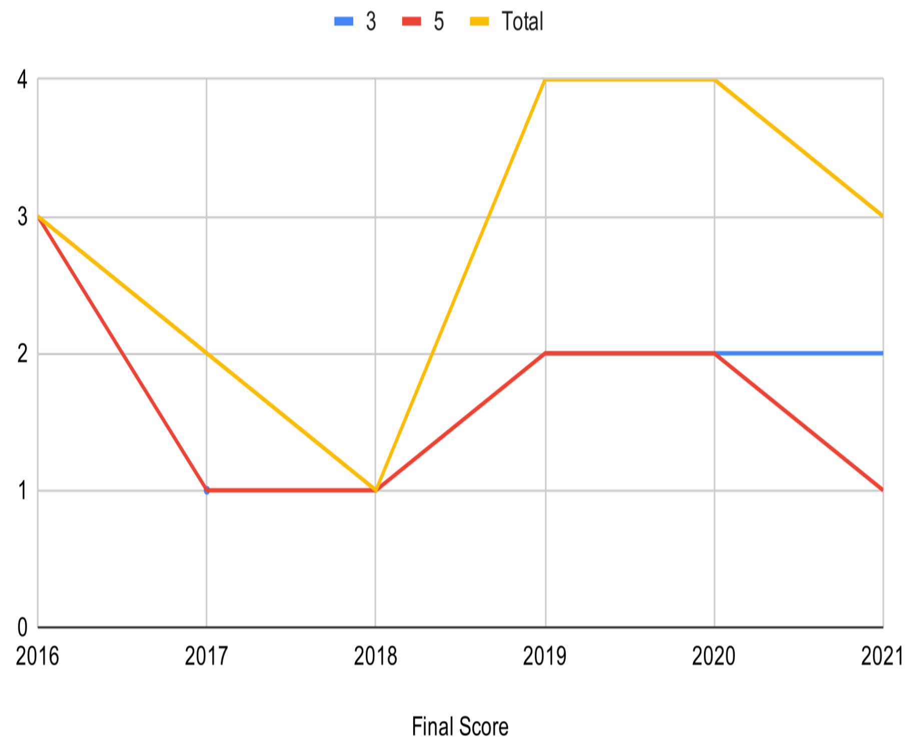
Fig. 9. Venues and Scores in the abstract and final paper review

As seen in Figure 9a, in addition to the total scores of each venue (orange bar), we gave the number of scores for each venue in blue for eight points, red for nine points, yellow for ten points, and green for twelve points. Even though Education and Information Technologies and IEEE Access journals are the most relevant venues after the abstract review process, this changes in the full paper review, as seen in Figure 9b. The final set of systematic mapping studies shows that the most important venue is the International Review of Research in Open and Distance Learning. There are eight second-place venues, which are mostly engineering venues with addition to the intersection of education and engineering.

The second categorization was performed with the trend. By mentioning trends, systematic mapping studies aim to show the importance of the topic and where the topic is progressing. As seen in Figure 10, for abstract review and paper review sets, the trends show that the important year in this topic was 2019. When reviewing papers from 2020 and 2021, the number of selected articles decreased.



a) The Trends based on Abstract Review



b) The Trends based on Final Review

Fig. 10. Trends based on Abstract Review and Paper Review.

Challenges, which are the third categorization, was performed with the answers for each research question based on the final set. To answer the first RQ, its final set was examined to extract the research challenges in collaborative curriculum development for a PLM master's degree program. The categories of challenges extracted from each paper can be seen in Fig. 11. The final set of papers was categorized based on the research challenges specified in each paper. The categories are mostly based on education. Assessing the outputs in a course and tools to be used in master's degree courses in PLM was found to be a challenge in the eight papers. In addition, the competence of the educators was found to be a challenge in five studies. Four papers found the content of the courses and curriculum to be a challenge in collaborative curriculum development. Only two papers identified the clarification of roles in an e-learning system as a challenge. However, the methodology to create a collaborative curriculum was found to be a challenge in 17 journal papers.

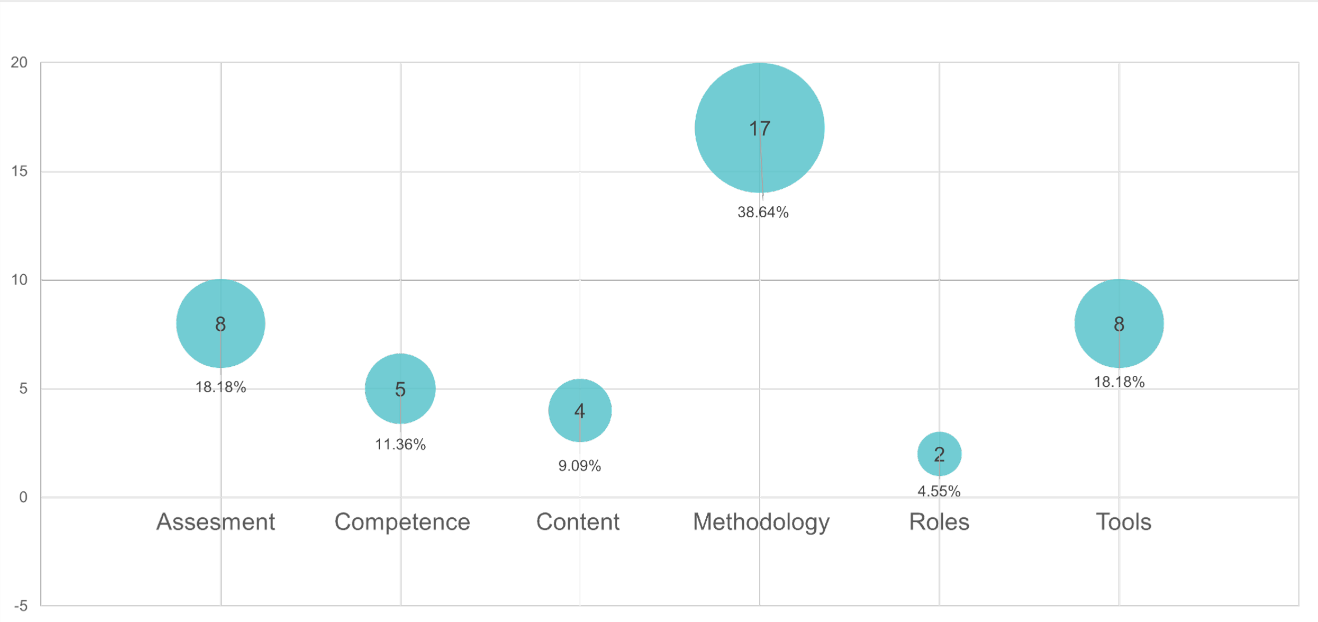


Fig. 11. Categories of Challenges.

The final set of RQ1 shows that the challenges in collaborative curriculum development for PLM master's degree courses are mostly in determining the appropriate methodology (Figure 11). On the other hand, the results of the literature show that the right tool to create this curriculum and assess the outputs of this curriculum are equally important to develop the appropriate collaborative curriculum methodology. In addition, only two papers found that determining the right role for developers in this process is a challenge in this research area.

As the results of RQ2 show, the methods to create a collaborative curriculum in master's degree courses have not yet been revealed in detail in the literature. The final set of RQ2 shows that half of the papers in the last group revealed some methodology for curriculum development. However, nearly a quarter of the final group used different approaches to develop these methods. Only 15% of the last set revealed a model for curriculum development. Two papers used roles in the methodologies, and only one paper used reasoning to develop the collaborative curriculum.

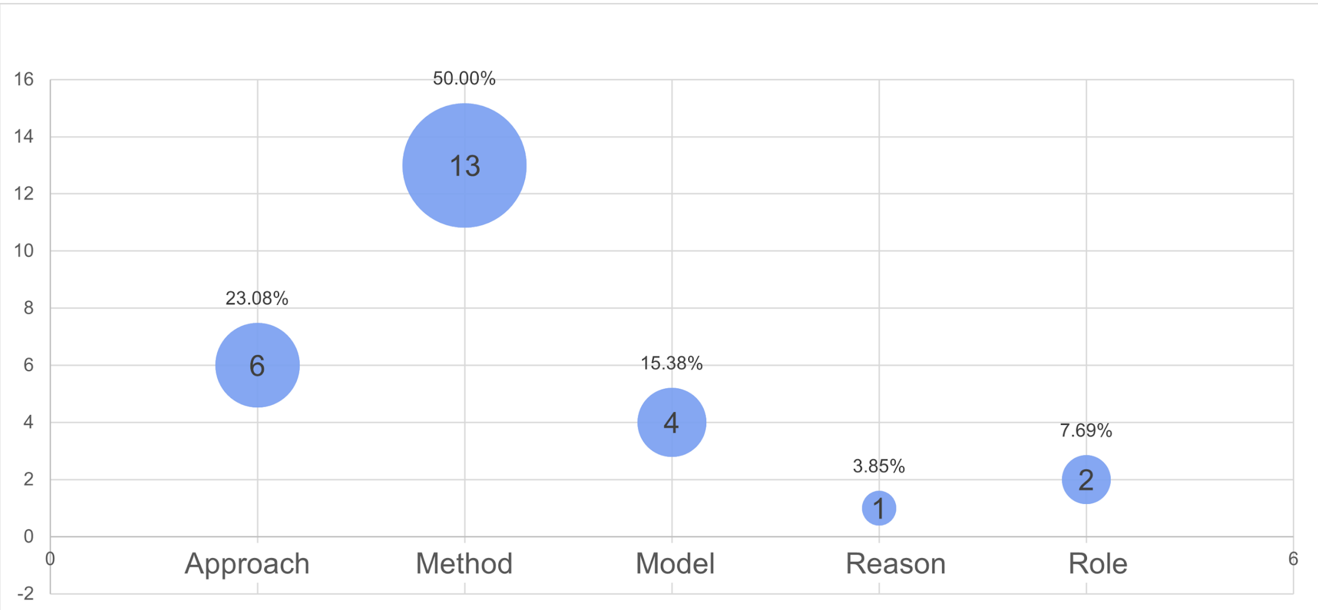


Fig. 12. Categories of Collaborative Curriculum Development Methods.

4. Results and Discussion

As we have seen, curriculum development in an e-learning environment is an emerging area in education. Engineering disciplines and their collaborations, such as PLM, need a solid curriculum to meet the standards of different fields. These standards come with the challenges that researchers must keep in mind to succeed in creating a collaborative curriculum for master's degree education programs.

The results of RQ1 show that challenges are widely categorized among different engineering disciplines. Each challenge in each paper can be categorized based on their referred types. In the RQ1 results, which are shown in Figure 11, we have organized the types of challenges, 38.64% of which are about the methodology to create a curriculum. Other challenges are categorized as tools to develop the curriculum and the ways to generate an assessment for these PLM-related master programs. From the results, we can see that 9.09% of the challenges categorized pertain to the content of the curriculum. All four challenges are mainly about the properties of the program. However, two different challenges are listed as competence, and roles are about the people who are responsible for executing this curriculum. The results show that 11.36% of the challenges in the literature are categorized as the competence of the professionals. This is followed by the proper distribution of the roles in an e-learning environment as 4.55%.

As seen from the results, all the categorized challenges listed in RQ1 are about e-learning environments and their use. These results show that creating a successful curriculum in a PLM master's program requires selecting the right professionals to run the platform and then choosing the suitable methodology for collaboration. We can also conclude that there is a significant gap in the literature in this research area because there is not an available collaborative curriculum between industry and universities.

The purpose of RQ2 is to list the methods by which a collaborative curriculum can be achieved. As the literature search was conducted and the result set was obtained, this study showed that the ways to create a curriculum are not clearly explained. The methods, which are described as bottom-up and top-down approaches, have strong ties with professionals' experiences. As seen in Figure 12, almost half of these approaches are methods to develop a curriculum; however, only 15.38% of the guidelines define a transparent curriculum model. For example, 23.08% of the results defined an approach to create a curriculum but not a model. Nevertheless, these methods are mostly created for bachelor's degrees. Moreover, they do not mention any connection to any e-learning platform in their methods. These results show that there is indeed a huge gap in the literature in terms of methodology and model for engineering programs to establish a collaborative curriculum.

In addition to the absence of a curriculum in this area, a method to develop this curriculum collaboratively has not been clearly defined. The SMS results show that there lacks a detailed and clear curriculum development methodology in the engineering literature. While there are some proposed methods to develop a curriculum, they are geared toward bachelor's degrees and do not meet the standard for collaborative effort in a master's degree course.

On the other hand, the results of RQ3 show that if the topic specializes in the curriculum outcomes of a PLM master's degree, then there is no research to answer this question. Even though the SMS covers 524 journal papers from the top five online databases for RQ3, after the elimination process, only one relevant journal paper was found.

The reason for this result is that the topics of RQ3 are diverse enough to find an intersection in the literature. Even though e-learning and PLM topics are related, curriculum or curriculum development is very selective in answering RQ3. This means that RQ3 is very complex, and an answer to this question is unreachable by using the literature. In conclusion, there is potentially a new research topic that our project outputs could cover.

Keywords were extracted from each paper and grouped into research questions and a full set. Moreover, we used the candidate keywords from the reviewers to enrich the keyword set upon their summarization. For RQ1, e-learning, learning objects, and project-based learning are the most used keywords from the reviewers and authors of the RQ1 final set. Challenges of collaborative curriculum development in PLM master's degree courses are mostly about e-learning and objects in an e-learning environment. In addition, project-based learning is the methodology for learning in the RQ1 final set. The top keyword of the RQ2 final set is e-learning. This shows that the methods for collaborative curriculum development are in an e-learning environment. As RQ3 has only one paper in its final set, keywording was not conducted for this question.

In terms of the popularity of the topic and venues, the International Review of Research in Open and Distance Learning journal and 2019 are the most promising venue and year from our final set, respectively. This behavior reinforces our decision to limit the revisions until five years ago. We divided the results into two groups: abstract review and full paper review. The reasoning behind this is that the results have changed dramatically with the full paper review. Since we expanded the SMS with reviewer scoring, the results are shown with their scoring in each categorization of venue and popularity measures. The venue results of the abstract review show that Education Information Technology and IEEE Access are the most valuable journals on the SMS topic. Both have three papers in the abstract review set. However, in terms of scoring, Education Information Technology had better scores from the reviewers. This particular case shows that the addition of the scoring to the venue categorization gives better diversity to the results. Although the International Review of Research in Open and Distance Learning journal was the fourth journal in abstract review, 75% of the journal's papers were selected for the final set. In terms of popularity over the years, 2019 was the best year to publish an article on the subject of SMS. However, the downward trend in 2020 is explained by many potential reasons. The COVID-19 pandemic may have affected the volume of paper submission. Lectures regarding the PLM and related subjects need laboratories for better review, both of which may have been delayed by the pandemic.

5. Conclusions and Future Work

This study explores the research work conducted within the relation between product life cycle management, curriculum development, and e-learning platforms on the scientific literature published in the last five years.

The search and results evaluation were guided by an expert group in these subjects. Thus, formulation of the research questions answered by the SMS (Systematic Mapping Study) was wide but also focused on the knowledge field object of study.

Collaborating on the SMS allowed us to review a large number of articles in less time. Establishing a scoring method for the items reviewed is evidence of the importance in collaborating throughout the process. In the first iterations in which the titles and abstracts were reviewed, we detected some cases in which any of the reviewers gave a low score for the corresponding article; nevertheless, the other reviewers scored them differently because they sensed some interest. We must keep in mind the different backgrounds of the reviewers; they specialize in research in different scientific fields. This way of proceeding allowed us to keep some articles that were not that relevant; however, under one particular criterion, they did end up being relevant. On the other hand, scoring also improves the results of each research question.

Although SMS uses reviewers to include or exclude each journal paper from the final set, there is no systematic way of combining this process with the others. This work defines an algorithm to combine each reviewer's decision to distinguish relevant papers for the final set to improve the results of the SMS. In our work, this improvement can be seen clearly. Scoring has dramatically improved the results on the venue and the trends.

One of the problems that we can find with the application of the SMS methodology, where several topics are combined, is the significant influence on the final results of the item less developed by the researchers. However, this is evidence of a gap to be covered. As is the case of RQ3, the outcomes for PLM master's degree courses using e-learning platforms are still pending subjects. This may be because of the novelty of the issue.

Having adjusted the keywords and the use of the agreed exclusion criteria through the methodology proposed has allowed refining the search to manageable quantities. In the final stage of this research, the full review of the remaining papers was divided among the experts, speeding up the process. The results of these revisions were stored in different documents using a template that collects the elements of interest for each RQ.

These results enable us to start the research project with a solid foundation about the state of the art and the achievements of other researchers. Through the final results, we can make a categorization, where the first categorization metric is the venue. Indexed journals were the most important venues. The second categorization was trend, where the important year in this field was 2019. In the third categorization, for the answer of the research questions, we can conclude that the main challenges are the *assessment outputs*, *the tools to be used*, *the competence of the educators*, *the content of the course,* and *the curriculum*.

The methods used to create a collaborative curriculum using e-learning platforms are mainly based on some methodology, but these methodologies are not described in detail. This is another gap to be covered by the project in the later stages.

The results of this SMS encourage us to address the deficiencies detected, focusing on a PLM master's degree course, where the use of e-learning tools seems to be particularly suitable.

For the collaborative review, a common template was prepared to store the relevant results of each paper. Categorization from these templates requires a narrowing of all the results into a single file. In future work, it could be interesting to automate this process. It could also be interesting to have all the results of all the papers narrowed down to a single document from which automate the categorization process and the way the results are shown.

Another important point to improve is the iterative process used by the reviewers to adapt the research sentences using Boolean operators. A methodology can be developed to propose changes and to test the relevance of those changes made in the searches.

Authors' contributions All authors contributed to the study conception, methodology, formal analysis, investigation and writing-Reviewing and Editing. The first draft of the manuscript was written by [Corresponding Author]. All visualizations are done by [Corresponding Author]. All authors read and approved the final manuscript.

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Data availability Data sets used and/or analyzed during the current study are available from the corresponding author under reasonable request

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose. The authors have no competing interests to declare that are relevant to the content of this article. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or nonfinancial interest in the subject matter or materials discussed in this manuscript. The authors have no financial or proprietary interests in any material discussed in this article.

Ethical statement We herby declare that this manuscript is the result of our independent creation under the reviewers' comments. This manuscript does not contain any research achievements that have been published or written by other individuals or groups. We are the only authors of this manuscript. The legal responsibility of this statement shall be borne by us.

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6. Annexes

Curriculum
46.944
Curriculum Design
2446
PLM OR Product Lifecycle Management
3
Joint OR Collaborative
955
Metadata: type
44
PLM OR Product Lifecycle Management
3
Challenge
622
PLM OR Product Lifecycle Management
89
E-Learning
102
Curriculum Development
2915
PLM OR Product Lifecycle Management
5
Joint OR Collaborative
1183
PLM OR Product Lifecycle Management
4
Challenge
762
PLM OR Product Lifecycle Management
2
E-Learning
119
PLM OR Product Lifecycle Management
0
Metadata: type
38
PLM OR Product Lifecycle Management
89
ADDIE
157
Concurrent Engineering
264
Course
622.676
Course Development
1546
Joint OR Collaborative
655
Metadata: type
24
PLM OR Product Lifecycle Management
1
PLM OR Product Lifecycle Management
2
Challenge
427
PLM OR Product Lifecycle Management
0
Course Design
3210
Joint OR Collaborative
1262
Metadata: type
63
Challenge
862
PLM OR Product Lifecycle Management
2
PLM OR Product Lifecycle Management
2
PLM OR Product Lifecycle Management
2
Challenge
427
PLM OR Product Lifecycle Management
0
Course Construction
368
Joint OR Collaborative
101
Metadata: type
3
Challenge
54
PLM OR Product Lifecycle Management
0
PLM OR Product Lifecycle Management
0
PLM OR Product Lifecycle Management
1
ADDIE
344