# Exploring eXtended-Based Learning Approaches in Portuguese Higher Education: A Study in Industrial Engineering and Management

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**Abstract**

This paper presents a comprehensive study of what is named in this study as eXtended-Based Learning (xBL) approaches within the Portuguese educational landscape, including Problem-Based Learning (PBL), Project-Based Learning (PjBL), Challenge-Based Learning (ChBL), Service-Based Learning, and others. The study will contribute to characterizing different approaches being implemented by educators in Industrial Engineering and Management (IEM). Data was collected through the official website information about the curricular plans of IEM programmes, a survey by a questionnaire to universities (public and private) and polytechnic institutes that manage programmes in Industrial Engineering and Management and semi-structured interviews with six Industrial Engineering and Management educators. The interviews explored the educators' experiences, perceptions, and challenges in implementing these pedagogical approaches. With a particular focus on xBL approaches, the study explored the factors contributing to the successful implementation of xBL approaches, including institutional support, resource allocation, and institutional culture. This study intended to promote future investigations into the challenges and significance of educator training and the impact of training initiatives on teaching effectiveness and student learning outcomes. By highlighting each approach's unique characteristics and pedagogical benefits, this study provides educators and other stakeholders valuable insights for informed decision-making and effective implementation in different learning environments. Ultimately, the study contributes to the continuous improvement of pedagogical practices in Industrial Engineering and Management education in Portugal.

**Keywords:** Engineering Education; Industrial Engineering and Management; Active Learning; Project Based Learning; eXtended Based Learning.

## 1. Introduction

Students' generations evolve, and what seems to be enough for the previous (seating and hearing the teacher lecture in a classroom) does not seem enough for Generation Z, who are accustomed to the digital and technological world. At the same time, if they want to learn, they know at their fingertips and count on powerful generative artificial intelligence (AI) tools such as ChatGPT (Majeed & Hwang, 2024).

In light of these changes, Higher Education Institutions (HEIs) deal with many challenges and, in particular, Engineering Schools that must continue preparing the future engineering workforce for a volatile, uncertain, complex, and ambiguous (VUCA) world that conducts to a brittle, anxious, non-linear, and incomprehensible (BANI) world (Figueiredo, 2023). According to this author, students need skills like autonomy, leadership, curiosity, initiative, grit, resilience, creativity, teamwork, mindfulness, adaptability, empathy, critical and design thinking, and social sense to be prepared for this world. These are included in the needed competencies and skills reported by many organisations (Autodesk & ASME, 2022; Council of the European Union, 2018; Sala et al., 2020; World Economic Forum, 2015, 2018, 2022; World Manufacturing Forum, 2019). The key competences throughout life, according to the Council of the European Union (2018, p. 15), are: 1) Literacy; 2) Multilingual; 3) Mathematical, science, technology, and engineering; 4) Digital; 5) Personal, Social, and Learning to Learn; 6) Citizenship; 7) Entrepreneurship and; 8) Cultural awareness and expression.

Nevertheless, teachers need to use suitable pedagogical approaches for the students to develop such competencies. Figueiredo (2023) considered there are six new generation pedagogies: 1) explanation, 2) empowerment, 3) projective, 4) socialization, 5) drill, and 6) exploratory. According to this author, the first category, which includes traditional lectures, is overvalued, and the remaining five are undervalued or ignored. This categorization is also related to the one adopted by many authors that considered passive vs active learning methodologies, being "passive" mainly characterized by lectures (Bonwell & Eison, 1991; Felder & Brent, 2006; Felder & Silverman, 1988; Freeman et al., 2014; Lima, Andersson, et al., 2017; Prince, 2004).

In the context of active learning, it is possible to consider many approaches. For a description of several approaches, see, for example, Lima et al. (2024, p. 19). Active learning creates an environment for students to be creative, constructive, innovators and agents of their learning through an education that is continuously evolving from Education 1.0 to Education 5.0 (Alharbi, 2023; Chea & Huan, 2019; Costan et al., 2021; Dervojeda, 2021; Gerstein, 2013; González-Pérez & Ramírez-Montoya, 2022; Gowripeddi et al., 2021; Miranda et al., 2021). Many of these methodologies were referred to as X-based learning (Pecore, 2015, p. 160): case-based learning, community-based learning, game-based learning, passion-based learning, service-based learning, and team-based learning. Considering the specific case of project-based learning, this can take several forms or a combined form of designing and/or creating a tangible product, performance, or event, solving a real-world problem (may be simulated or fully authentic), and investigating a topic or issue to develop an answer to an open-ended question (Larmer, 2015).

This paper focuses on a subset of approaches referred to by Pecore (2015) that are more common in the context where the study was developed: Problem-Based Learning (PBL), Project-Based Learning (PjBL), Challenge-Based Learning (ChBL), Service-Based Learning, Case-Based Learning (CBL), Game-Based Learning, and Team-Based Learning. Inquiry-Based Learning (IBL) and Retrieval-Based Learning (RBL) were also considered since they can be included in different active learning methodologies in various ways, namely in the PBL and ChBL approaches (Friesen & Scott, 2013; Lechuga et al., 2024). Thus, this work aims to contribute to the characterization of different approaches implemented by educators in Industrial Engineering and Management (IEM) in Portugal by studying their practices.

This paper is organized into five sections. The first section introduces the context and objectives of the paper. Section two presents the study context. Section three presents the materials and methods used. The fourth section presents the results and discussion. The last section draws some conclusions.

## 2. Study context

The Portuguese Industrial Engineering and Management (IEM) programmes define the scope of the context of the study. This interest emerged as IEM educators at the University of Minho have applying Project-Based Learning since 2004 (Alves et al., 2020; Lima, Dinis-Carvalho, et al., 2017; Lima et al., 2007). The way they apply is different according to the curricular year and is constantly evolving, involving some or all courses, involving a company or not (Alves et al., 2019, 2012, 2017, 2023; Alves, Sousa, Fernandes, et al., 2016; Alves, Sousa, Moreira, et al., 2016; Alves & Leão, 2015; Lima, Dinis-Carvalho, et al., 2017; Sousa et al., 2023).

This experience empowered the authors to build a collaborative learning community around active learning approaches focused on solving open-ended problems. This community project was funded by Centro-IDEA-UMinho (https://idea.uminho.pt/pt/apoio-a-projetos/Paginas/default.aspx). Within its aims and actions, the Centre IDEA-Uminho supports Teaching & Learning Projects at the university that stimulate innovation and quality in teaching practices that benefit student learning. With this community, the authors expected to mobilize a group of teachers who have been developing Project-Based Learning (PBL) activities in engineering

and extend it to all areas of the university and beyond who show interest in xBL approaches. Ideas are also expected to be shared, and these teaching/learning methodologies will be disseminated among the academic community. In this context, the authors are interested in understanding what other IEM colleagues are applying in the same field, as the competencies to be developed in each programme should be the same ( Lima et al., 2012; Lima et al., 2013; Mesquita et al., 2015). Based on a search on 30 March 2024, 18 Higher Education Institutions (HEIs) (universities and institutes) offer IEM programmes in Portugal. They are in Table 1. All of these programmes are first-cycle programme of three years (six semesters), corresponding to 180 European Credit Transfer System (ECTS). The second cycle corresponds to two years and 120 ECTS (four semesters).

Table 1. Portuguese institutions with IEM degrees

| Institution (name in Portuguese) | 1st cycle | 2nd cycle | Link |
|---|---|---|---|
| Instituto Politécnico do Cávado e do Ave | Yes | Yes | https://est.ipca.pt |
| Instituto Politécnico de Bragança | Yes | No | https://portal3.ipb.pt |
| Instituto Politécnico de Castelo Branco | Yes | No | https://www.ipcb.pt/estcb |
| Instituto Politécnico de Leiria | Yes | No | https://www.ipleiria.pt |
| Instituto Superior de Engenharia de Coimbra | Yes | Yes | https://www.ipc.pt |
| Instituto Superior de Engenharia de Lisboa | No | Yes | https://www.isel.pt |
| Instituto Superior de Engenharia do Porto | Yes | Yes | https://www.isep.ipp.pt |
| Instituto Superior Técnico de Lisboa | Yes | Yes | https://tecnico.ulisboa.pt |
| Universidade da Beira Interior | Yes | Yes | https://www.ubi.pt |
| Universidade de Aveiro | Yes | Yes | https://www.ua.pt |
| Universidade de Coimbra | Yes | Yes | https://apps.uc.pt |
| Universidade de Trás-os-Montes e Alto Douro | Yes | No | https://www.utad.pt |
| Universidade do Minho | Yes | Yes | http://www.dps.uminho.pt |
| Universidade do Porto | Yes | Yes | https://fe.up.pt |
| Universidade Lusíada (Famalicão) | Yes | Yes | https://www.fam.ulusiada.pt |
| Universidade Lusófona | Yes | Yes | https://www.ulusofona.pt |
| Universidade Nova de Lisboa | Yes | Yes | https://www.fct.unl.pt |
| Universidade Portucalense | Yes | No | https://www.upt.pt |

# 3. Materials and methods

This study employed a mixed-methods approach to investigate Higher Education Institutions' (HEIs) perceptions and practices regarding integrating active learning approaches in IEM education. Integrating quantitative and qualitative methods in this study offers a holistic understanding of the complex phenomenon of active approaches implementation in IEM education within HEIs (Morgan, 2014). Quantitative data provide breadth and generalizability, while qualitative insights offer depth and context. Together, these approaches provide a nuanced understanding of the multifaceted nature of technology integration, informing evidence-based recommendations for policy and practice within HEIs. The research methodology involved three main stages: 1) HEI website consultation through the links provided in All of these programmes are first-cycle programme of three years (six semesters), corresponding to 180 European Credit Transfer System (ECTS). The second cycle corresponds to two years and 120 ECTS (four semesters).

Table , searching for xBL approaches that could be referred to in the website, 2) application of an online questionnaire, and 3) semi-structured interviews. The procedure used for these last two stages is explained in the following sections.

## 3.1 Online Questionnaire

The quantitative component, conducted through an online questionnaire, aims to gather quantitative and qualitative data on various aspects of identifying which and how these active learning approaches focused on

open problem-solving are used in the IEM community. Identifying the factors contributing to these approaches' successful implementation is also expected. Participants were asked to respond to closed- and open-ended questions, allowing for the systematic analysis of trends and patterns across institutions. The quantitative analysis will quantify the extent of implementation and integration of active approaches. The online questionnaire was divided into four sections after a short context presentation, as presented in Table 2.

Table 2. Questionnaire sections and questions identification

| | Sections | Nr of questions | Questions type |
|---|---|---|---|
| 1. | Identification (optional) | 3 | Short answer |
| 2. | Courses identification | 8 | Mixed |
| 3. | Courses detailed characterization | 17 | Mixed |
| 4. | Other aspects (optional) | 1 | Open-ended |

Initially, emails with links to the online questionnaire and the study's primary objective were sent to all directors of the programs within the IEM field. Subsequently, employing a snowball sampling technique, these directors were asked to forward the email invitation to individuals within their networks who were knowledgeable about the area. Also, the research team members send to their counterparts, allowing for the recruitment of a diverse and representative group of participants with expertise in the subject matter. Furthermore, building upon this network, the questionnaire was sent to 87 IEM educators of different Portuguese HEIs and distributed according to Table 3. It was initially launched on 25 March 2024 and asked for answers until 03 April. Subsequently, the deadline was extended until 14 April to accommodate additional responses. This table also presents the number of respondents. The response rate was approximately 27%.

Table 3. Number of questionnaires sent to IEM educators of different HEIs and number of respondents

| Institution (name in Portuguese) | Nr | Resp. |
|---|---|---|
| Instituto Politécnico do Cávado e do Ave | 1 | |
| Instituto Politécnico de Bragança | 11 | |
| Instituto Politécnico de Castelo Branco | 1 | 1 |
| Instituto Politécnico de Leiria | 1 | |
| Instituto Superior de Engenharia de Coimbra | 6 | 1 |
| Instituto Superior de Engenharia de Lisboa | 4 | |
| Instituto Superior de Engenharia do Porto | 6 | 4 |
| Instituto Superior Técnico de Lisboa | 2 | 1 |
| Universidade da Beira Interior | 4 | |
| Universidade de Aveiro | 14 | 2 |
| Universidade de Coimbra | 6 | 1 |
| Universidade de Trás-os-Montes e Alto Douro | 3 | 1 |
| Universidade do Minho | 5 | 5 |
| Universidade do Porto | 3 | |
| Universidade Lusíada | 1 | 1 |
| Universidade Lusófona | 9 | 2 |
| Universidade Nova de Lisboa | 8 | 3 |
| Universidade Portucalense | 1 | 1 |
| Total | 86 | 23 |

## 3.2 Semi-Structured Interviews

Complementing the quantitative findings, the qualitative component of semi-structured interviews delves deeper into the underlying factors and contexts shaping the integration practices within HEIs. Through open-

ended questions and probing discussions, qualitative inquiry captures the richness of participants' experiences, perceptions, and perspectives.

A group of six teachers and researchers in IEM were selected from the list of those who answered the online questionnaire. Two authors conducted the semi-structured interviews individually with participants online, each lasting approximately 45 minutes to 1 hour. Prior consent was obtained from all participants for audio recording to aid in subsequent study and analysis. Given the time needed to present the results, one of the criteria used for selection was availability in the study's time frame. However, the aim is to extend the interviews to a broad group that includes at least one lecturer from each HEI. As the interview progressed, key topics related to the implementation and impact of xBL were covered, including (1) exploring teaching methodologies, (2) identifying challenges, (3) understanding perceived outcomes, and (4) how the interviewee evaluated the success of the approach used. Also, the potential and the need for specific use of the software were identified. Probing questions were used to delve deeper into specific areas of interest, extracting detailed insights from the participants and encouraging them to provide examples and elaborate on their responses.

Table 4 shows the interviewees' main characteristics: gender, whether the primary training area is IEM (Yes/No), which area they teach, and their knowledge of xBL (Low, Medium, or High).

Guidelines were developed to guide the semi-structured interviews and ensure they yield comprehensive insights into the implementation and impact of active learning approaches in IEM. Firstly, the purpose of the interview was introduced, the context of the research objectives was provided, and the pivotal role of the interviewee's contributions to the study was underlined. The insights are not just valuable, but they are instrumental in shaping the understanding of active learning in IEM. Open-ended questions were designed to encourage participants to share their perspectives freely. These questions focused on the interviewees' experiences with active learning methodologies in IEM education.

As the interview progressed, key topics related to the implementation and impact of xBL were covered, including (1) exploring teaching methodologies, (2) identifying challenges, (3) understanding perceived outcomes, and (4) how the interviewee evaluated the success of the approach used. Also, the potential and the need for specific use of the software were identified. Probing questions were used to delve deeper into specific areas of interest, extracting detailed insights from the participants and encouraging them to provide examples and elaborate on their responses.

Table 4. The main characteristics of the IEM educators interviewed

| ID | Institution (in Portuguese) | Gender | IEM core curriculum? | IEM's main area of teaching | Level of knowledge of xBL approaches |
|---|---|---|---|---|---|
| 1 | Instituto Politécnico de Castelo Branco | Male | Yes | Simulation | Low |
| 2 | Instituto Superior de Engenharia do Porto | Male | No | Simulation | Medium |
| 3 | Instituto Superior de Engenharia do Porto | Male | Yes | Quality/Project Management | Low/Medium |
| 4 | Universidade Nova de Lisboa | Female | No | Entrepreneurship | High |
| 5 | Universidade Nova de Lisboa | Female | Yes | Business Management | High |
| 6 | Universidade Lusíada | Female | No | Economic Project Evaluation | Medium |

In closing, a summary of the key points discussed during the interview was presented to ensure clarity and understanding. Also, participants were invited to share any additional insights or thoughts and give advice to other educators interested in implementing active learning approaches in the field of IEM. Lastly, they expressed sincere gratitude for the time and valuable input. Each participant signed an informed consent agreement before each interview.

# 4. Results and discussion

This section discusses the results obtained from the different sources.

## 4.1 Website information

Institution websites were consulted to retrieve helpful information on xBL approaches. As depicted in Table 5, nearly every university offers a Curricular Unit (CU) titled "Project" or a similar name. The primary objective of this CU is to cultivate the capacity to synthesize knowledge from various disciplines, foster an integrated perspective, and nurture soft skills such as teamwork, interpersonal communication, time management, responsibility, and leadership. Interestingly, two universities (Universidade Lusófona and Universidade Portucalense) explicitly mention using Active Learning methodologies. However, only the University of Minho specifies adopting a Project-Based Learning approach. Based in this information, most IEM degrees indicate a project and/or an internship in the last semester of the programme.

Table 5. Curricular Unit (CU) Project in IEM degrees

| **Institution** | ***CU* named *Project*** | **Observations** |
|---|---|---|
| Instituto Politécnico de Bragança | In the last semester | |
| Instituto Politécnico de Castelo Branco | In the last semester | Could be an *Internship* |
| Instituto Politécnico de Leiria | In the 5th semester | *Industrial Project* |
| Instituto Politécnico do Cávado e do Ave | In all semesters | |
| Instituto Superior de Engenharia de Coimbra | In the last semester | Could be an *Internship* |
| Instituto Superior de Engenharia de Lisboa | No | |
| Instituto Superior de Engenharia do Porto | Every year, annual | *Interdisciplinary Project* |
| Instituto Superior Técnico de Lisboa | In the last semester | *1st Cycle Integrative Project in Industrial Engineering and Management* |
| Universidade da Beira Interior | No | |
| Universidade de Aveiro | In the last semester | *Project in Industrial Engineering and Management* |
| Universidade de Coimbra | No | |
| Universidade de Trás-os-Montes e Alto Douro | No | |
| Universidade do Minho | One semester per year | *Project in Industrial Engineering and Management* |
| Universidade do Porto | In the last semester | *Project in Industrial Engineering and Management* and *Project FEUP* in the 1st semester |
| Universidade Lusíada | In the last semester | Could be an *Internship* |
| Universidade Lusófona | In the last semester | |
| Universidade Nova de Lisboa | In the last semester | *Project in Industrial Engineering and Management* and *Transversal Skills for Science and Technology*, in the 2nd semester |
| Universidade Portucalense | No | *Internship* in the last semester and *Transversal Skills for Science and Technology*, in the 1st semester |

## 4.2 Questionnaire

The presented results illustrate the participants' opinions and practices, reflecting the 23 responses from the online questionnaire. Despite the relatively low response rate to the questionnaire (27%), it is a valuable indicator of teachers' perspectives and attitudes toward the topic under analysis. Regarding which xBL approach(es) is/are implemented in the course(s), the most commonly identified was Project-based learning

(33%), followed by Problem-based learning (21%), then Challenge-based learning with 19%, and then Team-based learning (8%) (Figure 1a). Retrieval-based learning and Game-based learning with 6% each, Inquiry-based learning with 4%, and Service-based learning with 2%.

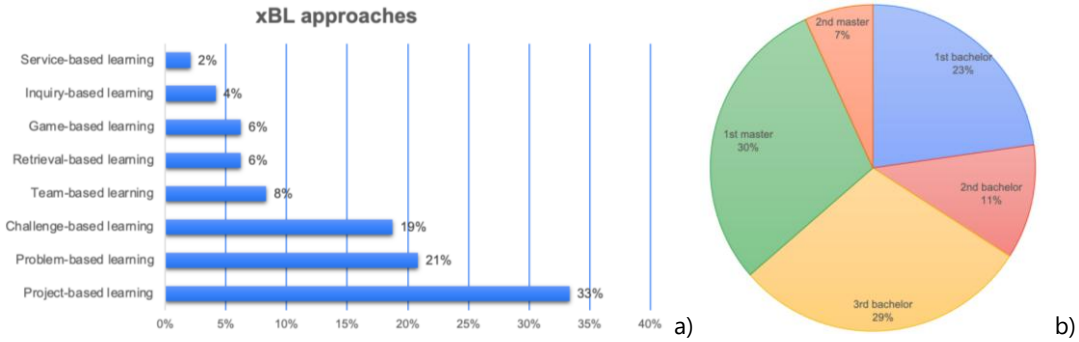


Figure 1. a) xBL approaches implemented according to the survey, b) Degree level of xBL approaches implemented

All the participants were course coordinators, however, 19% mentioned that the coordination of the course is dynamic and undergoes periodic changes, in some cases every two years. As illustrated in Figure 1b, xBL practices are more frequently implemented in the first year of the master's program (30%) and in the third year of the bachelor's degree (29%). The first year of a bachelor's degree appears in third place with 23%. Two participants reported that the project proposed to the students is in more than just the context of a curricular unit. It is also in the context of a real problem defined by a company.

Regarding competencies developed by students, the participants referred to an equilibrium between technical and transversal. Teamwork, time and conflict management, and critical thinking were identified as students' main transversal competences. The main deliverables assessed were oral presentations and reports (43%). Nevertheless, 22% of participants referred to an individual test as part of the evaluation methodology.

Regarding the presence of a tutor for a team of students, 4% mentioned that this role does not exist, and 17% did not answer this question. Based on the other answers, 70% mentioned that the tutor is simultaneously a teacher of the course, 22% said that the tutor is a teacher who is not from the course, and 13% said that also a student-tutor is a member included.

Since students' work is developed in a team, there is a question regarding how and if peer assessment influences individual student evaluation. Most participants (65%) referred to peer assessment as influencing the team's final grade through a correction factor. Nevertheless, 35% stated that it does not have an influence. One participant mentioned that it provides some clues for assessing group work, which is then done by the course instructors.

## 4.3 Interviews

The qualitative findings from the six semi-structured interviews will be presented, complementing the previous qualitative analysis (Table 4). These six interviews were not mere question-answer sessions but interactive discussions that delved into key topics related to the implementation and impact of active learning methodologies. Participants shared insights on teaching methodologies, identified challenges, and discussed their approaches' perceived outcomes.

All interviewees participants agreed on the evolving trends in education, particularly in response to the characteristics of new generations. They emphasized the importance of educators adapting their teaching approaches and recognizing contemporary students' unique needs and preferences. For example, "*working in*

*Agile SCRUM"*, quoted by ID4. ID1 also referred to the need to introduce a project-integrated course as demanded by the national accreditation agency and smiling, he said "*this probably was influenced by the PjBL developed in University of Minho*". This collective viewpoint underscores teachers' need to remain cognizant of evolving educational paradigms and tailor their pedagogical strategies to effectively engage and support learners in today's dynamic educational landscape. However, it is noteworthy that two participants specifically highlighted the significance of knowledge transmission as the most critical issue that must not be overlooked:

ID3 and ID5: "*Knowledge transmission*".

This opinion reflects the traditional thinking that a teacher should transfer knowledge, contrasting the teacher's role as a facilitator of student learning (Zhang et al., 2008). Nevertheless, this role change demands effort and time, which is not recognized in teachers' professional career progression. Furthermore, it is noteworthy that two participants explicitly expressed a keen interest in deepening their understanding and mastery of active methodologies, particularly Project-Based Learning at the undergraduate level. Their enthusiasm reflects a growing recognition of the potential benefits and effectiveness of PjBL in fostering student engagement, critical thinking, and real-world application of knowledge. This eagerness to explore and embrace innovative pedagogical approaches underscores a proactive stance towards professional development and a commitment to enhancing teaching practices to better meet students' evolving needs. Additionally, interviewees evaluated the strategies' success and highlighted the potential and necessity for specific software applications.

## 5. Conclusions

This paper presents a preliminary study about several active learning approaches included in what was named eXtended-Based Learning Approaches explored in Portuguese Higher Education focused on Industrial Engineering and Management programmes. The results achieved are interesting, showing an interest of IEM educators in renewing their practices but, at the same time, unaware of what xBL approaches really are. Many educators need a clearer picture of those practices and do not put them in the same package. That is, there is a general misunderstanding about the identification of the xBL approach. The use of "problem", "project" and "challenge" for the same approach, or the identification of all three knowing that only one was applied. However, the respondents are actively looking to transform their classes into more active classes, using or not the approaches referred to in this paper. Nevertheless, the results are limited, as just a response rate of 27% was obtained through the questionnaire. The interviewed teachers are only a small sample of the 18 IEM programmes in Portugal. The preliminary findings resulted from an exploratory analysis of the collected data. Subsequent stages will entail an integrated analysis to comprehensively examine eXtended-Based Learning (xBL) approaches within the IEM curriculum in Portugal.

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## 6. References

Alharbi, A. M. (2023). Implementation of Education 5.0 in Developed and Developing Countries: A Comparative Study. *Creative Education*, *14*(05), 914–942. https://doi.org/10.4236/ce.2023.145059

Alves, A. C., Costa, N., Nunes, M. L., Sousa, R., Lima, R. M., & Carvalho, D. (2023). PBL in a University-Business cooperation in Engineering and Operations Management Master: challenges and opportunities. *15th International Symposium on Project Approaches in Engineering Education (PAEE_ALE2023)*, *13*, 47–57.

Alves, A. C., & Leão, C. P. (2015). Action, practice and research in project based learning in an industrial engineering and management program. *ASME International Mechanical Engineering Congress and Exposition, Proceedings (IMECE)*, *5–2015*. https://doi.org/10.1115/IMECE2015-51438

Alves, A. C., Moreira, F., Carvalho, M. A., Oliveira, S., Malheiro, M. T., Brito, I., Leão, C. P., & Teixeira, S. (2019). Integrating Science, Technology, Engineering and Mathematics contents through PBL in an Industrial Engineering and Management first year program. *Production*, *29*, 1–19. https://doi.org/10.1590/0103-6513.20180111

Alves, A. C., Moreira, F., Fernandes, S., Leão, C. P., & Sousa, R. (2017). PBL in the first year of an industrial engineering and management program: A journey of continuous improvement. *International Symposium on Project Approaches in Engineering Education*, *9*, 44–51. https://hdl.handle.net/1822/67007

Alves, A. C., Moreira, F., Leão, C. P., & Fernandes, S. (2020, November 16). Ten Years of Positive Feedback on Project-Based Learning From First-Year Engineering Students' Perspective. *Volume 9: Engineering Education*. https://doi.org/10.1115/IMECE2020-23212

Alves, A. C., Moreira, F., Lima, R., Sousa, R., Dinis-Carvalho, J., Mesquita, D., Fernandes, S., & Van Hattum-Janssen, N. (2012). Project based learning in first year, first semester of industrial engineering and management: Some results. *ASME International Mechanical Engineering Congress and Exposition, Proceedings (IMECE)*, *5*, 111–120. https://doi.org/10.1115/IMECE2012-89046

Alves, A. C., Sousa, R. M., Fernandes, S., Cardoso, E., Carvalho, M. A., Figueiredo, J., & Pereira, R. M. S. (2016). Teacher's experiences in PBL: implications for practice. *European Journal of Engineering Education*, *41*(2), 123–141. https://doi.org/10.1080/03043797.2015.1023782

Alves, A. C., Sousa, R., Moreira, F., Carvalho, M. A., Cardoso, E., Pimenta, P., Malheiro, T., Brito, I., Fernandes, S., & Mesquita, D. (2016). Managing PBL difficulties in an industrial engineering and management program. *Journal of Industrial Engineering and Management*, *9*(3), 586. https://doi.org/10.3926/jiem.1816

Autodesk, & ASME. (2022). *Future of Manufacturing - New workflows, roles & skills to achieve Industry 4.0 business outcomes*. https://www.asme.org/topics-resources/society-news/asme-news/asme-autodesk-future-of-manufacturing-new-workflows-roles-skills-to-achieve-industry-4-0-business-outcomes

Bonwell, C. C., & Eison, J. A. (1991). Active Learning: Creating Excitement in the in the classroom. In *ERIC Digest*. http://files.eric.ed.gov/fulltext/ED340272.pdf

Chea, C. C., & Huan, J. T. J. (2019). Higher Education 4.0: The Possibilities and Challenges. *Journal of Social Sciences and Humanities*, *5*(2), 81–85.

Costan, E., Gonzales, G., Gonzales, R., Enriquez, L., Costan, F., Suladay, D., Atibing, N. M., Aro, J. L., Evangelista, S. S., Maturan, F., Selerio, E., & Ocampo, L. (2021). Education 4.0 in Developing Economies: A Systematic Literature Review of Implementation Barriers and Future Research Agenda. *Sustainability*, *13*(22), 12763. https://doi.org/10.3390/su132212763

Council of the European Union. (2018). *Proposal for a Council Recommendation on Key Competences for Lifelong Learning*.

Dervojeda, K. (2021). *Education 5.0: RehumanisingEducation in the Age ofMachines*. https://www.linkedin.com/pulse/education-50-rehumanising-age-machines-kristina-dervojeda/

Felder, R. M., & Brent, R. (2006). *Active Learning*. University of West Florida.

Felder, R., & Silverman, L. (1988). Learning and Teaching Styles in Engineering Education. *Engineering Education*, *78*(7), 674–681.

Figueiredo, A. D. de. (2023). Educating Engineers for Turbulent Times. In R. Vasconcelos, A. Alves, C. P. Leao, V. Carvalho, & R. M. Lima (Eds.), *5th International Conference of the Portuguese Society for Engineering Education* (pp. 5-7 july). School of Engineering, University of Minho Press. https://doi.org/10.13140/RG.2.2.27427.02084

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*(23), 8410–8415. https://doi.org/10.1073/pnas.1319030111

Friesen, S., & Scott, D. (2013). *Inquiry-Based Learning: A Review of the Research Literature*. https://galileo.org/focus-on-inquiry-lit-review.pdf

Gerstein, J. (2013). *Education 3.0: Altering Round Peg in Round Hole Education*. User Generated Education. https://usergeneratededucation.wordpress.com/2013/06/09/education-3-0-altering-round-peg-in-round-hole-education/

González-Pérez, L. I., & Ramírez-Montoya, M. S. (2022). Components of Education 4.0 in 21st Century Skills Frameworks: Systematic Review. *Sustainability*, *14*(3), 1493. https://doi.org/10.3390/su14031493

Gowripeddi, V. V., Bijjahalli, M. C., Janardhan, N., & Bhimavaram, K. R. (2021). Role of Education 4.0 Technologies in Driving Industry 4.0. *Volume 1231 AISC, 2021, Pages 576-587 17th International Conference on Remote Engineering and Virtual Instrumentation, REV 2020: Advances in Intelligent Systems and Computing*, 576–587. https://doi.org/10.1007/978-3-030-52575-0_48

Larmer, J. (2015). *Project-Based Learning vs. Problem-Based Learning vs. X-BL*. Edutopia. https://www.edutopia.org/blog/pbl-vs-pbl-vs-xbl-john-larmer

Lechuga, M. T., Ortega-Tudela, J. M., & Gómez-Ariza, C. J. (2024). Retrieval-based concept mapping makes a difference as a retrieval practice activity: a study with high school students. *Frontiers in Education*, *9*. https://doi.org/10.3389/feduc.2024.1287744

Lima, R. M., Mesquita, D., Amorim, M., Jonker, G., & Flores, M. A. (2012). An Analysis of Knowledge Areas in Industrial Engineering and Management Curriculum. *International Journal of Industrial Engineering and Management*, *3*(2), 75–82.

Lima, Rui M., Andersson, P. H., & Saalman, E. (2017). Active Learning in Engineering Education: a (re)introduction. *European Journal of Engineering Education*, *42*(1), 1–4. https://doi.org/10.1080/03043797.2016.1254161

Lima, Rui M., Dinis-Carvalho, J., Sousa, R. M., Alves, A. C., Moreira, F., Fernandes, S., & Mesquita, D. (2017). Ten Years of Project-Based Learning (PBL) in Industrial Engineering and Management at the University of Minho. In A. Guerra, R. Ulseth, & A. Kolmos (Eds.), *PBL in Engineering Education* (pp. 33–51). SensePublishers. https://doi.org/10.1007/978-94-6300-905-8_3

Lima, Rui M., Villas-Boas, V., Soares, F., Carneiro, O. S., Ribeiro, P., & Mesquita, D. (2024). Mapping the implementation of active learning approaches in a school of engineering – the positive effect of teacher training. *European Journal of Engineering Education*, 1–20. https://doi.org/10.1080/03043797.2024.2313541

Lima, Rui M, Carvalho, D., Assunção Flores, M., & Van Hattum-Janssen, N. (2007). A case study on project led education in engineering: students' and teachers' perceptions. *European Journal of Engineering Education*, *32*(3), 337–347. https://doi.org/10.1080/03043790701278599

Lima, Rui M, Mesquita, D., & Rocha, C. (2013). Professionals ' Demands for Production Engineering : Analysing Areas of Professional Practice and Transversal Competences. *International Conference on Production Research (ICPR 22)*.

Lima, Rui Manuel, Dinis-Carvalho, J., Sousa, R. M., Arezes, P., & Mesquita, D. (2017). Development of competences while solving real industrial interdisciplinary problems: a successful cooperation with industry. *Production*, *27*(spe). https://doi.org/10.1590/0103-6513.230016

Majeed, A., & Hwang, S. O. (2024). Making Large Language Models More Reliable and Beneficial: Taking ChatGPT as a Case Study. *Computer*, *57*(3), 101–106. https://doi.org/10.1109/MC.2023.3327028

Mesquita, D., Lima, R. M., Flores, M. A., Marinho-Araujo, C., & Rabelo, M. (2015). Industrial Engineering and Management Curriculum Profile: Developing a Framework of Competences. *International Journal of Industrial Engineering and Management*, *6*(3), 121–131.

Miranda, J., Navarrete, C., Noguez, J., Molina-Espinosa, J.-M., Ramírez-Montoya, M.-S., Navarro-Tuch, S. A., Bustamante-Bello, M.-R., Rosas-Fernández, J.-B., & Molina, A. (2021). The core components of education 4.0 in higher education: Three case studies in engineering education. *Computers & Electrical Engineering*, *93*, 107278. https://doi.org/10.1016/j.compeleceng.2021.107278

Morgan, D. L. (2014). *Integrating Qualitative & Quantitative Methods – A Pragmatic Approach*. SAGE Publications, Inc.

Pecore, J. L. (2015). From Kilpatrick's Project Method to Project-Based Learning. In M. Y. Eryaman & B. C. Bruce (Eds.), *International Handbook of Progressive Education* (pp. 155–171).

Prince, M. (2004). Does Active Learning Work? A Review of the Research. *Journal of Engineering Education*, *93*(3), 223–231. https://doi.org/10.1002/j.2168-9830.2004.tb00809.x

Sala, A., Punie, Y., Garkov, V., & Cabrera Giraldez, M. (2020). *LifeComp: The European Framework for Personal, Social and Learning to Learn Key Competence*. https://doi.org/10.2760/922681

Sousa, R. M., Alves, A. C., Lima, R. M., Sandra Fernandes, D. M., & Dinis-Carvalho, J. (2023). Project-Based Learning in Industrial Engineering and Management: analysis of three curricular projects. *PAEE_ALE2023*.

World Economic Forum. (2015). *The skills needed in the 21st century*. New Vision for Education - Unlocking the Potential of Technology. https://widgets.weforum.org/nve-2015/chapter1.html

World Economic Forum. (2018). *The future of jobs report 2018*. http://www3.weforum.org/docs/WEF_Future_of_Jobs_2018.pdf

World Economic Forum. (2022). *Unlocking Value from Artificial Intelligence in Manufacturing*. https://www3.weforum.org/docs/WEF_AI_in_Manufacturing_2022.pdf

World Manufacturing Forum. (2019). *Skills for the future of manufacturing*. https://worldmanufacturing.org/wp-content/uploads/WorldManufacturingFoundation2019-Report.pdf

Zhang, Q., Zimmerman, J., Mihelcic, J., & Vanasupa, L. (2008). Civil and Environmental Engineering Education (CEEE) Transformational change: tools and strategies for Sustainability integration and assessment in Engineering Education. *Proceedings of the 2008 American Society for Engineering Education Annual Conference & Exposition*.