Towards Active Evidence-Based Learning in Engineering Education

A Systematic Literature Review of PBL, PjBL, and CBL

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Review

Towards Active Evidence-Based Learning in Engineering Education: A Systematic Literature Review of PBL, PjBL, and CBL

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Abstract: Implementing active learning methods in engineering education is becoming the new norm and is seen as a prerequisite to prepare future engineers not only for their professional life, but also to tackle global issues. Teachers at higher education institutions are expected and encouraged to introduce their students to active learning experiences, such as problem-, project-, and more recently, challenge-based learning. Teachers have to shift from more traditional teacher-centered education to becoming instructional designers of student-centered education. However, instructional designers (especially novice) often interpret and adapt even well-established methods, such as problem-based learning and project-based learning, such that the intended value thereof risks being weakened. When it comes to more recent educational settings or frameworks, such as challenge-based learning, the practices are not well established yet, so there might be even more experimentation with implementation, especially drawing inspiration from other active learning methods. By conducting a systematic literature analysis of research on problem-based learning, project-based learning, and challenge-based learning, the present paper aims to shed more light on the different steps of instructional design in implementing the three methods. Based on the analysis and synthesis of empirical findings, the paper explores the instructional design stages according to the ADDIE (analysis, design, development, implementation, and evaluation) model and provides recommendations for teacher practitioners.

Keywords: problem-based learning; project-based learning; challenge-based learning; engineering education; instructional design; literature review

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1. Introduction

The present day and foreseeable future context require universities to organize engineering education in such a way that graduates are able to develop high technologies (high-tech) competencies, which are necessary for the extremely fast development of societal needs. Future engineers are expected to be able to handle complexity and ongoing changes in the workplace while at same time addressing sustainability problems [1]. Hence, the university student must not only be able to create advanced and sustainable technologies, but also anticipate the future needs of humanity and feel the future changes and challenges of societal development; therefore, transversal skills and social competences become crucially important [2–7].

The urgency to address sustainability problems, such as sustainable economic development [8], climate change, environmental degradation, and poverty, among others, call for a new type of engineer, equipped with knowledge and competences, which traditional teacher-centered curricula are no longer able to provide. Adaptability, flexibility, critical thinking, interdisciplinary collaboration, communication, complex problem solving, and systems thinking are examples of competences required to develop for the future [9]. To address such needs and educate for sustainability, engineering education has been changing in order to adapt to such changes and make education more aligned with what is the most relevant and needed. Such changes require that institutions revise their vision and mission, and their management operations and educational approaches, aiming towards a comprehensive integration of sustainability at system level. At an educational level, curriculum change and innovation, with sustainability integration combined with the use of active learning methodologies, is one of the most common approaches to educate engineers for sustainability [10,11]. Additionally, education for sustainability calls for a contextual, problem-oriented, reflective, interdisciplinary, collaborative, participatory, ethical, and empowered learning environment in order to educate for a sustainable future [12]. Problem-based learning (PBL), project-based learning (PjBL) and, more recently, challenge-based learning (CBL) are examples of such pedagogical approaches [13–15]. In the past years, PBL, PjBL, and CBL have been gaining popularity with the aim to address engineering megatrends, such as education for sustainability. Previous studies report on different drivers for their implementation. For example, students gaining experience in integrating technology with real-world conditions beyond the classroom/lab [16,17] as well as for improving learning retention and encouraging pursuit of a career in engineering [18]. CBL, which emerged and connected from PBL, as well as CDIO-approaches [19], is expected and described to be beneficial to the enrichment of students' knowledge and also employability. PBL, PjBL, and CBL can also be used to improve engineering students' desirable technical and transversal skills: teamwork, communication, and conflict resolution [5,18,20–23], collaboration [24,25], management of resources, such as time, money, etc. [18], entrepreneurship [21,26], critical thinking and problem solving [22,27–29], and self-directed learning (as an indicator of life-long learning) [17,23,30].

This, in turn, is also fostering the sustainability of learning itself, that is, the undergone teaching–learning process is, through the aforementioned educational; setting a sustainable education in the graduates as they become themselves continuous learners, and hence are enabled to continue adapting the skills and competencies according to the ever faster changing challenges we are facing.

Even though the motivations, drivers, and benefits of PBL, PjBL, and CBL are well documented, there is also criticism regarding their implementation, practice, and research. A lack of understanding of processes inherent to active learning and students' development (e.g., development of teamwork skills, complexity of social interactions, and impact on students' learning) and the measures on effectiveness of active learning focus on students' performance and products of learning (i.e., which aligns with the behaviorism perspective of learning) are examples of the criticism to these methodologies. The implementation of CBL, PjBL, and PBL is a complex process and requires a paradigm shift, where the organization, staff, and students change their view in relation to education; they change from transmitter of knowledge to be facilitators, promotors, and co-constructors of, and for, learning [31]. Therefore, the shift toward these pedagogies is a challenging process that often requires teachers and students to apply new skills and take on roles that they might have not needed before [21]. It is of paramount importance that teachers and students have a clear understanding of what characterizes these pedagogies and which ways they can be used to integrate sustainability in an engineering education. For many teachers across the world, implementing active learning is an innovation, for which they are not fully ready. Numerous recent studies, reports (various relevant reports can be accessed on the official websites of organizations, such as OECD (www.oecd.org, accessed on 15 October 2022)), conference panel discussions, practitioner blogs, etc., often report on teachers lacking more training on implementing new pedagogical approaches in training future engineers, especially if such educational interventions are to be enhanced with ICTs.

Without sufficient training to become strong independent instructional designers, teachers often improvise and try to implement adapted forms of such already established methods as PBL, which, in turn, makes it difficult to realistically measure the effectiveness of such learning. In addition, novice and/or inexperienced innovators end up developing hybrid teaching/learning strategies, which might also result in unexpected outcomes, such as failure to achieve the learning goals, reduced motivation, lack of self-efficacy, resistance to change, etc. It can be suggested that in order to avoid the aforementioned issues, it is important to implement the methods at least with a certain level of consistency across different contexts; moreover, the implementation should be based on evidence of prior studies and best practices. To address the latter point, by conducting a systematic literature analysis, this paper aims to investigate and report on recent evidence-based research that presents different aspects of implementing three active learning methods, namely, PBL, PjBL, and CBL. More precisely, since there is a lot of reported confusion about the overlapping parts of these methods, the paper focuses on the reported characteristics as well as similarities and differences between them. Furthermore, since in order to organize student-centered education (especially in a technology-rich context), the teacher needs to act as an innovative instructional designer, this paper also reports on teacher roles and activities that are indicated in the analyzed papers. In addition, the paper also reports on the attitudes of teachers and students as well as students' learning and behavior outcomes. Finally, based on the analyzed papers, the authors of the present paper provide recommendations for researchers and teachers-practitioners.

The paper further provides a brief overview of the three active learning methods. Further, in Section 3, research methodology is explained. Section 4 presents the main findings, whereas Section 5 contains a comparison of the findings. Section 6 proposes a number of recommendations to both researchers interested in this field as well as to teachers-practitioners. Finally, the paper is concluded in Section 6.

2. Active Learning Approaches: Problem-, Project-, and Challenge-Based Learning

2.1. Problem-Based Learning (PBL)

Problem-based learning (PBL) emerged in the mid-1960s and early 1970s in medical and engineering education, with McMaster University (Canada), Maastricht University (the Netherlands), and one of the biggest universities in Denmark having been the pioneers [5,17,29,32–34]. Since its first implementation by these innovative universities, PBL has been gaining popularity in engineering education around the world, leading to a wide range of models and practices (e.g., PBL as a cycle [23,29], PBL as case or project [7,26,29,35,36] and, even the use of inconsistent terminologies regarding the methodology of PBL (e.g., problems vs. issues vs. challenges vs. situations)) [16,17,29,37,38]. However, the literature shows a set of common features which can be used to define PBL as an approach to learning, in which: (i) ill-open, real, and unstructured problems act as the driver, motivation, and framework for learning; (ii) problem identification and problem-solving serve as the vehicle to acquire knowledge and develop different types of skills, and consequently achieve (learning) goals; (iii) self-directed, team-based, and collaborative learning, where "social organizations [that] promote participation and result in a sense of agency" on students [17], (p. 3); (iv) teachers become facilitators and "scaffolders" of learning processes; (v) learning is exemplary, contextual, and experiential, as well as (vi) reflective, promoting continuous negotiation, a construction of knowledge, and self-assessment [3,17,39,40].

As [41] indicates, the implementation process of PBL might consist of seven stages, from students exploring the problem with its context to research and final overall evaluation of the learning process (Figure 1).

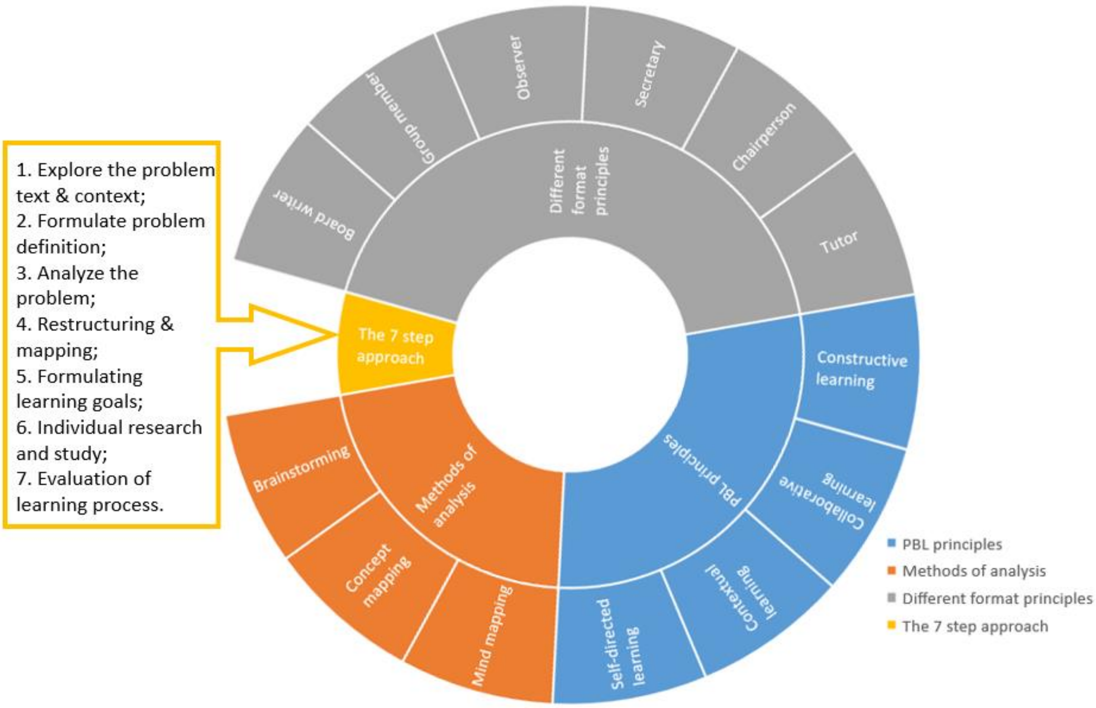

Figure 1. A summary of the problem-based learning process and its core principles, adapted from [41].

As demonstrated in Figure 1, in all the stages, students employ a number of different strategies, such as brainstorming and mind/concept mapping to engage in the learning process and achieve the learning goals, which is done in small teams where every member has an assigned role (e.g., tutor, secretary, board writer, etc.).

In general, PBL seems to benefit students' learning in terms of engagement and motivation, also encouraging their success and development of new thinking strategies [22,29,42–44]. Core subject matter might be taught in a manner that allows the learner to acquire the required material in a systematic and efficient manner, and might also balance subject matter, societal aspects, and the learner (individual) needs [7,28,34].

Even though the literature argues that PBL offers a "solution to several problems and challenges" in engineering education, this learning pedagogy is not free of criticism [45]. Some notable examples are: (i) lack of understanding of processes inherent to active learning and students' development (e.g., development of teamwork skills, complexity of social interactions, and impact on students' learning, etc.), and (ii) measuring the effectiveness of active learning, which mainly focuses on students' performance and products of learning (i.e., which aligns with the behaviorism theory of learning).

In sum, the aforementioned features undoubtedly fall in social constructivism, situated, contextual, and experiential learning theories. They also provide aspects on what and how to plan, design, and implement PBL in engineering higher education environments. For example, the type of problems (more or less open; real or hypothetical, etc.) and who defines them (students, teachers, or in collaboration with industry partners), the level of implementation and duration (e.g., course or program level; one day, one week, or three months), type of learning outcomes and knowledge (e.g., disciplinary or interdisciplinary), and students and teachers' attitudes and roles.

2.2. Project-Based Learning (PjBL)

As stressed by [46], design is one of the central functions of engineering practice; thus, it is essential to expose students to 'real-world' conditions. Active learning strategies, such as project-based learning (PjBL), emerge as one of the most relevant and studied strategies on the enhancement of learning in engineering schools [47].

Project-based learning dates back over a hundred years and its origin is associated with the educator and philosopher John Dewey [48]. Applied to science teaching practice since the 1970s, PjBL has been in development and has also been extensively implemented in engineering education [49].

Characterized as a constructivist pedagogy, with learners mobilizing theoretical and technical knowledge to find solutions for practical problems, PjBL is learner-centered and involves a dynamic classroom approach [48].

Project-based learning environments are, thus, defined by the main principle of student engagement in solving open problems with an interdisciplinary nature, typically in teams [50]. Teachers also develop communication skills and different teaching strategies from the ones used in a traditional classroom, with the goal of helping students to build their knowledge, by adopting roles such as tutor, mentor, or supervisor [47]. Moreover, the advantage of PjBL over traditional teaching practices related to significant improvements in learning outcomes is observed [51].

One of the main aspects of the PjBL objective, which distinguishes this method from others, is the creation of a final product. The seed of the project is a question and students search for information to develop a solution in multidisciplinary teams [52].

Project-based learning is often overlapped with problem-based learning, since both learning strategies are based on collaboration and self-direction [53]. However, they also stress that PjBL is more directed to the mobilization of knowledge and problem-based learning is more oriented towards the acquisition of knowledge. Moreover, PjBL activities are usually closer to real professional activities [53].

Considering that engineering project courses are particularly helpful in preparing students for real-world jobs in industry [54], PjBL assumes relevance. In fact, several studies reveal that student recruitment and retention are one of the main drivers of PjBL implementation, along with the industrial demand for engineers equipped with a broader set of skills [55]. Furthermore, it is assumed by the literature that engineering projects are more conducive to engaging students in higher-level cognitive skills, and thus helping learners to develop metacognition, critical thinking, and problem-solving competency [53]. Moreover, the development of students' teamwork abilities, communication skills, decision-making, and mobilization of knowledge to real-life situations have also been extensively reported [56].

Despite all the mentioned benefits, studies reporting PjBL implementation also stress challenges both for students and teachers. For example, studies show that students do not necessarily acquire specific technical content or experience real-world industry by simply conducting projects [54]. Moreover, it is also stated that, in order to learn by doing, students also need time to reflect, making experimentation as important as reflective tasks [53].

When PjBL is implemented in engineering education, students learn mostly how to conceive–design–implement–operate an engineering solution to a specific engineering challenge [57]. The process most often includes five stages (or seven, for some authors), such as:

(i). orientation: the drawn content or topic is usually significant to students;
(ii). identifying and defining: students are required to explore possible project topics and identify the group's own project topic;
(iii). planning: defined by a process of thinking and discussing how the project topic is going to be investigated (including project title, purpose, procedure, roles and responsibilities of group members, as well as a time estimation);
(iv). implementing: includes classroom/laboratory activities as well as autonomous tasks;
(v). reporting and evaluating: conclusion of groups' final reports as well as oral presentations [58].

2.3. Challenge-Based Learning (CBL)

The most prominent starting point of challenge-based learning was the "Apple Classrooms of Tomorrow—Today" (ACOT2), a project initiated in 2008 by Apple, Inc. [59]

to identify the essential design principles of the 21st century learning environment [60]. Nowadays, examples of CBL can be found in several phases of education, starting from kindergarten to elementary school, high school up to universities, and continued professional learning.

One of the leading promoters of challenge-based education, the European Consortium of Innovative Universities (ECIU), combined two of the most common definitions, and define such a teaching/learning method as a pedagogical approach that actively engages students in a situation that is real, relevant, and related to their environment. It takes place through the identification, analysis, and design of a solution to a sociotechnical problem. The learning experience is typically multidisciplinary, involves different stakeholder perspectives, and aims to find a collaboratively developed solution, which is environmentally, socially, and economically sustainable [19] (p. 22).

Challenge-based learning is a pedagogical approach that actively engages learners by integrating formerly traditional learning courses with real-life challenges. Those challenges require innovative, creative, and at least multidisciplinary interventions to be solved. These interventions may require learners and external stakeholders as well as training partners (industry or public sector based) to work together. This co-work may continue after the academic period is formally over (e.g., [61,62]). Even though CBL shares some key features with PBL and PjBL, it goes beyond in that the challenge is not fully predefined, as learners and the community members participate in its co-creation, but are also expected to be the expert of the subject, and the teacher just facilitates and accompanies the learning [62]. CBL asks learners to formulate a problem and relevant questions, to investigate compelling issues, to reflect on their learning and the impact of their actions, and then to publish their solutions to a worldwide audience. Following this, the learning and teaching activities in CBL are often divided into three interconnected phases (see Figure 2).

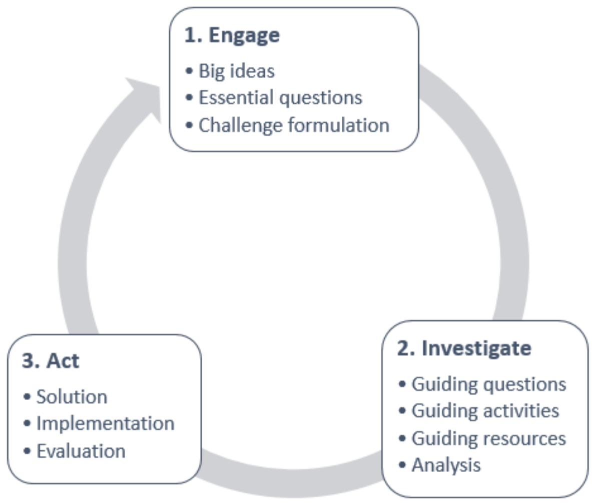

Figure 2. Stages of challenge-based learning implementation (adaptation based on the description by [63] and ECIU university project).

As seen in Figure 2, CBL consists of three phases: (1) Engagement phase, in which the learners move from an abstract big idea to a concrete and actionable challenge; (2) Investigation phase, in which learners conduct research to create a foundation for actionable and sustainable solutions; and (3) Acting phase, in which evidence-based solutions are developed and implemented with an authentic audience and the results evaluated [63].

However, studies analyzing changes in competencies, knowledge gain, or learners' attitudes indicate that results are not automatically guaranteed with CBL as a pedagogical approach, but has a strong interdependency with prior knowledge [64], intrinsic motivation [65,66], support in teamwork [66], as well as learning environment created by teachers and external trainings partner, [62,67,68].

2.4. A Comparison of PBL, PjBL, and CBL

Prior research indicates a number of similarities and differences between the three methods in focus. One of the core principles in the three is that they require environments suitable for a student-centered constructivist learning organization [29]. In addition, all of the methods have been reported to bring benefits to learning, including increased motivation and ability to meaningfully relate academic knowledge and their professional practice [16].

Some previous studies, for instance, [52] present a comparison of the three active learning methods based on different dimensions. For example, the methods are contrasted in terms of the learning activities, type of solution and its potential implementation, implementation outcome, and teacher's role [52]. The first dimension, learning, differs from a task given to complete a project (PjBL), to specific content applied to solve problems (PBL), and addressing real problems to complete the challenge (CBL). The second dimension, focus, shifts from solving real (PjBL & PBL) or fictitious problems (PBL) to solving real and open problems (CBL). The third dimension, product, varies from presentation of project executions (PjBL), describing the process and achieving the results (PBL), or producing a solution that translates into a concrete action (CBL). The fourth dimension, process, includes various activities, such as generating products for learning (PjBL), testing learners' ability to reason and apply their knowledge (PBL), or encouraging students to analyze, design, develop, and execute the best solution to the challenge (CBL). The fifth dimension, teacher, defines teacher's role in the process—from project manager (PjBL), to professional guide (PBL), or coach and co-researcher (CBL).

These dimensions are a good point of departure to compare the PBL, PjBL, and CBL by providing examples of dimensions to make such comparison; however, it lacks others that are defining and relevant. For example, more details on the teachers' role as instructional designers, the students' role, assessment, collaboration, learning goal, and level of implementation (e.g., course, program, or organizational levels) are missing, which makes the comparison narrow and simplistic. For instance, learning is referred to by being driven by tasks (PjBL), applying content to problems (PBL), or real problems (CBL). The literature review presented in this study shows that there is a diversity and complexity on how terms are defined (e.g., type of tasks, problems, and challenges (i.e., real problems)) as well as their operationalization in practice, leading to a diversity of models.

3. Methodology

The present paper is based on the typical procedure of conducting a systematic literature analysis. The logic and design of the present investigation can be seen in Figure 3.

Figure 3. Research design.

After establishing the topic and theoretical, as well as practical, relevance of the paper, the authors of the paper identified the selection criteria and databases for collecting the papers. More precisely, the search was performed in the following databases: Web of Science, Scopus, IEEE Xplore, Science Direct, as well as a number of EBSCO databases, such as Academic Search Complete, Computers and Applied Sciences Complete, Education Source, ERIC, and Teacher Reference Center. When it comes to paper selection, only papers that met the following criteria were included into the dataset:

- Papers are based on empirical data;
- Papers are published in peer-reviewed scientific journals;
- Full text is available;
- Papers report on the implementation of PBL, PjBL, or CBL in higher education;
- Paper report on the implementation of PBL, PjBL, or CBL in engineering education;

- Papers were published between 1 January 2016 and 31 August 2020.

To identify the initial dataset, responsible researchers applied a specific keyword-based search on the aforementioned databases. A number of different combinations was used until they were refined to such a combination that helped to retrieve the most suitable results. The search terms and the initial number of search outcomes can be seen in Table 1.

Table 1. A summary of the search strategies, findings, and sample reduction.

Method	Search Terms	Initial Number of Papers across the Selected DBs	Reasons for Sample Reduction	Final Number of Papers
Problem-based learning	'problem based learning' OR 'problem-based learning' AND 'engineer'	109	• Irrelevant implementation context; • Full text unavailable; • Describe a different method; • Not focused on HEIs.	65
Project-based learning	'project based learning' OR 'project-based learning' AND 'engineer'	252	• Irrelevant topic; • Irrelevant implementation context; • Full text unavailable; • Method not presented; • No distinction made between the methods.	103
Challenge-based learning	'challenge based learning' OR 'challenge-based learning' AND 'engineer'	59	• Not based on empirical data; • Not focused on HEIs; • Describe a different method/did not follow the given definition of CBL, although it was called CBL in key words or abstract.	9
	Total:	420	Total:	177

It should be noted that a large share of the papers was not suitable for the analysis based on a number of reasons, such as a mismatch to the above-mentioned criteria and the context of the paper, unavailability of full text, or faulty identification of the method.

Once the final number of papers was established, they were coded by using qualitative data analysis software MAXQDA. Coding was based on a pre-established, deductively developed coding scheme, which was supplemented with inductively derived codes later on. The coding scheme consists of the following parts: (1) metadata of the collected papers; (2) background on the three methods; (3) instructional design stages according to the ADDIE (analysis, design, development, implementation, and evaluation) model; (3) teacher-related attitudes; (4) student-related attitudes; and (5) miscellaneous.

4. Findings

4.1. Barriers and Challenges of Implementing Active Learning Methods

Papers on all the three methods in focus report at least some barriers of implementing the method, as well as challenges that different stakeholders had to solve in order to successfully implement the method and achieve the learning goals. In general, it should be noted that active learning methods require great efforts from all the parties involved. One of the biggest barriers for both teachers and students is resistance to change [57], but there is a number of other barriers and challenges as well. In [69], based on other previous studies, the barriers and challenges of implementing such active learning methods as PBL and the entailing issues related to: (i) planning and preparation; (ii) assignment and organization; (iii) development; and (iv) assessment, are summarized.

When it comes to teachers, a number of studies emphasize that implementing active learning methods requires great effort from them as well as a lot of time resources [65,70]. Likewise, because the biggest share of learning depends on students, they need to invest a considerably large amount of time in developing the solution, which often leads to spending more hours on it than is originally planned in the curriculum [71]. It is reported that because of time constraints, students often feel like they have to rush through developing a solution, which does not ensure that they deliver the best result at their capability [44]. Furthermore, if certain issues demotivate students, they are also reported to be reluctant to engage in debates and give feedback to colleagues, especially if some activities, such as listening to presentations, become repetitive [53].

In some cases, studies report that teachers found it challenging to combine the implementation of the new learning method and cover all the necessary course topics and materials [62]. Mills and Treagust finds that a mixed-mode approach introducing some of the project-based components with the traditional method used initially [72] is optimal. Furthermore, in CBL, for example, teachers usually need to rely on external stakeholders and additional resources for their students to be able to achieve the desired outcomes [62], which always requires great input and effort from the course teacher, university management, etc. If there is a lack of communication between universities and their industrial partners, it might cause problems in the course delivery and solving the selected problems and/or challenges [73]. In addition to that, teachers and students are at least, to some extent, dependent on the input of external stakeholder, and if they disagree with some steps of developing the solution [74] or cannot give enough time for consultations and providing input [73], it might have a significant effect on further course activities, learning outcomes, students' attitudes, and other important aspects.

The analyzed papers also indicate that students, who have never engaged in hands-on or teamwork learning experiences often struggle and feel insecure because they lack skills of learning in a way that requires significant input by the learner [44]. Moreover, [53] reports that students find it difficult to make connections between the prior knowledge and the new challenges that they will have to work with in the new course. Other reported barriers include students' lack of motivation to engage in active learning because they are much more interested in obtaining the course credits rather than developing an innovative solution to a problem [47].

In PBL, PjBL, and CBL, students work within teams, and because of different students' roles and team compositions, conflicts are normally difficult to avoid, and often it is up to the teacher to monitor and help solve them [65]. Studies report that students find it challenging to work within teams not only because of potential issues of fair work distribution but also because typically teams in PBL, PjBL, and CBL are multidisciplinary [71]. Moreover, because of the nature of team compositions, students might be struggling to pick up the pace of developing the necessary skills and solving the problem or challenge [62]. Improvement might also be hindered because students often need to communicate with their team members from/across different countries, speak in a foreign language, and adapt to colleagues of different socio-cultural, etc., backgrounds [47].

Teachers and students are reported to encounter challenges related not only to the implementation of a new teaching/learning method, but also due to the different modes of learning. For example, Ref. [1] notes that students who had to study online at home due to the imposed COVID-19 quarantine, did not have proper infrastructure and privacy or had to take up new roles that might have been of greater priority to them (e.g., taking care of homeschooled siblings).

4.2. Stages of Instructional Design Development: Analysis

Based on the ADDIE model, the first stage of developing instructional design is analysis. As is explained by [75], this stage entails analyzing the instructional goals, and trying to understand the target audience and required resources.

During this stage, if the teacher decides to implement, e.g., PBL, a deep theoretical understanding of the method is especially important [38,76]. The teaching scheme aims to aid students in their learning process [76]. Teachers have to think about which skills students aim to improve through the module [38], think about the teaching goals [76], the learning outcomes [23,77] and why this method is most appropriate. PBL seems to benefit students' learning in terms of engagement [34,42] and motivation [22,44,78], also in the encouragement success of the learners [22,29,34,79] and development of new thinking strategies [24,43]. Core subject matter might be taught in a manner that allows the learner to acquire the required material in a systematic and efficient manner, but might also balance subject matter, societal aspects, and the learner (individual) [7,28,34]. The results of the literature analysis showed that, firstly, teachers should follow the implementation strategy of PBL [80,81]. In relation to the organization of a course, it is important to decide in which parts of the course (e.g., topics or weeks or lessons) PBL should be used [82]. It is also significant that the balance between PBL and other learning approaches should be specified for every particular course activity [80]. Traditionally, the complexity (scope) of problems should be increased gradually from the beginning to the end of the course.

The analysis shows that teachers were mainly motivated to implement PjBL because of two main reasons: (i) to improve their students' meaningful learning and deep understanding of the scientific concepts related to the subject, and (ii) to connect science and technology to students with a learning process characterized by the need to solve a need or problem related to the professional field [83]. At this stage, Ref. [70] also reported on the learning goals, which are related to understanding, analyzing, and evaluating (un)known typologies, designing different parts of the solution, performing calculations and simulations, evaluating suitability and applicability, and creating a design of the solution. Another example is described in [84], where the learning goals are identified as developing discipline-specific competences as well as better understanding other disciplines. In addition to problem solving in (international) multidisciplinary teams, Ref. [85] also targets transversal skills, such as teamwork and communication.

PjBL environments provide students the opportunity to work on authentic projects and develop the skills and competences which are required in potential real-life work environments and real-world industry [54,86,87]. The advantages of applying PjBL in study process are numerous: students have the opportunity to solve real-life, client-centered problems, which also increases their knowledge and better understanding of the specifics of a future job [70,88], students become more engaged in the study process [89] as well as the interest in their future carrier [88], students become active and key participants of learning processes with the opportunity to apply their theoretical knowledge into industrial practices [70,87,90], students are more motivated to engage into acquiring deeper knowledge on the subjects they study [70,91], and their autonomy and creativity, as well as critical thinking, are developed [89,90]; moreover, PjBL focuses on team work and provides the opportunity for students to learn from multiple sources [47,92,93], even become experts in some areas and assume the roles of instructors [22,93].

In the analyzed papers, the motivation to implement CBL often did not come from teachers and how they understand what gaps need to be filled. More often, CBL is implemented because of governmental and institutional strategies and identified needs. Based on the understanding of what is a challenge, CBL implementation comes along with the expectation that future leaders of companies, institutions, or government will be responsible for incorporating sustainability and environmental awareness into decision making (e.g., [64] or [61]). Students should enable them to efficiently solve real-world problems related to implementing the circular economy [64]. An additional argument for CBL is that there is a gap between the industries' requirements and the skills that engineers learn in their university education to push industry in a leading position (e.g., [16,71]), as mentioned in the Introduction of the paper.

It is argued that lecture-based teaching demotivates and generates dissatisfaction, since students have a passive role as long teaching is not connected with the real or professional world. Instead, it is expected that challenge-based education creates conditions for students, faculty, and various societal actors from the involved universities and countries, to collaborate on education, research and innovation, and mutual capacity building to promote sustainable societal transformations [61].

4.3. Stages of Instructional Design Development: Design

In [75], it is explained that in the ADDIE model, the second stage, namely, design, refers to establishing a learning solution that bridges the learning goals and strategies.

To incorporate problem-based learning effectively within an existing course, an instructional model must be selected that will support the specific needs and constraints of the given course [38]. A literature analysis shows that special training sessions can be organized for teachers who plan to implement online PBL using Blackboard Collaborate Ultra, WebEX, Microsoft Teams, and Zoom [1]. Teachers can implement individual guidance or adjust course content and teaching approaches according to students' competences [80]. Designing problems also takes place during this phase [94]. Problem-based lectures have to be challenging for students to stimulate their curiosity and facilitate their interest [24,35]. It is advised that in order to make instructional practice effective it is necessary that theoretical principles, instructional design, and learning environment are connected [29]. When designing problem-based learning, the emphasis must be put on analyzing behavioral objectives and assessing learner performance with criterion-referenced tests [27]. The authors in [40] mention the following six activities, which are prominently featured in the planning stage:

I. Learning scenarios: teachers/tutors define a learning scenario that reflects real circumstances;
II. Learning space: teachers/tutors make space available for the students, which allows them to do research and share the kind of technology that is especially designed to encourage them to collaborate with each other;
III. Problems and challenges: teacher/client sets real-life problems that challenge the students to search and explore subjects to solve them in a strategically planned way;
IV. Objectives and evidence of learning: teacher defines the learning goals as well as describing the observable knowledge and the skills required by the students;
V. Content: this is related to sharing the artifacts produced by the teaching staff and the students (reports, plans, presentations, etc.);
VI. Teams: Teacher/tutor forms heterogeneous teams while considering the skills and complementary profiles.

The determination of students' and lecturers' roles in the classroom is essential for maximizing the effectiveness [24,95].

Designing project-based learning implementation is related to the previous analysis and the learning outcomes. The teacher's role in that stage is to visualize how the PjBL will proceed and to prepare, in detail, all the content and materials for the students [96,97]. The teacher needs to make decisions regarding the implementation process, the use of technology, the composition of the teams, or how to involve institutions in the project [48,96]. In the context where the teams of students will develop the project and the tools they may need to implement the plan, the products also need to be taken into account [98]. The process may involve various approaches, combining activities in a university setting as well as online collaboration [51,99]; industrial partners are active participants in formulating problems for PjBl tasks [99,100]; technologies involved and manipulated provide the opportunity for students to make authentic decisions in various contexts [22,93].

In CBL, the teacher's role is to be a guide and facilitator through the learning process. Such learning promotes team culture, helps students to manage the tasks required to solve the challenge, and show process. In addition, it is the teacher's role to enable students to move towards innovative thinking, in dependence of the understanding that CBL teachers are experts of a subject and provide knowledge by giving lectures, introducing new concepts, or sharing knowledge resources. Some of the analyzed papers contain examples in which the expert role was filled by the challenge provider or external experts.

The teacher's role as an instructional designer is not as strong as it might be in PBL and PjBL. Learners will decide what knowledge they lack and where to seek the answers. Learners take ownership of their challenge. They define their own challenges (not in all cases, not in Tect21 models) and take over responsibility for team composition (not in all cases, not in Tect21 models), as well as how to acquire the necessary knowledge and skills to solve the challenge.

4.4. Stages of Instructional Design Development: Develop

As is indicated in the ADDIE model, in this stage, the teacher develops and validates the appropriate learning resources [75].

The results of the literature analysis showed that during this stage, tasks and activities are formulated and organized. Defining a useful motivation activity helps to ensure that students feel that the problem that they are tasked with resolving is important and worth their time and attention [38]. Learning environments and collaborative techniques are included so that learners could work with peers, because learning is not only affected by previous experience but through their social interactions [29]. Teachers pilot a course and draw numerous conclusions about the learners' behavior and implemented didactics [82]. This information is used for improvement. The literature analysis shows that instructors, who decide on the initiative of implementing PBL based on their own motivation and interests instead of an institutional request, made efforts in the design of their courses with the support of the first author of the study, who works internationally to support pedagogical development for PBL [44].

As in PjBL and PBL, in CBL, learners also aim to co-create a solution related to an end-product. However, in contrast to PjBL and PBL, the learning cycle in CBL (in theory) and also the implementation of the prototype and the evaluation with the challenge provider, is desired together with an evaluation of the learning process individually and of the team of learners. Unfortunately, the papers analyzed focus on the presentation of the learners' solution, and evaluation of the learning outcomes from the teacher's perspective and need. Only rarely did they include information if the implementation of the prototype was done and how the learning process individually and of the team were reviewed. In CBL, teachers might have a list of resources in advance; however, students who work in multidisciplinary teams will realize that they need additional resources and seek them, possibly only guided/assisted by the teacher.

4.5. Stages of Instructional Design Development: Implement

In this stage, the teacher starts engaging the students in the learning process [75]. More precisely, students might receive communicative messages about the course, pre-course activities might be organized, etc. (ibid.). Further, the selected method is applied in the course.

4.5.1. Implementing PBL

The literature analysis shows that PBL implementation includes six stages [101], five stages [38], or sometimes three stages. All of them involve students analyzing the problem; identifying, locating, and evaluating further information for solving the problem; consulting with team members on approaches for solving the problem; making decisions on the final strategy for solving the problem; and proposing a solution and reviewing their own performance with respect to the overall activity. In some cases, the stages can be combined, so it was decided to analyze three main stages: (i) understand the problem; (ii) explore the curriculum; and (iii) resolve the problem.

- Understand the problem

For less confusion and students' higher level of concentration, they receive special information a couple of days before the course begins, where the instructor/teacher makes efforts to provide clear guidelines on how each course is restructured to accommodate the new way of learning [1,25,81]. Teachers organize additional online training sessions [1,7,28] through which the delivery of course content is explained by presenting the various activities that will engage students during the course [77].

Course participants are then split into teams of two to three [16], three to four members [102], or four to five members [40,103]. The membership of the teams is deliberately chosen to mix people based on their expertise and position in the university, or student groups are formed on a voluntary basis [103], and while some teams can have wide variation, others can have members with similar strengths and ranking. Each team is given a problem. Some problems can be matched to the expertise of the team, and other problems can be outside their normal expertise. Moreover, some problems can be engineering in nature, while others can be social or focused on finance. The literature analysis shows that all problems were given by the instructor. When students receive a problem, they analyze it and try to understand it as widely as possible. Only in one article was it was stated that the students formulate and solve real problems by planning the project, allocating resources and managing group work, and selecting and applying theoretical knowledge [3].

- Explore the curriculum

In this stage, after defining the base problem, teachers, supervisors, and students decided that they should begin to examine the necessary content [40], identify the problem, generate hypotheses, and further identify knowledge gaps [29]. Sharing opinions among students leads the way to action planning and finding the causes of problems [24]. This is part of cooperative learning, which is an educational approach that aims to organize classroom activities into academic and social learning experiences. It is noteworthy that students usually find that courses including the discipline-specific elements as well as the interdisciplinary PBL activities are more closely linked to research across the faculty than with industry partners [104].

A well-developed PBL task should reinforce the learning of concepts and theories, and improve students' problem-solving skills; it should have enough technical breadth and depth to challenge students and initiate their independent learning [36]. In classroom-based PBL, the instructors act as facilitators, walking around the groups while providing advice and discussion for the students. Some lectures can be provided to support project work in addition to a list of suggested materials on the course platform via online learning sources [44]. At this stage, the teacher makes an effort to encourage students to gather relevant information, conduct experiments, and obtain enlightenment in problem solving [105]. Then, students seek intended learning objectives during their own independent learning [29]. Research conducted by [24] reveals that the perceived richness of online discussion forums has a significant positive effect on student interaction and learning at this stage.

- Resolve the problem

Not all approaches to PBL emphasize that problem solving during learning is necessary. To decide upon a solution, group members have to consider the most accurate hypothesis for problem-solving by taking into account the synthesized information. If there is more than one seemingly accurate hypothesis, students are required to rank them according to probability [24]. The literature analysis shows that most teams applied content knowledge to solve the problem and discussed the problem space to assist in the development of a solution [37]. Typically, the problems solved in the analyzed literature were real-life problems [16,76,104,106]. The problems were solved and the PBL method was most commonly used throughout the course [36,77] or for a couple of weeks [16,95,101,104].

4.5.2. Implementing PjBL

The analyzed papers describe the implementation process. However, it does not always follow the same stages, nor do the papers provide detailed information on the implementation on the same level of informativeness. The aim of every paper differs and often the implementation of project-based learning is the method to achieve them, but not the main focus of the investigation [107]. The results are organized following the separate stages of the implementation, but not all of them give a detailed account of each stage. For instance, papers often merge aspects of the plan and research [56,62], which are important stages, especially For novice teachers and/or implementers.

Teamwork is an important aspect that emerges in the papers analyzed; aspects such as the number of teams and the composition of the roles are explained [107]. The tendency is to organize between four to six members with diverse profiles and competences into teams when possible [85]. The teams typically have a team leader who facilitates the teamwork and often acts as a link between the team and the teacher or group of teachers [108]. The development of soft skills, such as cooperation, communication, or creativity, among others, are usually pointed out as competences to develop while implementing PjBL [73,109].

- Question

All of the papers that report on implementing PjBL indicate that the process starts with a question to solve; although sometimes instead of a question, it is identified as a problem to solve, especially when the project is related to a real situation or involves external stakeholders [84]. The project initiates when the teachers or external stakeholders present a real situation (or several), and the students in teams start to reflect on it and to generate different questions that need to be solved [110].

- Plan

After each team defines a question or a real situation to solve, they generate possible solutions, sometimes using techniques such as brainstorming to generate as many possible options as they can to enhance innovation and offer creative solutions. In this stage, students also agree on a plan to develop the end-product [73].

- Research

The results show that in order to connect some of the scientific concepts of the subject, where the students are enrolled, research is necessary before starting the construction of the final product. Research involves a review of the literature, but also learning from other similar experiences, and if stakeholders are involved, getting to know their context better [111].

- Produce

All of the subjects implementing PjBL were aiming to co-create a solution related to an end-product. The development of this product allows the students to learn during the process and to connect real science and technological problems to students [112]. The development of the product requires students to proceed in a spiral learning process where the students, in teams, learn, co-create a prototype, validate with the teachers, sometimes also with peers and stakeholders, and pilot the implementation [97]. After the implementation, the process can start again to adjust and improve the product [73,83].

This stage is related to producing the final product. It involves the first step of prototyping the product and validating its use [113]. The second step is the creation of the end-product or solution to the initial answer. The produce stage is related to the improvement stage in the way that the final product can be improved during all of the time the subject is taking place [54].

- Improve

All of the papers reporting on implementing PjBL include a process of improvement after testing the possible solution(s) or product(s) created. The validation could involve teachers, peers, and stakeholders. The analysis of the papers shows that this process is often not described in detail [114].

- Present

The implementation stage always finishes with a solution that can be related to a final product that is shared in different ways [83]. Depending on the project and the persons involved, the solution is presented to the teachers, the peers, and the stakeholders [84,109]. Not all of the papers analyzed explain in detail how the presentation is developed and organized, but it is noted that they can vary in format or extent. For instance, some of them are oral presentations, posters, artefacts, written essays, or scientific papers. An important finding is that the intellectual property of some of the products is discussed aiming that students get more consciousness about the importance of it [114].

4.5.3. Implementing CBL

The Tec21 model [62,67,68] and implementation described in [61] has four phases for teachers. The first one is about designing the general structure, starting with partner scouting and later on followed by disciplinary and administrative work with the partner. This phase also includes intensive pedagogical training of the teacher. The second phase focuses on the development of the modules and the challenge. It includes pre-start activities as student's enrollment. The third phase for the teacher(s) involved coincides with the first phase for students. In this phase, work on challenges starts with weekly meetings with academic staff as well as training partners. The fourth phase encompasses the final delivery of the solution, evaluations of the process by surveys, and student grading.

For learners, mostly two phases were described. First, a phase that combines orientation (what is expected of them, explanation of the grading system, as well as access to resources and content modules) with knowledge gathering and gaining the base foundation on which they will solve the challenge and develop the solution. The second phase (mostly about more than half, up to two-thirds of the time) students spend all of their time in the company or labs to develop a prototype. In most cases, this phase is finished when a solution is presented to the challenge provider/training partner and the final survey about learning experience is filled. Challenges can be executed in a full business week [65], but were mainly described as a whole term experience (Tec21 model, [61]).

4.6. Stages of Instructional Design Development: Evaluate

The final stage of the ADDIE model deals with evaluation [75]. In this stage, the teacher evaluates a number of course-related aspects, such as students' learning outcome, suitability of the resources, tasks that were used, etc.

All information obtained in the PBL process is shared, discussed, and assessed among members [101]. The feedback is given during the course to help and motivate students [76]. Various assessment methods are used cumulatively towards assessing skills throughout the semester. These include inquiry updates [26,103], post-problem self-evaluations and peer evaluations [16,26,94], concept maps [16,94], written and oral presentations [26,76], and written assessment [24,76,94]. The assessment model might be structured in the following way [40]: make an assessment of the results based on such criteria as: suitability, complexity, clarity, significance, and innovation, by determining exactly how each group was configured. Moreover, students can be assessed by employing five domains: content, process, results, performance, and client satisfaction.

The evaluation of the students' work is usually done by the teacher, but often there is heteroevaluation in some tasks, the peers or external stakeholders being the ones who evaluate the work and validate the product during the process [115]. Tasks, such as a written report, a prototype, homework, exams, the implementation, the presentation, or the final product, are evaluated, as well as the team performance [83,111]. The evaluation takes place in different moments during the implementation process and different formats, sometimes using instruments such as rubrics [116,117].

Overall, four different instruments were used to collect qualitative and quantitative data about implementation of the three active learning methods, as well as to evaluate learning. Student surveys with closed-ended and open-ended questions were the primary source to gather the information of the learners. They were used to collect their opinions about the learning experience, gain in knowledge and skills, or changed attitudes by self-rating or information about their motivations (e.g., the Motivational Diagnosis Instrument for Engineering Education, as described in [65]). Student surveys were often accompanied by student interviews with which opinions about learning experience and how committed students felt were also collected. As the third instrument, field notes were described. They were used to keep track of the motivation and creativity of the students, as well as the experimental progress and development to make adjustments, if required. The fourth instrument described were sets of exams records. Those could include all challenge deliverables and competencies rubrics or reflection papers addressing students' attitudes, values, or development in creativity.

4.7. Teacher and Student Attitudes towards the Implementation

4.7.1. Reported Attitudes in PBL

Research results show that the achievement motivation of students of the PBL class was higher than the achievement motivation of students of the conventional class [26,78,118,119] because it followed their interests and used problem solving to stimulate learning, while also communicating comfortably with their lecturer and friends when questions arose [24]. It is also stated that that teams moved through positive and negative emotions over the course of developing their solution, toward reaching satisfaction [1,37]. Some participants expressed "nervousness" and "feeling insecure" at the beginning when they were unsure exactly what would happen [1] and when they were trying to cope with a new learning method that required them to use skills that they did not have [103], such as high self-motivation or the ability to be motivated by long-term rewards [102]. This is also described as a "culture shock", when students transition from passive roles in the traditional lecture-based classrooms to leaders of their own self-directed learning [4,23].

In the process of learning, learners play the influence of the problem-based learning strategy on enhancing roles of active problem solvers, and are responsible for learning and cultivating self-oriented lifelong learning skills, problem-solving competence, and communication skills for teamwork [4,23] and conflict resolution traits [5]. Communication skills (with a lecturer, but also with other students) are gradually more efficient through iterative interactions [22].

There is only one mention that PBL implementation allows for the deep understanding of topics [120].

One of the critical points more highlighted in the literature is that students, especially novice problem solvers, are motivated by finding a solution rather than gaining a clear understanding of the task and tend to adhere to relatively rigid structures and minimize effort when tackling unfamiliar ill-defined problems [29]. It is also stated that novices are often known to skip the step of developing a deep understanding of the problem, and attempt to quickly apply equations or solution methods that match the problem on surface features [16].

The teachers' role in PBL is very well described in the literature (e.g., [27,35,80]) as a learning facilitator, coach, or guide as they become partners in learners' problem solving [26,80]. Changing the role as a university teacher—from master of knowledge to a learning facilitator—is not an easy thing because it involves a lot of communication, discussion, mutual interaction, group work, reading, writing, teamwork, drafting, and presenting in class, which takes a lot more effort/workload on the part of staff [5,36,76,80,102]. Moreover, PBL requires the instructor to be more prepared and expert in designing problems, coaching students, and evaluating student performance and experiences [5,102], so extra training is essential for lecturers and tutors [36,102]. Some key tasks that are defined as essential are:

- to enforce the teams strictly following the course schedule and abiding by all the deadlines [78];
- the effective communication with the students [78];
- to be cognizant of the frustrations associated with PBL for students [78];
- to organize overall class discussions, small group facilitation (as a floating facilitator), or provide scaffolding activities to support students in acquiring needed skills [103];
- to adopt suitable facilitation techniques for students' active participation [35];
- to be able to craft and create at least five basic types of questions—factual, divergent, convergent, evaluative, and combinations of those mentioned [34];
- to resolve team conflicts through diplomatic and negotiation skills [35];

- to ensure an appropriate level of participation and the optimum use of resources in order to increase group effectiveness [35];
- to be aware of how their students participate in small group discussions, and thus adopt suitable facilitation techniques to encourage active student participation [35].

4.7.2. Reported Attitudes in PjBL

It should be noted that the analysis of the collected PjBL papers reveals that not all papers report on teacher and student attitudes towards implementing PjBL. When such attitudes are addressed, the authors mainly report on: (i) the attitudes towards the method and its advantages; (ii) the position on different aspects of students' attitudes, behavior, and learning outcomes; or (iii) a combination of both. To exemplify the latter case, [89] notes that because of PjBL, students not only developed the technical competences, but also gained a number of transversal competences that are an integral part of the method, namely, "communication, teamwork, time management, and problem-solving" (p. 133). Students in numerous studies confirm the same outcome (e.g., in [121]), also emphasizing that the process of building such competences was enjoyable (e.g., [122]). Interestingly enough, one study reveals the opposite outcome, i.e., that the aforementioned transversal competences were not enhanced because of PjBL; however, the researchers believe that this result is caused by freshmens' inability to objectively judge what competences they will need in their future professional life [121].

Furthermore, a number of studies, such as that of [121], affirmed that students' attitudes towards their profession changed for the better after getting more hands-on experience and developing the project.

Another important positive outcome indicated by the aforementioned authors is that the implementation of PjBL as a teaching and learning method may also result in an increase of teachers' reflection on the course design, delivery, and other course elements, as well as result in more collaboration between course teachers and other experts who are not necessarily responsible for the course delivery. Based on a variety of positive experiences, PjBL teachers also state that the method allows students to build on the previously gained knowledge and combine it with the new knowledge to develop the projects into a successful outcome [123]. More importantly, students found it valuable to apply their technical knowledge for trying to solve the issues of the area relevant to them, which, in turn, also resulted in the increase of interest in engineering [124]. Furthermore, students expressed their desire to have more PjBL-based courses as they were found to be not only interesting, but also useful (e.g., in [125]).

Overall, some authors, such as in [126], state that teachers have a more positive take on the outcome of implementing PjBL as a teaching and learning method. In some cases, the attitudes of teachers and students clash. For example, ref. [126] found that both teachers and students felt that learning via PjBL did not help to achieve the course aims. In [123], students claim that what they learned while developing the project was not useful to other courses taken in the study program. In addition, ref. [127] notes that students criticized the time given to develop the project, whereas the course teacher believed that students simply did not manage their time spent on working efficiently enough.

Time given for developing the project is very important. In the study in [124], students claim that lesser learning outcomes were achieved due to the lack of time and the project being introduced too late in the course, which resulted in them having to rush too much, where more assistance and time for consolidation was needed.

Despite the abovementioned, in general, studies selected for the analysis report positive students' attitudes towards this active learning method. The study in [128] revealed that this type of learning was perceived as beneficial and, moreover, increased students' interest and enthusiasm. An important finding, however, is that despite the positive feedback on active learning, where students are given more responsibility on controlling the learning process, they report that it was easier to grasp the course material when a slide presentation was also delivered [128]. In a similar vein, ref. [124] report that, in addition to tutorials, visual materials aided in understanding the whole task and its process. However, the authors also note that at times students struggled because of the lack of clear instructions and constant feedback, which would help to avoid building the project on errors. Having clear instructions and proper preparedness is essential when a new teaching/learning method is implemented. The study in [123] reported that students were not ready for active learning and managing their own learning; moreover, they were reluctant to contact their teachers for assistance, whereas the latter were anticipating students' pleas for help when needed.

Active learning methods require students' active role in all steps from the initial research to final presentation, and some studies (e.g., [129]) reveal that they are not willing to engage in some activities that are not always typical for traditional learning, such as peer evaluation or regular review meetings, which might take too much time off from developing an actual project.

4.7.3. Reported Attitudes in CBL

It was stated that openness, independence and self-responsibility are too unfamiliar to the students; therefore, they find it difficult to deal with [62]. CBL requires learners who are eager to learn to be proactive and committed to the development of competencies [68]. Once students overcome their resistance in, for example, making individual decisions or working with challenges that have not yet been solved [68], good performance could be achieved.

Concerning teachers, the model demands a transition from lecturing to facilitating and mediating. Unfortunately, the analyzed papers only describe roles and attitudes expected to be necessary for teachers towards the implementation of CBL, while their individual experiences have not been investigated as closely as those of the learner. No results of surveys, questionnaires, or interviews addressing teachers could be found.

4.8. Teacher and Student Roles

First and foremost, the roles of teachers and students change dramatically in student-centered active learning, be it problem-, project-, or challenge-based learning. The study in [100] differentiates between four teacher roles in active learning. They are as follows: (1) professional coach; (2) project coordinator; (3) motivator and facilitator; and (4) evaluator of knowledge and skills. Other analyzed papers emphasize that the teacher becomes a facilitator, whose essential task is to guide the students, monitor sessions, and inspire discussions when student teams are working together [35]. Interestingly enough, it is emphasized that there must be some limitations on the role of the teacher, and s/he can only monitor the process and assign roles to the team members [35]. Some studies also emphasize that in guiding students, teachers should also aim to provide students with not only group feedback, but also personal guidance [130]. Furthermore, in addition to the changed roles and activities, some of the teacher-centered education elements are kept. For example, teachers need to organize students' learning (including adapting it to any challenges encountered on the way), so that they have enough time to reach the learning goals and have sufficient resources in doing so [93].

It is important to note that for teachers, such change of roles, might be difficult to handle [4]. On the other hand, students might also find it stressful, so it is also reported that the teachers' role in reducing it via communication is very important [78]. To avoid stress and confusion, teachers also introduce the students to the course design and previous students' works [96,109]. Moreover, teachers should expect that students might feel afraid and find it difficult to handle uncertainty and self-learning [68,131]. Furthermore, if the course is delivered in a new format, especially via distance, students are given clear instructions and explanations on how such more complex learning will take place, because despite the promises of a potentially more engaging format, students still need motivation to study through new media and ICTs [99]. Studies report that students lacking digital literacy skills did not feel motivated to engage in technology-enhanced learning because they were not given the necessary skill set to do it [132]. It is important that in the process, teachers also discuss students' progress with them and reflect on it in order to adjust pedagogies, and add new resources, etc., if needed [70].

Studies also indicate that teachers are able to engage in new activities, such as searching for international companies that would agree to get involved in consulting students, giving them feedback, visiting laboratories for testing prototypes, etc. [96]. In addition to establishing a connection with the industry and finding such a partner who would be willing to share their data for building the projects, the instructor also needs to act as the mediator between the students and the external stakeholders, helping them to establish rapport [116].

Other papers report that in addition to mentoring and facilitating, teachers must continuously track whether the planned learning outcomes are being met, and, if needed, make changes [34].

Furthermore, even though teachers take a secondary role in the process of teaching/learning, they also become learners who, together with students, explore the path towards solving a particular problem [80].

The most typical aspect of such active learning methods is to organize the learning process through teamwork. Students are typically assigned into teams, where they get specific roles and responsibilities. For instance, it is reported that such roles and responsibilities might include leadership, orientation, monitoring, coordination, communication, feedback, giving feedback, seeking feedback, receiving feedback, backup behavior, backup seeker, and backup supporter [37]. One of the analyzed studies reports that students mostly took up the roles of orientation, leadership, feedback provision, and communication, whereas other behaviors were two or three times less commonly adopted, albeit not being of lesser importance (ibid.). The study in [28] emphasizes the importance of students taking up different roles and responsibilities, as well as consistently working together, e.g., holding regular meetings, visiting target communities, etc.

It is often the teacher's responsibility to carefully devise a strategy to assign students into teams. The study in [26] notes that it might be complicated to make such choices, because in some cases, distributing academically strong students across the teams might help them motivate others as well as themselves to work harder, whereas in other cases, it might be demotivating. To ensure fair distribution and monitoring of work, as is reported in some analyzed papers, teams had moderators who kept track of everyone's contributions [26]. Even though teamwork is an essential part of active learning, teachers might also have to deal with students' resistance because they do not appreciate the pressure they experience when not all team members are performing with the same effort [37]. According to [5], due to unequal work distribution, because of an unknown new way of learning, and numerous other reasons, students might enter into conflicts, which must be resolved in order to successfully finish their projects. In some cases, to anticipate and prevent conflicts, student teams were asked to develop their own rules for solving conflicts (e.g., [85]). When there are issues with teamwork distribution, for the final evaluations, the teacher might examine the students as the whole team, asking them questions and allowing them to randomly answer or ask individual students to respond [26].

The study in [93] notes that in active learning, the dynamics of the roles held by teachers and students might change fast, and very often, students might have to act as teachers themselves to assist a struggling team member. For instance, in [78], to level the gaps in the missing knowledge, students filmed videos to each other. Scholars note that to successfully implement such active learning methods as CBL, teachers need to change students' mentality and attitudes towards learning [65].

4.9. Reported Learning and Behavior Outcomes

In student-centered learning, motivation to engage in the learning process actively is essential. The analyzed research on PBL, however, indicates that the levels of student motivation did not always increase because of introducing this new method of learning [106].

Some students need to readjust their usual roles and workload to accommodate filling the activities that used to be performed by teachers, e.g., searching for information, which for students might accumulate to 2/3 of the entire time spent on one course [43]. Moreover, as is reported in [29], students, misjudging the seriousness of the problem and its potential solution, are likely to look for more simplistic solutions, which needs to be overcome. On a more positive note, in PBL, students report on their progress multiple times throughout the course, so teachers can track it rather easily. As a result of PBL, they become efficient and more critical presenters [76]. In general, a number of studies also report that because of PBL, students were able to improve in areas such as the fundamental skills and competences of the discipline, including data preservation and processing, business logic, public speaking, presentation, as well as teamwork, goal setting, and time management (e.g., [26,28,118]). Other studies also report on an overall improvement in students' achievement compared to traditional learning, especially in them becoming more innovative [23].

PjBL papers report that students improved not only their knowledge of the specific engineering area, but also their technical skills of hardware and software, which were implemented in practice to develop a working solution (e.g., in [86]), on students achieving cross-curricular learning objectives that are desired in real-life work practice, outside the universities. In addition to that, students also got a variety of other learning gains, such as self-confidence, self-efficacy, and creativity (e.g., [86]), other higher-order skills, such as the ability to create, evaluate, and analyze (e.g., [97]), and becoming more entrepreneurial (e.g., [100]). In addition to the aforementioned, students report to have become better at organizing, planning, and problem-solving as well as more likely to strive for innovation and know how to deal with the unexpected [47]. Because in a lot of cases while developing the projects students had to either work within or consult intercultural teams, they report having improved their cultural competence (e.g., [92]) and became more open, flexible, and original (e.g., [56]). Furthermore, it can be claimed that students enhanced their global competence as they tried to find solutions to problems that are not only of local, but more global significance as well (e.g., in [92]). Finally, developing the aforementioned competences motivated students to improve their attendance, which also resulted in a more dynamic classroom working environment (e.g., [133]).

In higher education, CBL has the potential to foster learners' disciplinary and transversal competencies. Disciplinary competency includes the knowledge of theoretical concepts as well as the ability to apply such knowledge. Transversal skills that could be addressed include applied ethics, and effective oral and written communication, but also competencies needed in the workforce, such as collaborative work, project management, leadership, resilience to failure, competitiveness, confidentiality in results, and critical analysis, as well as thinking and creativity [62,71]. Additionally, a positive motivation to be able to continue one's learning process and to contribute to the teacher–learner relationship is of importance [64,65].

5. A Comparison of Findings

Previous scientific papers that contain comparisons of active learning methods focus on different layers of the implementation. Unlike other systematic reviews of the literature, the present paper compares the three methods across the dimensions that correspond with the stages of the ADDIE model, supplemented with such additional important dimensions as the role, attitudes, and behavior outcome of teachers and students (see Table 2).

As seen in Table 2, surprisingly, the majority of papers do not elaborate much on the different stages of implementation design; the found instances are summarized and described above.

Table 2. A comparison of the findings.

Dimensions of Comparison	PBL	PjBL	CBL
Analyze	The teachers implement PBL with the aim to address: (1) students' lacking practical skills; (2) students not being able to use their knowledge in practice; (3) educating life-long learners and independent thinkers; and (4) empowering students to live in a knowledge-based economy, future, and ever-changing context.	Teachers implement PjBL with the aim to: (1) improve students' meaningful learning and deep understanding, and (2) connect theory and practice of solving problems typical in real-life work contexts.	Teachers implement CBL because it is a university policy or initiative, or demand from external stakeholders.
Design	The teacher decides when, why, and what situations might be formulated as problems.	The design stage is related to the analysis stage; the teacher makes decisions about the implementation and the use of technology, composition of teams, and inclusion of external stakeholders.	The teacher designs the course so that students can take responsibility of their own learning.
Develop	The teacher discusses the updated course content, etc., with other teachers.	The develop stage is not described in depth, but some information relates to learning resources, such as online tools to assist students in the learning process. Furthermore, innovation management tools, such as "Bono hats, TRIZ . . . ". Some include guides for students. Some papers include information about work groups composition and the impotence of group formation. For validation, some papers include the importance to work with a team of teachers and companies.	Not described.
Implement	Teachers facilitate students' self-directed learning process, in which students decide what to study based on the problem case, question, or scenario that drives their learning. Working in teams and individually, students develop a problem solution.	The process does not always follow the same number of stages, they are often merged. Building teams with diverse profiles and competences and teamwork are very important aspects. The process is facilitated by the teacher and team leaders who act as a link between their teammates and the teacher.	Teachers, partners–trainers, and students first meet to discuss the expectations. Students later take theory classes and visit the company that is going to consult them. After that, they continue learning theory in their classes and spending extra time on solving the challenge. Prototypes and simulations are developed, which are later improved and implemented in a physical environment.
Evaluate	Evaluation is done by teachers and, in some cases, by external reviewers, such as the scientific staff. Students also give each other peer reviews. Often, there is no final examination, and students are evaluated based on their reports and presentations. All evaluation is done based on rubrics.	Evaluation is done by the teacher and is often supplemented with peer review and feedback by external stakeholders. Students are evaluated based on rubrics that assess different aspects of their written reports, prototypes, exams, presentations, overall performance, and final products. All evaluation is done based on rubrics.	Evaluation is done similarly, as in PjBL and PBL. A slight difference is inclusion of self-assessment. All evaluation is done based on rubrics.

Table 2. *Cont.*

Dimensions of Comparison	PBL	PjBL	CBL
Teacher's role	The teacher is the learning facilitator, coach, or guide, as well as a partner in problem solving. The teachers' role in PBL involves a lot of communication, discussion, mutual interaction, group work, reading, writing, teamwork, drafting, and evaluating the students' presentations in class. PBL requires the instructor to be more prepared and an expert in designing problems, coaching students, and evaluating student performance and experiences.	In PjBL, teachers design a course, and make decisions on how and to what extent to involve industrial partners. Teachers are facilitators, they monitor students' work at different phases of PjBL, they also are the link between the students and the industrial partners. Sometimes teachers create environments where students have to change their roles to being experts in the field.	Teacher transitions from lecturing to facilitating and mediating. In CBL, teachers are challenge designers, coaches, tutors, mentors, evaluators, and coordinators of different parts of the learning process. CBL loves team teaching. A team from different fields/disciplines may teach together as well as different persons not being teachers by profession might teach together.
Student's role	PBL promotes roles of active problem solvers, and cultivates self-oriented lifelong learning skills, problem-solving competence, and communication skills for team work, including conflict resolution.	Students are active learners; they are at the center of PjBL activities. They are team members who work autonomously, but in teams, make autonomous decisions, deepen their knowledge in the subject, work on real world problems, and "taste" future jobs.	Students take ownership of their challenge. That is their task to: • define their own challenges (the problems they want to work on) • take over responsibility for team composition • acquire the necessary knowledge and skills to solve this challenge.
Teachers' and students' attitude	A "culture shock" is described when transitioning from passive roles in the traditional lecture-based classrooms, especially to students in becoming leaders of their own self-directed learning: teams move through positive and negative emotions.	Teachers prefer PjBL, as it provides a real-world problem-solving setting; they work close to industrial partners and prepare students for their future jobs and professions. Students become active and core elements of the study process. Students have the opportunity to realize what their future job is about and make better decisions if they want that for themselves. Usually, they like to have a better understanding of their profession and that motivates them more.	Not all students were ready to become active and autonomous learners and preferred to learn in the traditional way where everything is prepared by the teacher. Students are afraid to take on a challenge that has not been solved yet.
Learning and behavior outcomes	Motivation of different levels is reported. For students, taking up new roles takes much more time and effort compared to traditional learning. Students' fundamental skills improve.	Students gain engineering and technical skills, real-life practice, and intercultural competence.	Students develop and improve their interdisciplinary and transversal competences.

When it comes to the first stage of instructional design, namely, analyze, very few papers explain the teachers' actions and decisions. When providing background information on why active learning methods have been chosen for implementation, in PBL and PjBL papers, teachers are reported to focus on addressing the gaps in students' knowledge, lacking competences, and preparing them for solving real-life problems. The literature on CBL also acknowledges an important reason for implementation, which is top-down initiatives of the higher education institution or their partner organizations (e.g., business and the industry). In such a case, it is important that such teachers get a lot of support in training and implementation. That is because earlier studies report that when teachers are not making changes through a bottom-up approach, they might experience feelings of resistance to change, fear, and uncertainty, which, in turn, might lead to ineffective implementation that might discourage teachers and students from engaging in active learning.

In the design stage, teachers make decisions about what problems might be tackled in the course and how it might be supported. Contrary to the initial expectations, teachers rarely enhance their courses with educational technology other that specific software that needs to be mastered in order to be prepared for professional life (e.g., Matlab, Mathematica, Maxima, and Maple in [98]). When additional tools are used, they are mostly employed for supporting communication and teamwork (e.g., Google Hangouts in [95]; Google Drive in Bisballe [66]; piazza.com in [37]; Slack in [65]). Interestingly enough, some studies, e.g., [68], report that the use of such platforms as Blackboard did not enhance the experience of active learning. This outcome might be due to some shortcomings of the instructional design, which emphasizes that the use of any educational technology needs to be carefully planned and have a pedagogical grounding.

In essence, from the evidence provided in the analyzed papers, the implementation stage is not too different across the three methods in focus. The key pillars are organizing teamwork and facilitating students through the entire process of trying to address a problem or a challenge. Interestingly enough, the majority of studies do not really differentiate between what is considered to be a problem vs. a project vs. a challenge, and understanding of these concepts seems to be taken for granted. This issue is mostly addressed in CBL as one of the stages of implementation for students to understand what a challenge is and narrow down what challenge they are going to develop a potential solution for.

When it comes to the evaluation stage, ref. [37] notes that in a higher education context, where active learning methods are implemented, students are often assessed based on the end product as opposed to developing certain skills and competences. It is also acknowledged that the evaluation of group work is a challenging task for teachers [37]. Moreover, teachers often combine different teaching and learning methods, so it is challenging to ensure balanced grading [76].

The study in [76] reveals that a constant tracking of students' progress through checking their work-in-progress presentations and giving them feedback motivates students to improve their work and try harder. Another alternative is to also keep track of students' progress reports [5,26] and explain that students can make group presentations with a specific time slot assigned to each student (e.g., 6–10 min), which might be followed by a group discussion on the outcome, where students elaborate on such stages of the problem solution as research on the problem, methodology, and the conclusions. The key issue in such a case is ensuring that all questions given to individual students are fair and truly capture the complexity of a student's contribution (ibid.). Another way to help students improve is giving them feedback and the evaluation rubrics that help them see what they achieved through learning within a team [27].

The outcome of the analyzed papers is that in all of the three active learning methods, teachers and students engage in new, often enriching, albeit challenging, experiences. In PBL, PjBL, and CBL, teachers give up their traditional roles and put students more in charge of their learning. Teachers need to accept that they are not the sole experts anymore, but have to function as a lenient support mechanism for students. Moreover, teachers become learners themselves. Even though the analyzed studies report that both teachers and students might encounter a number of different barriers and experience culture shock, overall, active learning is mostly seen as a positive learning experience that enhances student's achievement.

6. Conclusions and Recommendations

The present paper provides a systematic analysis of the literature of 177 scientific papers on the implementation of active learning methods, namely, problem-, project-, and challenge-based learning. One of the motivations for this study is to clarify the three active learning methods by describing them, point out similarities and differences, and which ways they have been implemented in engineering education, and which ways they can be a promotor of sustainability integration. Overall, the three active learning methods enable the integration of sustainability from three main perspectives. First, the three share ground learning principles, namely problem orientation, contextual learning, self-directed learning, and collaborative. These characteristics aligned with education for sustainability [12]; however, there are limitations to take into consideration, and the share of learning principles do not guarantee the development of knowledge and competences for sustainability [10]. Therefore, sustainability integration needs to be explicit and it can be framed in different moments, or stages, of these active learning methods [134]. For example, the type of problems and situations engage learning goals, collaborations and partnerships, and students' and teachers' roles. Considering the differences between the three methods and the aims and characteristics of education for sustainability, challenge-based learning is presented as the most suitable and can be presented as an evolution of project-based and problem-based learning. In challenge-based learning, socially relevant challenges, involving different partners (from industry partners, to local communities) and processes of co-creation and participation, are the point of departure for learning. Furthermore, there are a few suitable places where, in particular, when it comes to CBL, we can address how this setting is very suitable to address the challenges as indicated in the Sustainable Development Goals (SDGs), as they are unsolved problems. Having students freely choose those big issues/challenges and be part of defining what angle of a challenge they want to solve within the larger challenge is crucial to succeeding in solving the challenge. From all of the SDG's perspective, there are engineers as well as various other disciplines necessary to tackle those multi-faceted problems. We need to organize our learning and acting in multidisciplinary ways to include the perspectives of ethics, medicine, and sociology to just name a few. This review of the literature focuses on the different stages of instructional design, in order to address the confusion and differences of implementation between the different active learning methods that have been widely noticed and reported in a number of scientific papers, conferences, and practitioners' blogs, etc. The paper discusses the findings based on the reported teachers' activities, aligning them to the ADDIE (analysis, design, development, implementation, and evaluation) model and supplementing by additional focus on the role, attitudes, and behavior outcomes of teachers and students. Other motivation is also to provide recommendations for teachers, practitioners, and researchers to re-design their teaching and learning practices as a first step towards education for sustainable development.

The authors of the paper would like to suggest recommendations that are two-fold, namely, for researchers and for teachers–practitioners. When it comes to the recommendations for the former, there is a need for more research (especially longitudinal) on active learning methods that is based on bigger samples and focuses on other aspects than attitudes towards implementation and perceived learning outcomes. From the pedagogical side, more studies are needed to better understand and improve teachers' as instructional designers' skills, especially when the interventions in engineering education need to be enhanced with ICTs. Papers analyzed in the present paper rarely report on enhancing teaching/learning with other technology than the software needed for performing tasks related to engineers' day-to-day practice.

According to the findings of [92], the fact that students know technical knowledge does not mean that they will be able to communicate it, especially to an audience of non-experts. This suggests that together with developing the technical skills, teachers should also consider incorporating improving students' communication competences. A similar need is also expressed by the Accreditation Board of Engineering and Technology (ABET), which, according to [92], notes "that engineering students should be capable of communicating effectively, working on multidisciplinary teams, and understanding the broad impacts of their work in global, economic, and social contexts" (p. 42). In addition, it is also very important that whatever problem students are about to tackle is relevant to them [135]. The study in [53] notes that allowing students to make mistakes might be a great learning opportunity. It is important, however, that course teachers create an environment where students feel comfortable to make mistakes and learn from them.

It is suggested that active learning approaches should not replace traditional academic learning [53]. Nevertheless, to achieve the best results, teachers are encouraged to supplement lecture-based education with hands-on experiences (e.g., in the lab) and closely collaborate with the industrial partners, organize visits, and look for possibilities for students to join projects that are run by the partner organizations [136]. According to [96], collaboration with industrial partners is essential "to sustainably provide the resources necessary for prototyping, international field-testing and long-term career development opportunities to our students" (p. 168). Furthermore, industrial partners might serve as an important and motivating source of feedback on students' work and ideas [53]. In addition to that, scholars emphasize the importance of modern engineering programs adopting a multidisciplinary approach for developing the technical and transversal competences, as well as generating more students' motivation and engagement [137]. Moreover, it is important that the development of technical, transversal, and other competences in a particular course is connected to the study aims, content, etc., of other courses as well [47].

In contrast to traditional lecture-based education, active learning typically drastically reduces teacher-centered instruction, and students are expected to actively seek for knowledge in various sources. It is essential that students are made aware of their vs. the teacher's role in active learning because students, to whom this way of learning is new, might not even perceive such learning as normal [138]. It is also important that teachers welcome the shift from teacher-to student-centered education, where instead of the main knowledge provider, they become facilitators and learn together with students, also trying to establish informal relationships with students outside the classroom context [35]. Studies, e.g., [124], also reveal that students still prefer receiving instruction, at least in the format of tutorials and screenshots. Students' self-directed active learning can also be supported by clear instructions, screen-capture, and video and audio explanations, as well as constant feedback mechanisms (e.g., self-check opportunities and communication with the course teachers) [124]. Another related issue is assessment. The analyzed studies highlight the importance of peer-assessment and techniques to assess the equal distribution of work within teams [127].

Studies report on students struggling with the time given to familiarize with the new learning method and developing the project. Therefore, when designing active learning scenarios, teachers might want to consider assigning a separate time slot for introducing the students to the new learning method and teamwork, as well as equipment or technology that is going to be used in the course, which, in turn, is expected to kick-start the course work more efficiently [86,109].

It has been found that active learning methods allow students to build on their previous knowledge. However, it is also important to acknowledge that students might have varying degrees of the prior knowledge and competences, and the pace of acquiring new competences might be drastically different, thus it is suggested that students document their progress in a great detail, so that teachers can make an intervention if needed [86]. For this, ref. [53] suggests to employ relevant project management tools that would allow students to work collaboratively and build up their progress.

Since active learning requires an investment of time resources that sometimes also exceed what has been initially planned, scholars suggest that both teachers and students need considerable institutional support [109]. Students might need assistance in acquiring the necessary information, tools, other resources, and most importantly, have access to the course teacher(s) or tutor(s) who can support them fast with whatever they might need, be it methodological or psychological help [125]. For this reason, some studies do not recommend implementing active learning methods with larger groups of students (e.g., [127]). Finally, teachers might need additional training and consultations in order to be able to implement any of the active learning approaches in their courses [89]. In these scenarios, teachers could greatly benefit from exploring learning analytics to monitor students' progress, give feedback, and design interventions [37], especially if such educational interventions are enhanced with Information and Communication Technology [132].

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