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METHOD FOR RISK ASSESSMENT OF PROJECT-BASED LEARNING FAILURE VIA AHP AND BBN AIMING AT IMPROVING THE QUALITY OF ENGINEERING EDUCATION

Método de avaliação do risco de falha na aprendizagem baseada em projetos via AHP e BBN com vista à melhoria da qualidade do ensino da engenharia

Método de evaluación del riesgo de insuceso en aprendizaje basado en proyectos vía AHP y BBN con vista a la mejor calidad del ensino de ingeniería

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Abstract: Project-based learning (PBL) has become a prominent approach in engineering education, fostering students' professional knowledge. However, universities often encounter unforeseen challenges with PBL, leading to a return to conventional teaching methods. The complexities of PBL introduce numerous variables, increasing the risk of failure. This study proposes a method to identify risk factors in employing PBL for teaching engineering students. It involves assessing risk probability and impact to derive global risk scores, utilizing the Bayesian Belief Network (BBN), and crafting responses to high-scoring risks. A case study validated the method, gathering data from various sources. Risk factors were identified, categorized, and assessed using a survey and Analytic Hierarchy Process (AHP). BBN and sensitivity analysis identified

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high probability risks, allowing for the formulation of response actions. The proposed method enhances the PBL process, offering a proactive risk mitigation process and insights into the education sector that benefit professors, students, and decision-makers.
Keywords: active learning; engineering education; risk ssessment.

Resumo: A aprendizagem baseada em projetos (PBL) tornou-se uma abordagem proeminente no ensino de engenharia, promovendo o conhecimento profissional dos alunos. No entanto, as universidades geralmente encontram desafios imprevistos com a PBL, o que leva a um retorno aos métodos de ensino convencionais. As complexidades da PBL introduzem inúmeras variáveis, aumentando o risco de fracasso. Este estudo propõe um método para identificar fatores de risco no emprego da PBL para o ensino de alunos de engenharia. Ele envolve a avaliação da probabilidade e do impacto do risco para obter pontuações globais de risco, utilizando a Rede de Crença Bayesiana (BBN) e elaborando respostas para os riscos de alta pontuação. Um estudo de caso validou o método, reunindo dados de várias fontes. Os fatores de risco foram identificados, categorizados e avaliados por meio de uma pesquisa e do Analytic Hierarchy Process (AHP). O BBN e a análise de sensibilidade identificaram riscos de alta probabilidade, permitindo a formulação de ações de resposta. O método proposto aprimora o processo de PBL, oferecendo um processo proativo de mitigação de riscos e percepções sobre o setor educacional que beneficiam professores, alunos e tomadores de decisão.

Palavras chave: aprendizagem ativa; educação em engenharia; avaliação de riscos.

Resumen: El aprendizaje basado en proyectos (ABP) se ha convertido en un enfoque destacado en la enseñanza de la ingeniería, fomentando los conocimientos profesionales de los estudiantes. Sin embargo, las universidades se enfrentan a menudo a retos imprevistos con el ABP, lo que lleva a volver a los métodos de enseñanza convencionales. Las complejidades del PBL introducen numerosas variables, lo que aumenta el riesgo de fracaso. Este estudio propone un método para identificar los factores de riesgo en el empleo del ABP para la enseñanza a estudiantes de ingeniería. Se trata de evaluar la probabilidad y el impacto del riesgo para obtener puntuaciones de riesgo globales, utilizando la Red de Creencia Bayesiana (BBN) y elaborando respuestas a los riesgos con puntuaciones altas. Un estudio de caso validó el método, recopilando datos de diversas fuentes. Los factores de riesgo se identificaron, categorizaron y evaluaron mediante una encuesta y el Proceso Analítico Jerárquico (AHP). El BBN y el análisis de sensibilidad identificaron los riesgos de alta probabilidad, lo que permitió formular acciones de respuesta. El método propuesto mejora el proceso de PBL, ofreciendo un proceso proactivo de mitigación de riesgos y conocimientos sobre el sector educativo que benefician a profesores, estudiantes y responsables de la toma de decisiones.

Palavras clave: aprendizaje activo; enseñanza de la ingeniería; evaluación de riesgos.

1 INTRODUCTION

Student-centered teaching methods utilizing Project-Based Learning (PBL) have seen widespread adoption. However, universities often struggle to navigate unforeseen challenges during the implementation phase, leading to a retreat to conventional teaching methods. Consequently, it is crucial to identify, describe, and address risk factors that directly impact the outcomes of PBL. Notably, the current literature on using PBL in engineering education has not adequately addressed the risks of PBL failure. The study integrated a literature review and a case study. The methodology combined data from archives, interviews, questionnaires, and observations to pinpoint and list key risk factors associated with implementing PBL in engineering education. Awareness of these risks and how to effectively respond to them can enhance the success of PBL implementation, fostering improved student learning and offering a sustainable teaching approach within university settings. The primary objective is to propose a method for risk assessment utilizing the Analytical Hierarchy Process (AHP) and Bayesian Belief Networks (BBN). This approach aims to identify risks and formulate responses, ensuring the successful execution of PBL collaborations with local companies. The study addresses the risks associated with the Project-Based Learning Method in teaching engineering students, contributing to a literature gap. The diverse risk factors underscores the complexity of implementing PBL in engineering education. Failure to identify and appropriately address these risks could lead to the failure of PBL projects, with students, professors, and partner organizations falling short of expected benefits. This research is significant as it aids in the professional development of professors and students while elevating the quality of PBL and contributing to the sustainability of universities. Notably, the study focuses on project-based learning involving companies, an aspect overlooked in previous studies. None of the studies reviewed herein specifically delved into risk assessment and its impacts on PBL. Previous literature revealed that most studies on PBL addressed challenges but lacked a method for systematically prioritizing risks using AHP and Bayesian Belief Networks. The paper responds to the following research questions:

Research Question a): How can the most significant risk factors in using PBL be identified in teaching engineering students? Research Question b): How can the probabilities and impacts of these risks be combined to generate a risk index, and how can sensitivity analysis using BBN be conducted? Research Question c): How to define responses to high-scoring risks?

The paper is organized into five sections: the first introduces the study's concepts, the second discusses previous studies on PBL Risk assessment, BBN, and AHP, Section 3 details the methodology, Section 4 presents the results, Section 5 discusses the results, and Section 6 presents the conclusion.

2 PROJECT BASED LEARNING

Studies about PBL highlight its effectiveness in promoting active learning, critical thinking, problem-solving, collaboration, and other skills essential for academic, professional, and personal success. The importance of PBL is recognized in various educational settings to prepare students for the challenges of the 21st century. This section presents previous studies about the design of the PBL Method, Challenges and Risk Assessment of PBL Failure, the use of BBN (Bayesian Belief Network), and the respective application of these methods on risk assessment of PBL failure.

2.1 Design of PBL Method

Previous significant studies about PBL are presented herein. Palmer and W. Hall (2011) presented a PBL offering in engineering at Griffith University in Australia, observing that students generally enjoyed the experience, with aspects needing improvement listed and documented. Du *et al.* (2013) developed a framework of change in educational culture for sustainability using a PBL methodology, inspiring curriculum design for sustainability education. García-Martín and E. Pérez (2017) presented a method to guide teachers using PBL principles and instructional design models, focusing on fundamental issues in active learning. Marques (2018) proposed a formative monitoring method to enhance students' individual and team performance, with results indicating that PBL effectively enhanced the learning experience. Vathayan (2018) presented an experience of evolving a hybrid-teaching model over three semesters, using the action research cycle plan-act-observe-reflect. Setiawan (2019) conducted a study on implementing PBL, explicitly focusing on opportunities and challenges, where students chose their topics and explained their problem-solving approaches. Moliner *et al.* (2019) described the experience of using PBL in Materials Science courses conducted by Spanish universities, analyzing the perceptions of students and lecturers in the PBL process. Schneider (2020) used PBL to enhance student engagement. Daun (2016) discussed results from the long-term application of such a course design in a graduate setting, indicating that project-based learning techniques foster different teaching goals in graduate and undergraduate settings. Bhaskar *et al.* (2023) study identified and prioritized four main inhibiting factors. Institutional-level factors have secured the highest rank, followed by technological, operational, and personal-level factors. Merola *et al.* (2022) study explores how international student satisfaction is affected by certain aspects of the learning and living experience, including university reputation, size and proportion of international students, and student gender and stage of study. Nguyen *et al.* (2022) provided a conceptual structure and charts the evolution of human resource management research in higher education from 1966 to 2019. Using co-word analysis, the current study analyses 352 publications on human resource management practices in higher education from the Scopus database. Sousa *et al.* (2022) analyzed the organizational culture of two higher education institutions, one from Portugal and another from Spain, and how it has changed – or should be expected to have changed – following a modification in their legislative frameworks and mission definition imposed coercively by their governments in the transposition of European directives.

Previous studies show that project-based learning (PBL) is a teaching method that involves students investigating and solving complex, real-world problems. Various factors can influence the design of PBL, and educators need to consider these factors to create effective and engaging learning experiences. By carefully considering these factors, educators can create PBL experiences that are engaging, meaningful, and aligned with educational objectives. The flexibility of the PBL method allows for customization to suit the unique needs of students and the learning environment. However, many challenges and risks of failure exist in applying PBL. Item 2.2 presents some of the challenges and risks.

2.2 Challenges and Risk Assessment of PBL Failure

This compilation presents previous significant studies on the challenges of Project-Based Learning (PBL). According to the survey by Henderson *et al*. (2012), universities acknowledge student-centered teaching methods but encounter difficulties handling unforeseen issues during implementation, often reverting to traditional teaching methods. Kjellberg *et al*. (2015) assert that implementing PBL requires a holistic perspective on the project, where non-technical responsibilities are often ambiguously defined, contributing to an incomplete infrastructure and possibly stemming from a holistic project perspective and project management methods. They note that novice teams impact knowledge transfer and communication within extended teams, affecting group dynamics, commitment, and responsibilities. The author highlights the deficiency of teacher teams, leading to one teacher performing both the roles of examiner and project manager, and underscores the challenges posed by the "two-hats" issue, increasing teacher workload and inducing emotional stress due to a lack of tools, support, and continual concern for addressing emerging issues.

Beddoes *et al*. (2010) explain that challenges in PBL implementation and execution encompass theoretical and practical aspects. Theoretical debates persist regarding the optimal approach to incorporating PBL and the performance required for student benefit. Some engineering educators argue for a comprehensive integration of PBL across the entire curriculum, while others propose starting with small-scale initiatives to familiarize instructors with PBL incrementally. The evolving roles of teachers and students are recognized as significant barriers to PBL implementation by Prince and Felder (2006) and Strobel (2009). PBL is challenging because it necessitates a shift in perceiving learning and knowledge, and it can create difficulties for faculty and students, as Savin-Baden (2007) highlighted. Students may resist PBL due to the unfamiliar level of personal responsibility and potential conflicts within teams. Teachers, too, may struggle to adapt to PBL.

Furthermore, institutional challenges include resource allocation, program sustainability, scalability, physical facilities, and management, as Bielefeldt *et al.* (2009) noted. These diverse challenges collectively underscore the multifaceted obstacles facing the effective implementation of PBL in educational settings. Pereira *et al.* (2021) and Pereira *et al.* (2022) conducted a risk assessment of Project Based Learning Failure via Bayesian Belief Networks and the Analytical Hierarchy Process.

Previous studies have shown that project-based learning (PBL) is an instructional methodology through which students learn by actively engaging in real-world and personally meaningful projects. While PBL can be highly effective, there are challenges and risks associated with its implementation. Careful planning, ongoing teacher professional development, and continuous evaluation and adjustment of the PBL approach are essential to mitigate these challenges. Providing sufficient resources and support can also contribute to successful project-based learning experiences. Many risk assessment methods can be used to assess PBL failure. Item 2.3 presents previous studies on the importance of BBN, a method used in several fields.

2.3 Use of BBN (Bayesian Belief Network) in risk assessment

Bayesian Belief Networks (BBN) serve as a causal structure employed by specialists in probability risk analysis to gather information concerning significant risk events and the requisite interventions to mitigate risks (Mosleh, 1992; Rechenthin, 2004). The utilization of BBNs in safety, maintenance, and reliability has experienced rapid growth (Mahadevan, 2001). Bayesian methods, comprehensively applied in various contexts, offer a structured approach to address the limitations of human reliability analysis (Mosleh and Apostolakis, 1986; Droguett *et al.*, 2004; Groth and Swiler, 2013; Podofillini and Dang, 2013). BBNs have found extensive application in estimating risks related to corrosion (Yang *et al.*, 2016) and in facilitating knowledge acquisition of causal dependence in the Contextual and Human Factors Analysis (CREAM) through Bayesian Belief Networks (Ashrafi *et al.*, 2016). Moreover, Bayesian variables were crucial in analyzing regular resolution IV two-level fractional factorial designs (Chipman *et al.*, 2016). In a study by Mkrtchyan *et al.* (2022), a top-down approach was employed to derive key performance indicators (KPIs) for assessing the risk profile of refineries, explicitly focusing on fire and vapor cloud explosion events. Bayesian Belief Networks were integral to developing a probabilistic model to quantify the risk indication for these events by synthesizing knowledge from domain experts. Sharma *et al.* (2022) contributed to risk enablers modeling by identifying critical success factors for risk management and establishing cause-and-effect relationships between them, developing a Bayesian Belief Network (BBN) model. Zio *et al.* (2022) proposed a novel analytical framework that quantifies screen-out occurrence risk, identifies the riskiest scenarios, and determines optimal risk mitigation strategies using Bayesian Belief Networks. Notably, there is a scarcity of literature specifically addressing the application of BBN to Problem-Based Learning (PBL) risk assessment. Mkrtchyan *et al*. 2022; Sharma *et al*., 2022; Zio *et al*., 2022) stated that BBN methodology aims to facilitate more straightforward predictions of risk events by representing arguments within a structure that accounts for uncertainty, where nodes signify variables and arcs denote direct dependencies.

Bayesian Belief Networks (BBNs) have been widely used in various fields for risk assessment due to their ability to model and represent uncertain knowledge. Previous studies show that the field of risk assessment is dynamic, and new applications of BBNs have been emerging. Researchers and practitioners continuously explore innovative ways to apply Bayesian Belief Networks to address evolving challenges in risk management across various domains. BBN can be combined with other methods, such as AHP (Analytical Hierarchy Process). Item 2.4 presents previous studies on AHP.

2.4 Use of AHP (Analytical Hierarchy Process) in risk assessment

Saaty (1980) was the first to use AHP as a decision-making tool to provide the relative weight of criteria based on a hierarchy structure. The author proposed the use of pairwise comparison to evaluate alternatives. The method has been used extensively to solve complex decision problems. It divides a problematic issue into smaller parts, aiming at ranking them hierarchically from the highest to the lowest risk. Thus, the relative importance of alternatives is weighed accordingly. This paper uses AHP to consider/prioritize the key risks affecting the stacking process. The AHP is an excellent tool for weighing risk levels (Mls and Otcenaskova, 2013). Kim *et al*. (2022) used the Analytic Hierarchy Process (AHP) technique and Delphi survey analysis to quantify the influence factors and the grading system for the risk evaluation of tunnel collapse. The significant influence factors were selected using the grading guide based on each considered influence factor's weight importance and rating score. Zhang *et al*. (2022) built an ecological risk assessment model to evaluate the risks of microplastics in the Yangtze River Estuary and adjacent marine areas using AHP. Providakis *et al*. (2022) conducted a risk assessment, considering the analysis of several factors required for sustainable and resilient urban areas and underground space planning using the Analytical Hierarchy Process (AHP). Previous studies show that AHP in risk assessment can vary across industries and sectors. Researchers and practitioners continue to explore and develop new methodologies and applications for AHP in addressing emerging risk-related challenges. Analytical Hierarchy Process (AHP) has been commonly used in various fields for decision-making and risk assessment. Pereira et al. (2014), Pereira *et al*. (2015), Pereira *et al*. (2017), Pereira *et al*. (2021), and Pereira *et al*. (2020) conducted studies on the use of AHP in risk assessment.

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3 METHODOLOGY

An in-depth analysis of a university strategy, challenges, and outcomes related to PBL was conducted. The goal was to provide a rich and nuanced understanding of PBL that can contribute to theory development or inform practical applications. The study adopted the approach of building theory from Case Study Research proposed by Eisenhardt (1898), Baxter and Jack (2010), Yin, R. (2014), and Hancock *et al.* (2021). It combined data from archives, interviews, and observations in conducting PBL projects. The PBL process employed in a specific university was mapped out, the associated risks were identified and categorized using an affinity diagram, and risk probabilities were elicited through a survey.

Additionally, the authors estimated risk impacts using the Analytic Hierarchy Process (AHP) and derived global risk scores. The BBN was then employed to combine risk probabilities with a subsequent sensitivity analysis to pinpoint high probability risks. Finally, the study outlines the process of defining responses for these identified high-scoring risks. The outcomes of this research are presented through a visual PBL process map highlighting associated risks, a categorized list of risk factors, the survey instrument for obtaining risk probabilities, the AHP matrix for risk factors, risk categories, a sensitivity analysis conducted through BBN, and a list of response actions for high-scoring risks.

3.1 Population and Sample

The sample for the study was the PBL process utilized in the engineering course from the population of courses of a specific university. The number of stakeholders participating in the study is listed in Table 1.

Table 1 - Stakeholders participating in the study

Area	Function	# Participants	Time of experience (years)
University	Professors	3	10, 10, 6
	Engineering Students	3	4
Company	PBL leader focal point	1	20
	Company member of PBL	1	25

Source: Prepared by the authors.

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These stakeholders were selected based on their expertise. The sample size is appropriate and significant since all the stakeholders are covered.

3.2 Instruments and Tools

A process map was created to comprehend the variables involved in the PBL process and pinpoint potential risks. An affinity diagram was employed to categorize these risk factors. Analytic Hierarchy Process (AHP) was utilized to assess the impacts of these risks. Google Forms were employed to elicit probabilities. Bayesian Belief Network (BBN) was applied to consolidate these probabilities and conduct a sensitivity analysis, ultimately identifying the risks with the highest likelihood.

3.3 Data Collection:

Data were collected from archives, interviews, surveys, and observations. Risk factors were compiled by referencing existing literature and the process map. Participants, including students, professors, and organizational leaders, were surveyed to ascertain the probabilities associated with these risk factors.

3.4 Data Analysis & Actions:

The research team created an Affinity Diagram to categorize the risk factors and establish the cause-and-effect relationship with the failure of Problem-Based Learning (PBL). They employed the Analytical Hierarchy Process (AHP) to assess the impact of the identified risk categories. Google Forms gathered probabilities in the Bayesian Belief Network (BBN), facilitating sensitivity analysis. Ultimately, risk responses were formulated to address those risks that scored high in the assessment. The probabilities for each risk factor were elicited from students and professors. The survey used in this process is the one shown in Table 2.

Table 2 - Risk Factors affecting PBL failure.

Survey on Impact of Risk Factors on PBL Success Introductory Explanation
We are conducting a study on the impact of risk factors on the success of PBLs and would appreciate a contribution to let us know about your experience on this subject. We would appreciate it if you could complete this 5-minute anonymous survey. Responses will be used only to help us validate the model we are developing to estimate the impact of risk factors on the effectiveness of PBLs. This first section will ask you to provide your background on PBL experience. In sections 2, 3, and 4, you will be asked to estimate the likelihood of risk factors impacting the effectiveness of PBL results in each question. Thanks for your contribution.
Section 1 – General Questions

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Number	Question
1	What is your age?
2	In which department do you work?
3	How many years of experience in the University or Company?
4	How many years of experience with PBL?
5	What role do you play in University/Company?
6	Which university/company do you work at?

Section 2 - Estimate in each statement the likelihood (1 to 10) of risk factors related to Cognitive Learning Risk Factors to impact the effectiveness of PBL results

Number	Question
1	C1 - Lack of procedure for the PBL process
2	C2 - Students and professors not appropriately trained on the procedure
3	C3 - Lack of standard work for the execution of PBL's
4	C4 - Poor explanation of expectations to students
5	C5 - Lack of background definition on principle behind projects
6	C6 - No clear definition of requirements
7	C7 - Project complexity incompatible with time and resources
8	C8 - Project not related to discipline
9	C9 - Workload too heavy for the student
10	C10 - Low ability of students (slow learner)

Section 3 - Estimate in each statement the likeliness or unlikeliness (1 to 10) of risk factors related to Social Learning Risk Factors to impact the effectiveness of PBL results

Number	Question
1	S1 - Number of Students in the team is inadequate (too big or too small)
2	S2 - Team members not equally strong
3	S3 - Assign students to teams rather than let them select the team themselves.
4	S4 - The Professor does not give feedback.
5	S5 - Nonexistence of guidelines for team operation
6	S6 - Students not encouraged by professors
7	S7 - Some of the students are not active
8	S8 - No focus on the project
9	S9 - The relationship between professor and student is not good
10	S10 - Lack of patience and enthusiasm

Section 4 - Estimate in each statement the likelihood (1 to 10) of risk factors related to Theoretical and technical Learning Risk Factors to impact PBL results

Number	Question
1	T1 - Professor does not support knowledge base construction
2	T2 - The Professor does not support Argument base construction.
3	T3 - Lack of professor technical content knowledge and experience
4	T4 - The Professor has no industrial skills.
5	T5 - Lack of definition for the project content organization
6	T6 - No definition of report content
7	T7 - Problem-solving methods not defined
8	T8 - Students are not familiar with the specific process theory behind PBL
9	T9 - Students have no knowledge of Quality Tools for problem-solving
10	T10 - Students not trained on specific PBL industrial process

Source: Prepared by the authors.

4 RESULTS

The PBL Process Map used in the studied university to support companies in the region is shown in Figure 1. The red letters represent the risk category: C: Cognitive Learning Failure, S: Social Learning Failure, and T: Theory and Practice Learning.

Figura 1 Structure in the conduction of PBL projects and risks

Source: Prepared by the authors.

The risk factors impacting PBL failure identified in the researched literature and in the process map reviewing are shown in Table 3.

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Table 3 - Risk Factors impacting PBL failure

Risk ID Number	Risk Factors
1	Lack of procedure for the PBL process
2	Students and professors are not appropriately trained on the procedure.
3	Lack of standard work for the execution of PBL's
4	Inadequate explanation of expectations to students
5	Lack of background definition of the principle behind projects
6	No clear description of requirements
7	Project complexity incompatible with time and resources
8	The project is not related to discipline.
9	The workload is too heavy for the student.
10	The low ability of students (slow learners)
11	Number of Students inadequate (too big or too small)
12	Team members are not equally strong.
13	Assign students to teams rather than let them select the team themselves.
14	The professor does not give feedback.
15	There is a nonexistence of guidelines for team operation.
16	Students are not encouraged by professors.
17	dome of the students not active
18	No focus on the project
19	The relationship between the professor and students is not good.
20	Lack of patience and enthusiasm
21	The professor does not support knowledge-based construction.
22	The professor does not support the Argument base construction.
23	Lack of professor technical content knowledge and experience
24	The professor has no industrial skills.
25	Lack of definition for the project content organization
26	There is no description of the report's content.
27	Problem-solving methods not defined.
28	Students are not familiar with the specific process theory behind PBL.
29	Students have no knowledge of quality Tools for problem-solving
30	Students not trained on specific PBL industrial processes.

Source: Prepared by the authors.

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The risk factors are clustered into categories to establish the cause-and-effect relationship to the failure of PBL using the Affinity Diagram shown in Table 4. It shows the risk factors within three learning principles and nine categories, as suggested by Xiangyun (2013).

Table 4 - Risk Factors clustered into categories

Type	Categories	Risks Identification	Risk Factors
C: Cognitive Learning Failure	CA: No Standardization of PBL Procedure	C1	Lack of procedure for the PBL process
		C2	Students and professors are not appropriately trained on the PBL procedure.
		C3	Lack of standard work for the execution of PBL's
	C.B.: PBL-specific requirements not defined accurately	C4	Poor explanation of expectations to students
		C5	Lack of background definition of the principle behind projects
		C6	No clear definition of the requirements
	CC: Wrong Choice of Project	C7	Project complexity incompatible with time and resources
		C8	The project is not related to discipline.
		C9	The workload is too heavy for the student.
		C10	The low ability of students (slow learners)
S: Social Learning Failure	S.A.: Team Building practices not used	S1	The number of Students in the project is inadequate (too big or too small)
		S2	Project team members are not equally strong.
		S3	Assign students to teams rather than let them select the team themselves.
	S.B.: PBL Professor not active in the project	S4	The professor does not give feedback on the project
		S5	There is a nonexistence of guidelines for team operation in the project.
		S6	Students are not encouraged by professors.
	SC: Team lack of Motivation	S7	Some of the students were not active in the project
		S8	No focus on the project
		S9	The relationship between professor and student is not good.

		S10	Students and professors lack patience and enthusiasm.
T: Theory and Practice Learning Failure	TA: PBL Professor not prepared for the project	T1	The professor does not support knowledge-based construction.
		T2	The professor does not support Argument-based construction.
		T3	Lack of professor technical content knowledge and experience
		T4	The professor has no industrial skills.
	T.B.: No definition of PBL records organization	T5	Lack of definition for the project content organization
		T6	No definition of project report content
		T7	Problem-solving methods not defined.
	T.C.: Students not prepared for the PBL	T8	Students are not familiar with the specific process theory behind PBL
		T9	Students have no knowledge of Quality Tools for problem-solving
		T10	Students not trained in specific PBL industrial process

Source: Prepared by the authors.

The Analytic Hierarchy Process (AHP) was employed to systematically assess and compare risk factors within each learning category pairwise. An interview was conducted with professors and students to gauge the impact of each risk on the failure of problem-based learning (PBL). The quantitative risk weight values (impact) calculation was derived from a completed pairwise comparative matrix. The empirical data underwent conversion into mathematical models by utilizing a hierarchy table established by Saaty (2009), as depicted in Table 5.

Table 5 - Relative Importance

Importance	Definition
1	Both elements are of equal importance
3	Moderate importance of one element compared to the other
5	Decisive importance of one element compared to the other
7	Very strong importance of one element compared to the other
9	The extreme importance of one element over the other

Source: Prepared by the authors.

An interview was conducted to elicit input from professors and students regarding the extent of influence each risk has on the potential failure of Problem-Based Learning (PBL). The study team prepared the AHP Matrices. To illustrate how this was performed, follows an example: When preparing Table 6 for risk categories, the participants were asked a specific question: "In the event of PBL failure, how crucial is one category (e.g., C.A.) in comparison to another (e.g., C.B.) in contributing to the failure?" For instance, assuming a score of seven is assigned based on Table 5, denoted as a12=7, it signifies that element C.A. holds considerable importance concerning element C.B. For symmetry, if a12=7, then a21=1/7 is presumed. This implies that the significance of element C.B. concerning element C.A. is inversely proportional.

Table 6 - AHP Matrix for Risk Categories

Criteria Comparison Matrix										
Risk Factors	CA: No Standardization of PBL Procedure	CB: PBL specific requirements not defined	CC: Wrong Choice of Project	SA: Team Building practices not used	SB: PBL Professor not active in the project	SC: Team lack of Motivation	TA: PBL Professor not prepared for the project	TB: No definition of PBL records organization	TC: Students not prepared for the PBL	Weights
CA: No Standardization of PBL Procedure	1	1	7	5	3	7	3	5	3	0,26
CB: PBL specific requirements not defined accurately	1	1	3	5	3	7	3	7	3	0,23
CC: Wrong Choice of Project	1/7	1/3	1	1	5	3	3	3	3	0,13
SA: Team Building practices not used	1/5	1/5	1	1	1	1	1/3	3	3	0,07
SB: PBL Professor not active in the project	1/3	1/3	1/5	1	1	3	1	3	3	0,08
SC: Team lack of Motivation	1/7	1/7	1/3	1	1/3	1	1	3	1/3	0,04
TA: PBL Professor not prepared for the project	1/3	1/3	1/3	3	1	1	1	5	3	0,10
TB: No definition of PBL records organization	1/5	1/7	1/3	1/3	1/3	1/3	1/5	1	1/3	0,03
TC: Students not prepared for the PBL	1/3	1/3	1/3	1/3	1/3	3	1/3	3	1	0,06
TOTAL	3,69	3,82	13,53	17,67	15,00	26,33	12,87	33,00	19,67	

Source: Prepared by the authors.

The relative importance of all other risks outlined in Table 4 was estimated similarly and translated into a numerical pairwise comparison matrix. Upon completion of the pairwise comparative matrix, the risks' weight values (impact) can be quantitatively determined using the eigenvector corresponding to the maximum eigenvalue of the pairwise comparative matrices as the weighted values. The Analytical Hierarchy Process (AHP) applied to the Cognitive Learning principle indicates that the most influential risk factors are C1 and C3. To address risk factor C1, it is recommended that a procedure for documenting the Problem-Based Learning (PBL) process be implemented. As for risk factor C3, the suggested action involves establishing standard protocols for applying PBL. The Analytical Hierarchy Process (AHP) applied to the Social Learning principle reveals that the most significant risk factors are S3 and S6. To mitigate risk factor S3, it is recommended that students not be assigned to the Problem-Based Learning (PBL) group but rather allow them to choose the group they wish to work with. Addressing risk factor S6 involves training professors to encourage students to engage in PBL activities actively. The Analytical Hierarchy Process (AHP) analysis for the Technical Learning principle indicates that the most significant risk factors are T3 and T4. The recommended actions for mitigating risk factor T3 involve ensuring that the professor assigned to a project possesses the necessary technical knowledge and experience.

Regarding risk factor T4, confirming that the professor also possesses practical experience in the industry where the Problem-Based Learning (PBL) project is slated to be developed is imperative. The Analytic Hierarchy Process (AHP) analysis for risk factor categories reveals that C.A. and C.B. exert the most significant influence. Both CA and C.B. exhibit identical actions for risk factors C1 and C3. Specifically, C1 pertains to addressing procedural concerns in documenting the Problem-Based Learning (PBL) process, while the recommended action for risk factor C3 involves establishing standardized procedures for implementing PBL. The Impact Scores associated with the weights were derived from Table 7. These impact scores are color-coded, with ranges marked in Red, Yellow, Orange, and Green to signify varying levels of impact.

Table 7 - Risk Factors impacting PBL failure

Impact Level Score		
Score	Impact Level	Impact
5	High	More than 0,16
4	Elevated	0,12-0,16
3	Moderated	0,08-0,11
2	Low	0,04-0,07
1	Limited	Less than 0,04

Source: Prepared by the authors.

The risk index was derived for each learning principle. The risk index is determined by multiplying the probability and impact scores. The color classification of the risk index is determined using the risk scoring matrix illustrated in Figure 4 (Hyun et al., 2015). To illustrate the definition of risk index, the ultimate risk index for the risk factor T1 from Table 9 was computed as follows: considering the probability for T1 as 0.7 and the impact as 0.05, the probability rating score is 4 (refer to Table 8), and the impact rating score is 2 for the risk factor T1. The final risk index for T1 is obtained by referencing Figure 4, resulting in a score of 8, which is the product of 4 and 2. The risk index for each learning principle is calculated using the same method.

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Table 8 - Risk Factors impacting PBL failure

Probability Level Score		
Score	Probability Level	Probability
5	Expected	More than 0,80
4	Very probable	0,51-0,80
3	Probable	0,31-0,50
2	Improbable	0,11-0,30
1	Almost no probability	Less than 0,10

Impact Level Score		
Score	Impact Level	Impact
5	High	More than 0,16
4	Elevated	0,12-0,16
3	Moderated	0,08-0,11
2	Low	0,04-0,07
1	Limited	Less than 0,04

Source: Prepared by the authors.

The risk index color is obtained by combining the probability and impact and consulting Figure 2.

Figure 1 - Risk scoring matrix

			RISK				
			Limited	Low	Moderate	Elevated	High
			1	2	3	4	5
Probability	Almost no probability	1	1	2	3	4	5
	Unlikely	2	2	4	6	8	10
	Probable	3	3	6	9	12	15
	Very probable	4	4	8	12	16	20
	Expected	5	5	10	15	20	25
Risk Factor Classification							
1 - 5	Insignificant	6 - 9	Tolerable	10 - 16	Undesireble	17 - 25	Intolerable

Source: Prepared by the authors.

The risk index for Theory and Practice Learning Failure, as determined by the risk scoring matrix, is illustrated in Table 9. The risk index for Social Learning Failure and Cognitive Learning Failure were prepared similarly, and the results are presented in the next paragraph.

Table 9 - Risk Factors impacting PBL failure

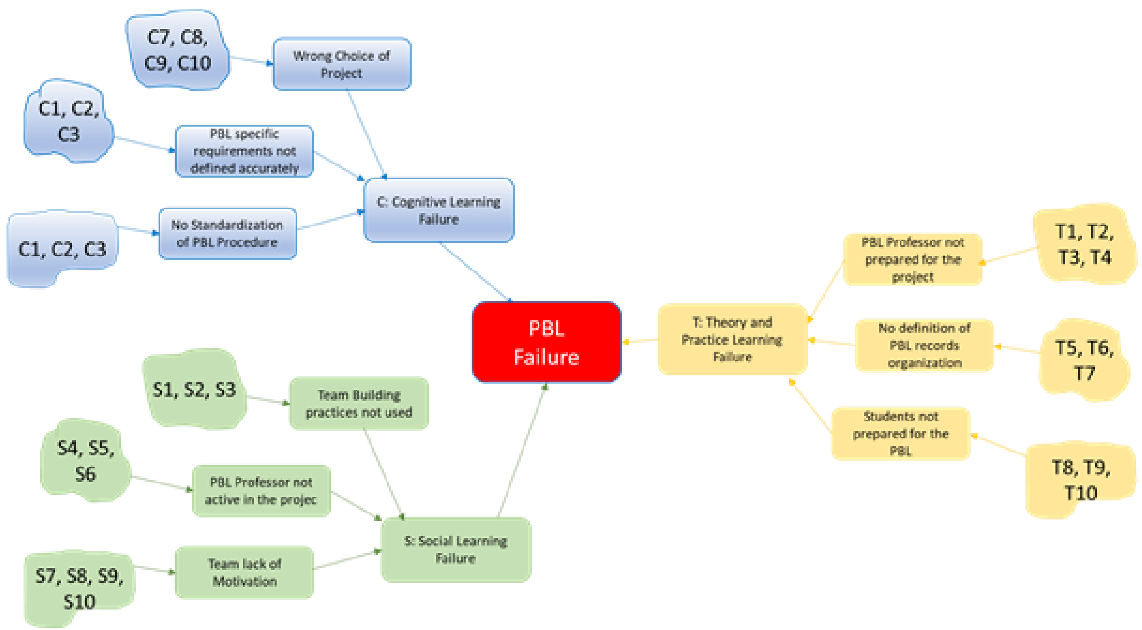
Factors	Probability	Impact	Probability Score	Impact Score	Risk Index
T1 - Professor do not support knowledge base construction	0,7	0,05	4	2	8
T2 - Professor do not support Argument base construction	0,7	0,0404	4	2	8
T3 - Lack of professor technical content knowledge and experience	0,5	0,2401	3	5	15
T4 - Professor has no industrial skills	0,6	0,2189	4	5	20
T5 - Lack of definition for the project content organization	0,7	0,0457	4	2	8
T6 - No definition of report content	0,8	0,026	5	1	5
T7 - Problem solving methods not defined	0,6	0,1075	4	3	12
T8 - Students are not familiar with specific process theory behind PBL	0,2	0,0935	2	3	6
T9 - Students have no knowledge of Quality Tools for problem solving	0,5	0,1102	3	3	9
T10 - Students not trained on specific PBL industrial process	0,3	0,0666	2	2	4

Source: Prepared by the authors.

The Probability and Impact Score for Cognitive Learning Failure shows that the highest risk Index is C1. The actions to be taken for risk factor C1 are the issue of a procedure to document the PBL process, and risk factor C2 is to train professors on the documented procedure. The Probability and Impact Score for Social Learning Failure indicates that the highest risk indices are associated with S3, S6, and S9. To mitigate the risk associated with S3, the recommended action is to refrain from assigning students to PBL groups and instead allow them to choose the group with which they wish to collaborate. For S6, the proposed action involves training professors to motivate students to engage in PBL activities. Finally, for S9, the suggested measure is to provide training in team building for both professors and students. The Theory and Practice Learning Failure, as illustrated by the Probability and Impact Score, reveals that the highest risk indices are associated with T4 and T3. To mitigate the risk linked to T3, it is imperative to ensure that the assigned professor possesses the requisite technical knowledge and experience. As for the risk factor T4, the proactive measure confirms that the professor possesses practical experience in the industry relevant to the PBL project's development.

Figure 3 displays the Bayesian Belief Network (BBN) constructed using the logical connective OR to amalgamate the probabilities derived from the survey. This amalgamation encompasses all the risk factors across various categories of learning principles.

Figure 2 - BBN combining all risk factors



Source: Prepared by the authors.

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The probability values derived from the survey underwent adjustments based on the respondents' experiences, as illustrated in Table 10. After the corrections, these probabilities were inputted into Bayesian Belief Network (BBN) software. The probabilities associated with each risk were amalgamated, facilitating the execution of sensitivity analysis to identify the most significant risk factor.

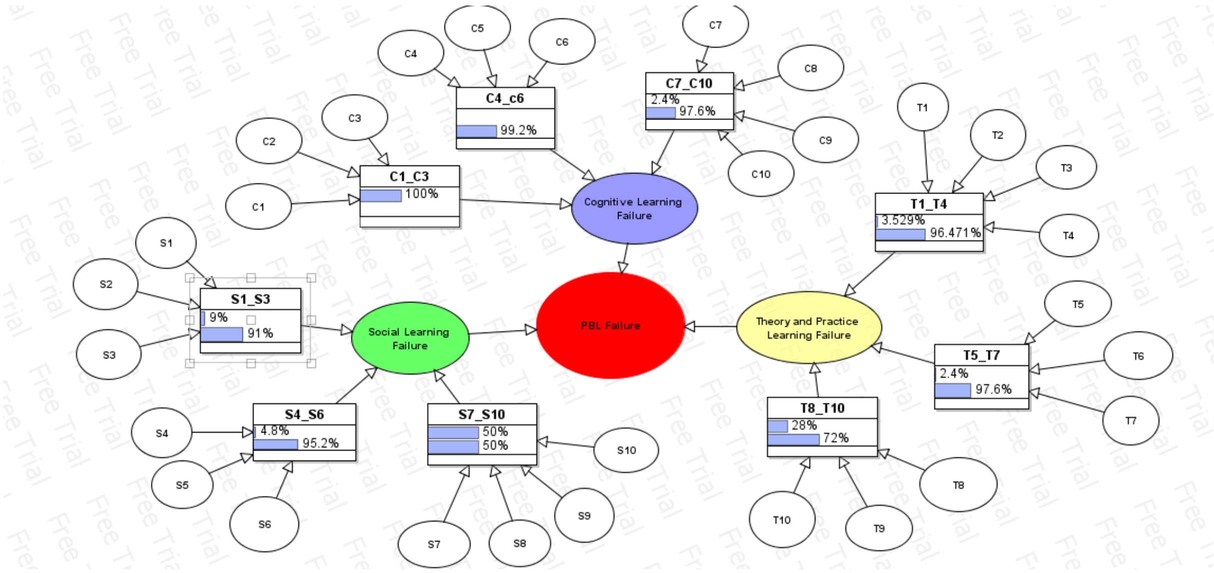
Table 10 - Experience Period & Weight

Experience Period (E) & Weight	
Less than 5 years	0.60
6-10 years	0.75
11-15 years	0.09
More than 15 years	1.00

Source: Prepared by the authors.

Figures 4 and 5 show the charts generated with BBN software.

Figure 3 - BBN combining all risk factors prepared with Agena Risk software



Source: Prepared by the authors.

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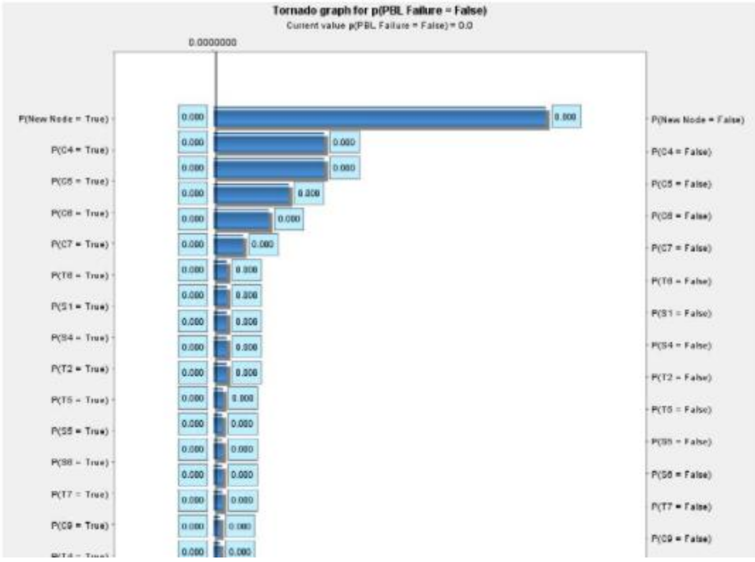
Figure 4 - Tornado Chart



Source: Prepared by the authors.

The Tornado chart depicted in Figure 7 reveals that the risks carrying the highest probabilities are associated with the highest risk index, namely C4 (Poor explanation of expectations to students), C5 (Lack of background definition on principles behind projects), and C6 (No clear definition of requirements). To address the risk factor C4, it is imperative to ensure that the procedure encompasses clarifying expectations to professors and students. Similarly, the action plan for risk factor C5 involves incorporating coverage of the principles behind projects within the procedure. Finally, for risk factor C6, it is essential to guarantee that the procedure comprehensively includes defining project requirements. A summary of the main actions recommended for the high-scoring risks is presented in Table 11.

Table 11 - Response actions for the risks.

Risk Identification	Response actions for the risks
C1 and C2 (from AHP)	The actions to be taken for risk factor C1 are the issue of a procedure to document the PBL process, and risk factor C2 is to train professors on the documented procedure.
S3, S6, and S9(from AHP)	To mitigate the risk associated with S3, the recommended action is to refrain from assigning students to PBL groups and instead allow them to choose the group with which they wish to collaborate. For S6, the proposed action involves training professors to motivate students to engage in PBL activities. Finally, for S9, the suggested measure is to provide training in team building for both professors and students.
T4 and T3(from AHP)	To mitigate the risk linked to T3, it is imperative to ensure that the assigned professor possesses the requisite technical knowledge and experience. As for the risk factor T4, the proactive measure confirms that the professor possesses practical experience in the industry relevant to the PBL project's development.
C4, C5 and C6 (from BBN)	To address the risk factor C4, it is imperative to ensure that the procedure encompasses clarifying expectations to professors and students. Similarly, the action plan for risk factor C5 involves incorporating coverage of the principles behind projects within the procedure. Finally, for risk factor C6, it is essential to guarantee that the procedure comprehensively includes defining project requirements.

Source: Prepared by the authors.

5 DISCUSSION OF RESULTS

The outcomes of this research are presented through a visual PBL process map highlighting associated risks, a categorized list of risk factors, the survey instrument for obtaining risk probabilities, the AHP matrix for risk factors, risk categories, a sensitivity analysis conducted through BBN, and a list of response actions for high-scoring risks.

As outlined in the introduction, this study demonstrates in the section results the effective utilization of the Analytic Hierarchy Process (AHP) in conjunction with Bayesian Belief Networks (BBN) for assessing and prioritizing risk factors associated with Project-Based Learning (PBL) failure. A comprehensive examination of existing literature facilitated the identification of risk factors in the PBL process. The proposal for a global risk matrix is substantiated, as it furnishes crucial insights for identifying and prioritizing potential risks leading to PBL failure. This method proves to be a potent decision-making tool for universities. The study underscores that PBL is susceptible to diverse risks, some with the potential to compromise the sustainability of universities. Probabilistic risk analysis is pivotal for comprehending and implementing risk responses to avert failure.

6 CONCLUSION

This paper has provided a comprehensive review of prior literature on risks associated with Project-Based Learning (PBL) and has introduced a novel model for risk assessment in this context. The significance of this study lies in its potential to help the decision-making of professors and engineering school coordinators by identifying significant risks inherent in the PBL process. By introducing this innovative risk assessment method, we fill a critical gap in the existing literature, as previous studies have not explored this specific aspect thoroughly. The contribution is noteworthy as it empowers decision-makers to strategically allocate funds, thereby safeguarding essential activities that contribute to the sustainability of universities.

In response to Research Question 1: How can the most significant risk factors in using PBL be identified in teaching engineering students? The proposed model for risk assessment of PBL failure integrates the Analytic Hierarchy Process (AHP) and Bayesian Networks to prioritize risks effectively. In addressing the research questions concerning identifying significant risk factors, the study demonstrates how AHP identifies critical risks within Cognitive, Social, and Technical Learning principles and associated risk factor categories.

In response to Research Question 2: How can the probabilities and impacts of these risks be combined to generate a risk index, and how can sensitivity analysis using BBN be conducted? The combination of probability and impact for risk index determination and sensitivity analysis using Bayesian Belief Networks (BBN) was adequate, and the study offers a comprehensive approach. Additionally, specific response actions for each identified high-scoring risk factor are outlined, addressing the third research question.

The primary aim of this study was to identify critical risk factors affecting PBL and propose an optimized process for enhancing quality in PBLs. The implications are substantial, as modifications to the PBL process can lead to significant improvements and prevent failures. The proposed methodology, supported by robust results, contributes to existing research and addresses challenges encountered by educators, students, and professionals striving for quality education. Rooted in the experiences and insights of professors and students, this study is poised to enrich the understanding of education stakeholders.

Significantly, this study stands out as the first to apply AHP and BBN to identify risks in PBL. The proposed optimized approach holds universal applicability in any university or educational institution, offering a pathway to enhance teaching effectiveness and sustainability. By highlighting the interconnectedness of various factors influencing the PBL process, this study underscores the importance of process analysis in driving improvements.

Recognizing the importance of understanding the most impactful risk factors in PBL, this study emphasizes its relevance for professors, students, and university decision-makers. The modified method can potentially optimize engineering education, contributing to overall quality and effectiveness. In conclusion, avenues for future research are suggested, including broader applications of risk analysis in PBL and enhancements to the existing methodology to mitigate the risk of failures.

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Authors' contributions

José Cristiano Pereira – Project coordinator, responsible for developing the theoretical-conceptual framework, actively involved in data collection and analysis, and in writing the manuscript.

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Declaration of conflict of interest

The authors declare that there is no conflict of interest regarding the article "Risk Assessment Method for Failure in Project-Based Learning through AHP and BBN Aiming at Improving the Quality of Engineering Education".

Data availability

The data underlying this research are contained within the article.

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