Personalized Learning Model for University-Industry Integration Through PBL Problem-Solving

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Modern educational models recommend Problem-Based Learning (PBL) and Adaptive Learning (AL) to increase the alignment of education and work organization. PBL is a technique that focuses on learning through problem-solving. However, understanding how and why PBL works is a current challenge. To advance this issue, systems that personalize learning processes are recommended. The present study developed an AL approach for PBL to align education with industry through problem-solving. The proposed approach is based on ontologies, complex multilayer networks, Bayesian networks, a recommendation system, and multi-agent architecture. The proposed tool consists of descriptive, diagnostic, predictive, and prescriptive models. This tool is available on eduCAPES with guidelines for implementing these models. Reduced PBL planning effort, increased collaboration in the development of innovation projects, enhanced educational quality, and the availability of data for Artificial Intelligence (AI) training are some benefits of this tool. To evaluate the proposed approach, nine graduate students completed the User Experience Questionnaire. The attractiveness, hedonic quality, and pragmatic quality of the models were positively perceived. Therefore, the results showed that students have a positive perception of the model's functions. The present study was limited to experiments with a small sample of students. Evaluation of the perceptions of university, educational administrators, the graduate program, the educational institution, industry, and a larger sample of students is suggested for future studies. Currently, the model is implemented with a set of existing tools. Therefore, studies to develop a platform with a user-friendly interface that integrates the proposed models are recommended.
Keywords: Personalized Learning. Adaptive Learning. Problem-Based Learning. Industry. University.

The current educational landscape is characterized by the emerging concept of social organization known as Society 5.0 [1]. This model is challenged by the emergence of new types of work and the automation of many existing jobs [2]. To address this challenge, 4.0/5.0 educational models have been proposed [3]. These models are based on Problem-Based Learning (PBL) and Adaptive Learning (AL) [3].

PBL is an approach in which students learn by solving problems contextualized within their future professional environment [4]. Collaborative, contextualized, self-directed, and constructive learning are the main functions of this technique [5]. Understanding how and why PBL achieves these functions is a research gap [6]. Therefore, a lack of quality control techniques for PBL educational functions challenges the adoption of this technique.

To address this challenge, AL techniques are recommended for prescribing PBL specifications that achieve previously defined learning outcomes [6]. AL are approaches that adapt learning aspects to student needs to improve their outcomes [3]. The solution proposed by the present study is an AL model to integrate university and industry through PBL problem-solving.

Related Work

PBL has expanded to a variety of courses. Consequently, the initial proposed format of this technique has been modified. Therefore, there is considerable variability in PBL implementations [7]. This variability has challenged research on how and why PBL works (Figure 1) [6,8].

The present study aims to advance the fourth and current wave of PBL research. This wave aims to answer the question: “Why does PBL

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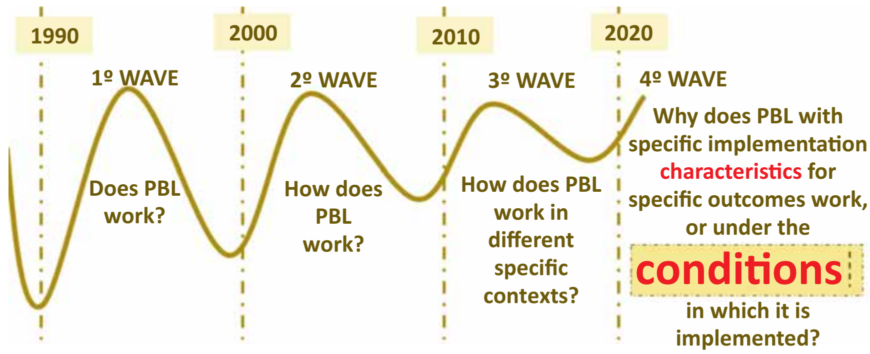
Figure 1. Wave of PBL research.



with particular implementation characteristics for specific outcomes work or not work in the condition where it is implemented?" [6]. The discovery of this period of research was made through a review study of reviews and meta-analyses published between 1980 and 2019 conducted by [6].

To advance this issue, Hung and colleagues [6] recommend the development of theoretical approaches and probabilistic models. Studies that advanced in the fourth wave of research proposed guidelines for developing realist reviews [9], design-based research [10], and causal maps [11]. These studies recommended: the use of personalized approaches [10], the development of repositories [11], the use of AI in causal maps [11], and the investigation of adaptations of PBL approaches [12].

The AL approaches include the adaptation mechanism, student models, content models, and instructional models [13,14,15], as shown in Figure 2. The use of AL approaches for PBL focuses on adapting content [16], curriculum [17], feedback [18], and learning resources [19]. Therefore, there is a gap in AL development that advances the issue of the fourth wave of PBL research.

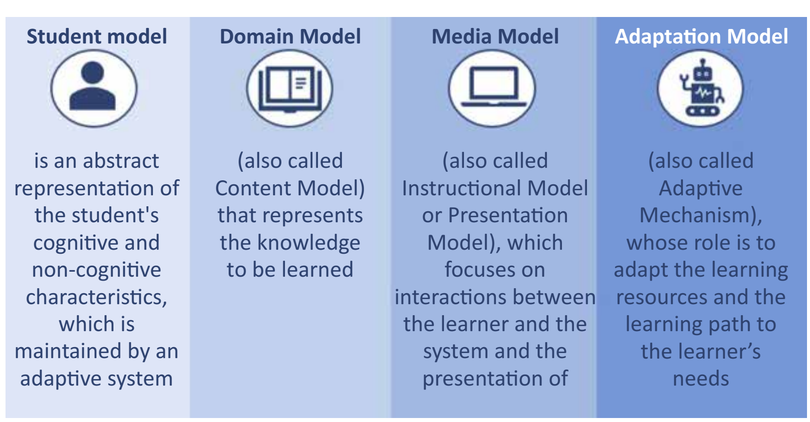
Materials and Methods

The AL approach proposed in this study encompasses descriptive, diagnostic, predictive, prescriptive, integrative, and evaluative models, as illustrated in Figure 3.

The ontologies will be used in the descriptive model. These data structures allow the representation of concepts within a given domain [20,21]. The complex multilayer networks will substantiate the diagnostic model.

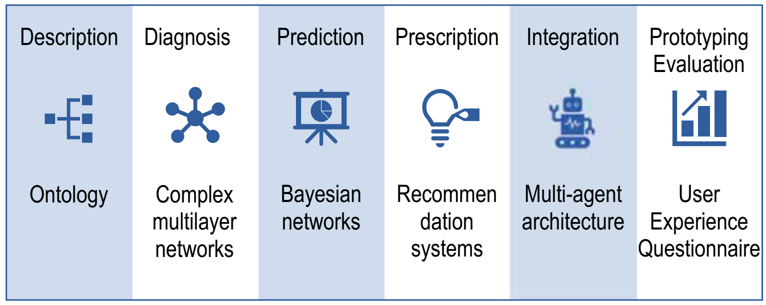
These approaches represent the connections of nodes in layers [22]. In these networks, connections can grow vertically or horizontally [22]. The

Figure 2. AL approaches.



Based on the studies by Martin and colleagues, Shute and Towle, and Vandewaetere and colleagues [13-15].

Figure 3. Methodology.



predictive model will be a Bayesian network. This network is a conditional probability graph [23]. The prescriptive model will be a recommender system. This system makes prescriptions based on user preferences [24]. To integrate these models, multi-agent architectures is used. This approach is standard for describing the integrated parts of a system [25-27]. The User Experience Questionnaire (UEQ) translated into Portuguese by Cota and colleagues [28] is used to analyze the students' perception of the AL proposed in the present study. This questionnaire analyzes three aspects. Attractiveness assesses whether users liked the proposal presented [29,30]. Hedonic quality analyzes non-task-related aspects [29,30]. Pragmatic quality assesses task-related aspects [29,30]. Nine postgraduate students of the integrated manufacturing systems discipline answer the UEQ in a pilot study.

Proposed Model

The proposed technological solution is an adaptive learning (AL) approach that aims to evaluate the performance of project-based learning (PBL) applied to technological disciplines. This solution is structured around five models to describe, diagnose, predict, and prescribe PBL characteristics and conditions that, when implemented, achieve the educational functions of PBL (Figure 4).

Variables

The characteristics are the problem, the assessment, the solution, the teacher, and the teams. The conditions are the implementation time, environment, format, and educational level. The functions of PBL are to promote knowledge acquisition, problem-solving, and collaborative, constructive, self-directed, and contextualized learning.

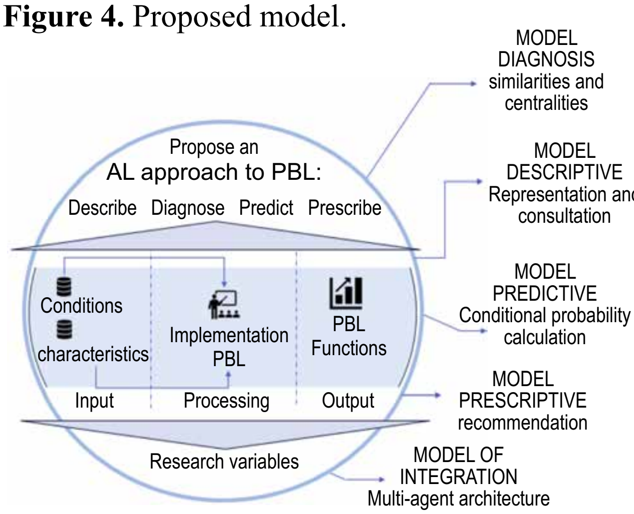
Model functions

The functions of the models are illustrated in Figure 5 and described in Table 1.

Forms of Use

The forms of use for teachers, students, researchers, industry, and educational institutions are detailed in Table 2 and 3.The problems and solutions developed can integrate teams from universities and industry. The models proposed in this study allow: consultations, metrics analysis, and recommendations regarding which teams are developing specific solutions.

Figure 4. Proposed model.



Expected Benefits

The expected benefits are described in Table 4.

User Guidelines

Six modules were developed that present the proposed models, development techniques, usage methods, and extension methodologies (Figure 6).

The present study also proposes guidelines for utilizing the models in conjunction with existing tools. These guidelines are available in http://educapes.capes.gov.br/handle/capes/983876. The proposed tool is licensed under the Creative Commons CC BY-NC 3.0 BR license. Therefore, non-commercial use, adaptation, and sharing of the proposed models are allowed.

Validation

The results show that the proposed approach was positively evaluated by the students in terms of attractiveness, hedonic quality, and pragmatic quality (Figure 7).

Figure 5. Proposed model.

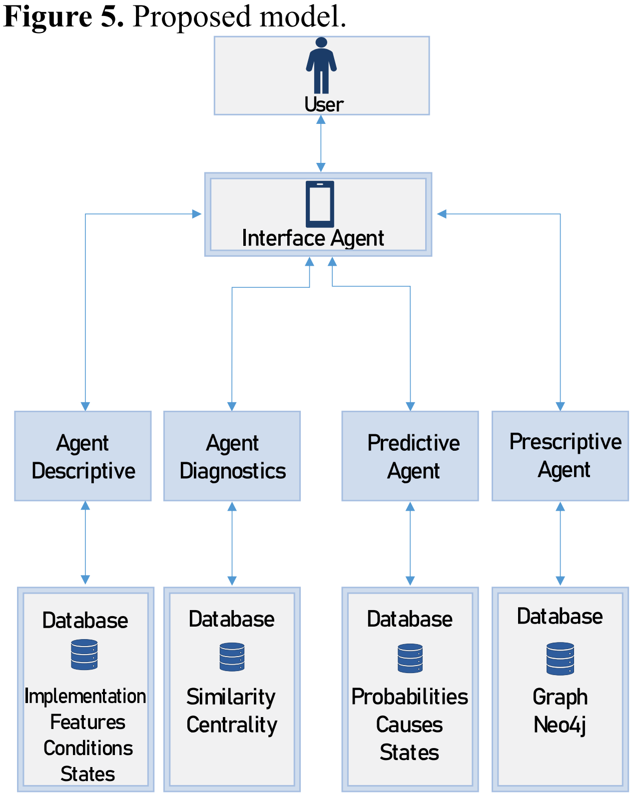


Table 1. Model functions.

Model Function	Description
Descriptive	The descriptive model aims to allow access and querying of the characteristics, conditions, and functional states of a PBL implementation.
Diagnostic	The diagnostic model proposes metrics to calculate centralities and similarities in the characteristics, conditions, and functional states of the PBL.
Predictive	The predictive model identifies the causal relationships related to the characteristics and conditions that lead a PBL implementation to achieve or not its educational functions.
Prescriptive	The prescriptive model aims to provide recommendations for characteristics and conditions to improve the PBL implementation results.
Integration	The integration model aims to establish how the descriptive, diagnostic, predictive, and prescriptive models are related.

As shown, students liked the proposed approach. The function-related and non-function-related aspects of the proposed models' approach were also positively evaluated.

Discussion

This study proposes novel AL models for PBL. These models advance the fourth wave of PBL research. Existing approaches focus on content and the learner model. The proposed approach considers broader aspects, such as the team, the problem, the solution, the assessment, and the teacher. This approach presents diverse functions for students, educational researchers, universities,

Table 2. Teaching and educational research.

User	Forms of Use
Researchers	Conduct research, train AI algorithms, and develop educational technologies using data generated by the proposed model.
Researchers	Conduct performance investigations of PBL implementations.
Researchers	Implement the integration of the technological solution's descriptive, diagnostic, predictive, and prescriptive models on a single platform.
Teachers	Plan the characteristics and conditions of a PBL implementation with process reuse, for example, projects, unsolved problems, and assessment models. Reuse has the potential to reduce the effort and time on planning PBL.
Teachers	Evaluate the quality of a PBL implementation by: (i) calculating similarities between implementations and states; (ii) analyzing the relationship between adaptations in implementations and the approach or distance from the achievement of PBL functions.
Teachers	Improve the quality of a PBL implementation through predictive analysis of the likely causes of the achievement or lack thereof of PBL functions in a specific implementation.
Teachers	Improve the quality of a PBL implementation through recommendations for: problems and students based on familiarity; problems based on area; existing solutions based on techniques; existing problems based on solutions; characteristics and conditions most likely to achieve collaborative learning, problem-solving, and knowledge acquisition.
Teachers	Manually integrate the descriptive, diagnostic, predictive, and prescriptive models of the technological solution with existing tools.
Educational managers	Develop initiatives and strategically direct resources.
Students	Identify teams for collaboration and solutions to existing problems to analyze innovation potential.
Students	Using metrics, assess the team's level of multidisciplinarity, familiarity with problems, and the scope of PBL learning functions.

graduate programs, the Ministry of Education, and industry.

Improved educational quality, increased collaboration on innovative projects, a database for AI training, and strategic educational decisions are some benefits of the proposed model.

The model validation showed positive student perception. However, this study was limited to experiments with a sample of students. Limitations and robustness related to study design are described in Table 5.

Future studies to analyze the perceptions of other potential users of the proposed model are recommended. Modules developed by the present study that guide the implementation of the proposed models in existing tools could aid these future studies. Manual integration of the models is a limitation of this study. Therefore, the development of a platform with a user-friendly interface is another recommendation for future studies. This research advances several AL challenges described in Table 6.

Table 3. Use in the integration between universities, government, and industry.

User	Forms of Use
Graduate Program	Considering that the problems are master's and doctoral projects, the problem data repository can help students identify: (i) advisors based on the projects; (ii) problems in topics of interest, familiarity, and ideal multidisciplinarity. This process can reduce research time and improve the indicators of postgraduate programs in Brazil.
Industry and Corporate Environment	Considering that projects developed in a corporate environment are problems that generate commercialized solutions, identifying development conditions (such as time, format, implementation environment) and characteristics (such as team, problem-solution, supervisors' role) that lead the team to develop the project with self-direction, collaboration, constructiveness, and a problem solved within a specified timeframe impacts the success of this organization. Identifying the most appropriate teams for developing specific projects more quickly is another benefit for the corporate environment.
Higher Education Institution	An overview of PBL practices implemented at the institution identifies: (i) the projects and problems solved; (ii) the teams developing the solutions; (iii) the integration of teams within the institution; (iv) the implementations that achieve PBL functions. This process enables the educational institution to have a broad view of the projects developed for direct strategic resources.
Government represented by the Ministry of Education	The Ministry of Education proposes new curricular guidelines for engineering programs and other technologically-based programs. Therefore, identifying the characteristics and conditions that bring PBL implementations closer to achieving their intended purpose allows for: (i) identifying best practices; (ii) assisting in the improvement of these guidelines; and (iii) analyzing the results of the proposed guidelines.

Table 4. Expected benefits of the project.

ID	Benefits of the Project
1	Reduced effort and time required by teachers.
2	Increased collaboration within the educational institution.
3	Increased innovative solutions designed in educational environments.
4	Performance analysis of PBL implementations.
5	Access to a database of educational needs and processes.
6	Improving educational quality.
7	Strategic development of research, initiatives, educational technologies, and AI algorithm training.

Figure 6. User guidelines.

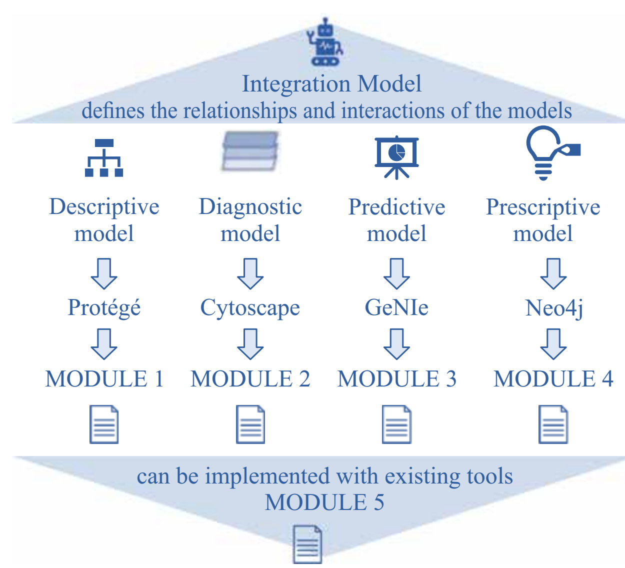


Figure 7. Students' perception of the proposed models.

Conclusion

The present study developed an AL approach to PBL. This innovative approach have potential: (i) reduced teacher effort in PBL planning; (ii) increased collaboration educational institution and industry; (iii) increased innovative solutions designed in educational environments; (iv) performance analysis of PBL implementations; (v) access to a database for improving educational quality, strategic development of research, initiatives, educational technologies, and AI algorithm training; (vi) interoperable with various technologies, such as ontology editor software, network analysis, knowledge graph analysis, and Bayesian network analysis. The functions of the proposed model were positively evaluated for students.

Table 5. Limitations and robustness.

ID	Limitations and robustness
1	No reducing education to measurable outputs and no restricting it to corporate efficiency: The approach accommodates qualitative and quantitative data from descriptive and diagnostic models. This combination enriches the possibilities for understanding PBL and does not restrict education to measurable outcomes. The diverse uses for research, teaching, management, and organizational strategies demonstrate that the proposed approach considers critical analysis and is not limited to corporate efficiency.
2	Validation: The UEQ technique is not intended to assess educational quality. It only indicates evidence that potential users are interested in using it. The adaptability of PBL during implementation challenges evaluations using case-control designs. The diagnostic model's metrics can be used to measure the quality of the PBL implementations and analyze whether improvements in PBL functions are being achieved. Therefore, the proposed approach helps improve educational quality.

The study's limitations include: (i) validation related to the user experience with students; (ii) implementation with manual data integration using existing platforms. It is recommended that future studies: (i) implement the technological solution to integrate universities and industry; (ii) develop a web implementation of the solution with user training and support; (iii) use other validation techniques with a larger sample of students.

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Table 6. Advances.

ID	Advances
1	Epistemological conflicts: Studies indicate epistemological weaknesses in AL related to reducing the complexity of education by providing rules for action [31]. For Ross [31], AL should suggest possible actions and an understanding of possibilities. In line with this author's recommendations and unlike existing approaches, this study proposes recommendations for the characteristics and conditions of PBL for critical analysis by teachers and scientific research. The proposed approach is a digital method, and understanding epistemological limits is a challenge in multidisciplinary areas of science [32].
2	The proposed approach reconciles algorithmic personalization (AL) with the collective and open nature of PBL in: (i) scalability—the proposed approach is open to collaborations; (ii) variables—collaborative learning, the team, and interactions are model variables; (iii) use—access to data from the prescriptive model allows solutions to be developed more collaboratively by allowing students to contribute to project solutions from other disciplines, courses, and institutions.
3	How can we avoid this from reducing PBL to a mechanistic process, emptying its critical and multidisciplinary function? How to prevent students from perpetuating disciplinary bubbles? The proposed approach has the following characteristics: (i) it does not reduce PBL to a mechanistic process—the intention is to provide data for investigations into the complex interaction of PBL components; (ii) it considers criticism—teachers and students consult on aspects of PBL, critically analyze it, and choose how they will plan the PBL; (iii) it considers multidisciplinarity—problems can be modeled with a level of multidisciplinarity and familiarity defined by the teacher. With the help of the proposed approach, the teacher can prevent students from restricting themselves to their areas of expertise.
4	AL can reduce flexibility by standardizing ideal responses with limiting causality modeling by Bayesian networks, which stand out for their transparency [33]. AL needs transparency about algorithmic bias: The proposed approach does not indicate ideal responses, but rather possibilities. Access to implementation variability tends to increase the flexibility of PBL. The proposed Bayesian network does not recommend learning paths, but rather indicates probable causes of problems, which must be critically analyzed by the teacher and investigated by researchers.
5	No restriction of the predetermined paths and considering autonomous learning: There are no recommendations for predetermined paths in the proposed AL. Therefore, the system recommends, and the student has the autonomy to select problems and develop solutions different from those registered.

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