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Development of a Virtual Mentor Integrated with Retrieval-Augmented Generation Artificial Intelligence for Project-Based Learning

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Keyword

Artificial Intelligence; Higher Education; Project-Based Learning; Retrieval-Augmented Generation; Virtual Mentor

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Abstract

Project-Based Learning (PjBL) is a learning model that can enhance the quality of higher education, particularly in developing critical thinking, creativity, and collaboration skills. However, implementing PjBL often faces challenges such as limited resources and the need for intensive guidance from lecturers. To overcome these challenges, Artificial Intelligence (AI) technology offers great potential, although traditional AI systems often provide responses that are less relevant to the context of the learning material. The Retrieval-Augmented Generation (RAG) technique in AI can serve as a solution, enabling the system to generate more accurate and contextually relevant responses. By utilizing data sources such as course materials, RAG can enhance the relevance of AI responses in supporting project-based learning. It is expected that developing an AI-based virtual mentor using the RAG approach can optimize students' PjBL experiences. Specifically, this virtual mentor is designed to provide contextual guidance, help students overcome project-related challenges, and foster independent learning, thereby improving the quality and effectiveness of PjBL in higher education.

1. Introduction

Project-based learning has long been recognized as an effective approach in higher education [1]. This approach emphasizes active student engagement in solving real-world problems, encouraging the development of critical and creative thinking skills. Project-based learning focuses on exploration and problem-solving processes, fostering deep and meaningful understanding. It also contributes to improving students' critical thinking abilities [2]. This aligns with constructivist theory, which emphasizes the active role of students in constructing their own knowledge through experiences and interactions [3].

In the implementation of project-based learning, students often face difficulties in independently understanding materials, designing project ideas, and managing project timelines effectively. The implementation of PjBL can lead to active engagement and the development of critical thinking skills [1]. However, studies have shown that these difficulties are often linked to students' limited ability to independently construct knowledge. The use of technologies such as Retrieval-Augmented Generation (RAG) offers potential to enhance this process, although its success depends on the individual's ability to effectively utilize generated information and integrate it into design and time management processes [4].

Although PjBL literature emphasizes its benefits and the value of constructivist approaches, there remains a significant gap in the availability of intelligent support systems that directly assist students throughout the PjBL process [5]. Existing digital tools typically deliver content or support collaboration but seldom offer

context-aware, adaptive, and real-time assistance for understanding materials, generating project ideas, or managing project timelines [6]. Although research on Retrieval-Augmented Generation (RAG) and agentive AI is expanding, their combined application to address students' cognitive and metacognitive needs in PjBL settings has not been thoroughly explored. This gap underscores the need for a virtual mentor capable of providing personalized and contextually relevant guidance to enhance student autonomy and learning effectiveness.

The use of RAG in this study stems from its clear advantages over traditional generative AI. While conventional models depend solely on pre-trained parameters often resulting in outdated domain knowledge and a higher risk of hallucinations RAG incorporates a retrieval component that draws on external, verified, and current sources during inference. Recent studies show that this approach significantly improves factual reliability and contextual accuracy in educational applications, making RAG more suitable than standard LLMs for delivering dynamic, trustworthy, and context-sensitive support to learners [5].

By leveraging Retrieval-Augmented Generation (RAG) and multi-agent technology, this application provides adaptive personal support in material discussions, idea exploration, and project planning. The system utilizes RAGflow to integrate knowledge from various sources, including documents, articles, and databases [7]. Additionally, Agentive AI technology enables the system to dynamically interact with users, understand their needs, and provide relevant suggestions. The adopted development approach is the Prototyping Model, which allows for rapid iteration and user feedback at each development stage.

This application has the potential to address major challenges faced by students in project-based learning. The lack of ability to construct knowledge independently is a common issue. By utilizing RAG, the system provides instant access to relevant information, helping students overcome confusion and deepen their understanding. Furthermore, Agentive AI technology enables the system to act as a proactive learning partner, facilitating idea exploration and offering support during the design and project planning stages [8].

2. Research Method

The Prototyping Model is a system development approach emphasizing the creation of an initial model that functions as a temporary representation of the final system [9], [10]. This approach relies on rapid iterations and user feedback, allowing continuous identification and refinement of requirements. The selection of the Prototyping Model aligns with the research titled "Development of a Virtual Mentor Integrated with Retrieval-Augmented Generation Artificial Intelligence for Project-Based Learning", as it allows iterative exploration of core concepts, user needs validation, and rapid design adjustments—critical in developing interactive and adaptive learning systems. The stages used in this model are as follows: Needs Analysis, Rapid Design, Prototype Development, Early User Evaluation, and Prototype Refinement.

2.1 Needs Analysis

In this study, the Needs Analysis phase involved collecting data from students enrolled in project-based learning courses through interviews and short surveys. The goal was to identify specific challenges related to understanding course materials, generating project ideas, and managing project timelines. The findings were translated into a set of functional and non-functional requirements, which guided the initial design of the Virtual Mentor.

2.2 Rapid Design

Based on the identified requirements, low-fidelity interface sketches and early interaction flows were created. These designs included the planned RAG-based question-answering module, idea-generation assistant, and project-planning helper. A quick review with two lecturers and a small group of students was conducted to validate the core functions before moving to prototyping.

2.3 Prototype Development

A functional prototype was developed by integrating RAGflow. This initial version enabled students to inquire about course materials, request project ideas, and generate draft project timelines. The prototype included

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the core retrieval pipeline—where external documents were indexed, retrieved, and fused with generative outputs—and agent modules designed to manage context, intent detection, and task-specific reasoning.

2.4 Early User Evaluation

Ten students tested the prototype during a project-based learning session. Data were collected through observation and short usability questionnaires. Feedback focused on clarity of responses, relevance of retrieved information, ease of interaction, and usefulness for the project design process. Several usability issues were identified, particularly response organization and workflow clarity.

2.5 Prototype Refinement

Based on user feedback, improvements were made to the retrieval prompts, agent coordination rules, and interface layout. RAG sources were expanded to include additional course documents, and the guidance flow for idea exploration and project planning was streamlined. The refined prototype served as the final version used for analysis in this study.

2.6 Participants

The Early User Evaluation involved 10 undergraduate students enrolled in a Project-Based Learning (PjBL) course within the Education and Technology program, aged 19–22 years. Participants were selected using convenience sampling and had prior experience working on project-based assignments, making them suitable for testing the Virtual Mentor system.

2.7 Evaluation Instrument

The evaluation instrument was adapted from prior usability research in digital learning systems [11]. The evaluation utilized a 5-point Likert scale questionnaire (1 = strongly disagree, 5 = strongly agree) designed to measure content relevance, project idea recommendation, project scheduling assistance, system usability, context awareness, student engagement and overall satisfaction.

2.8 Data Analysis Procedure

Quantitative data from the questionnaire were analyzed using descriptive statistics, focusing on mean scores and interpretation levels for each evaluation aspect. These scores provided insights for refining system responsiveness, clarity, and contextual adaptation. Also, these findings informed the next iteration during the Prototype Refinement stage.

3. Result and Discussions

The Virtual Mentor system is designed to actively support students throughout the project-based learning process. It is developed through a structured methodological sequence:

1. Conducting Needs Analysis to identify students' specific requirements in the context of PjBL;
2. Applying Rapid Design to create initial prototype iterations;
3. Building a functional prototype using Retrieval-Augmented Generation (RAG) and Agentive AI to provide material discussion support, idea exploration, and project planning;
4. Performing Early User Evaluation with a small group of students to gather initial feedback on system usability and effectiveness;
5. Conducting Prototype Refinement based on feedback to continuously improve the learning experience and achieve PjBL learning objectives.

Building upon that comprehensive methodological foundation, the system has been developed to deliver three principal functionalities:

3.1 Answering student questions about course content

The system provides real-time, contextually relevant responses to students' content-related questions. This capability is strengthened by the RAG mechanism, which retrieves verified and up-to-date course materials, guidelines, and references before generating an answer. By grounding the model's outputs in retrieved

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documents, RAG significantly reduces hallucinations, enhances domain specificity, and ensures that the explanations closely align with actual instructional resources. As a result, students receive high-quality, accurate, and pedagogically aligned support when confronting conceptual difficulties.

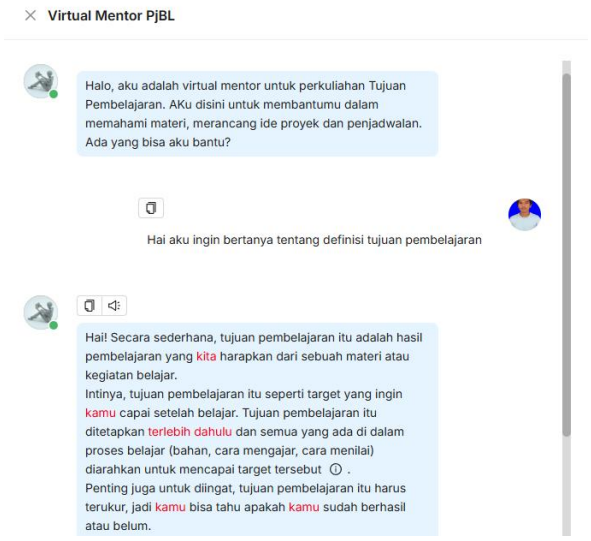

Figure 1 Student asking the tools for course content

3.2 Helping students determine a suitable project idea

To support idea development, the system utilizes a combination of context-aware retrieval and agentive reasoning. RAG extracts relevant examples, prior project cases, and thematic materials from the course repository, while the agentive layer analyzes the student's stated interests and project constraints. This enables the system to recommend feasible, contextually grounded project ideas that align with learning objectives. Through this approach, students are not only provided with options but are guided to understand why certain ideas are appropriate within the PjBL framework.

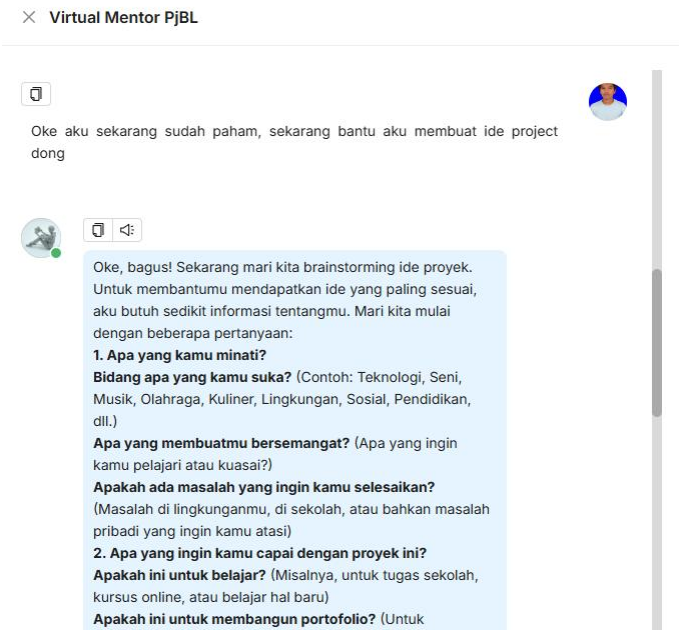

Figure 2 Student asking the tools for project idea brainstorming

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3.3 Assisting students in scheduling their project

The system assists students in forming structured project timelines by analyzing retrieved workflow templates, course schedules, and best-practice project milestones. Agentive components adapt these recommendations to the student's pace, progress, and stated preferences. The resulting timeline suggestions support improved planning literacy, enabling learners to manage tasks more effectively and maintain sustained progress throughout their project.

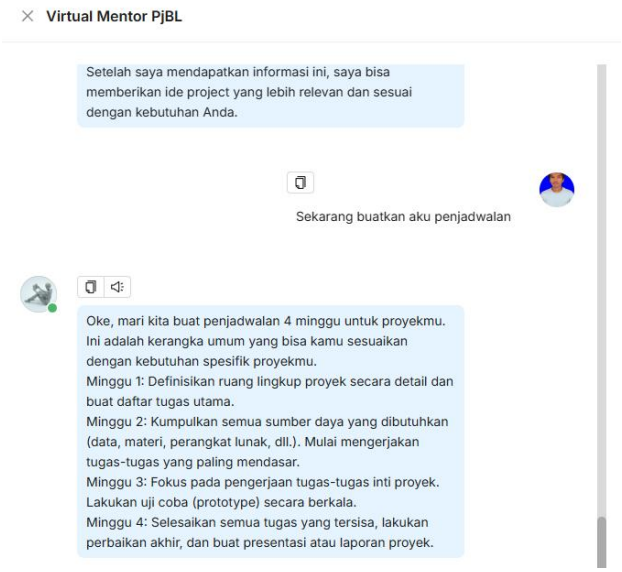

Figure 3 Student asking the tools for project scheduling

To provide a clearer understanding of how these features operate in practice, the following illustration presents the overall workflow of the Virtual Mentor system, depicting the interaction between students, the AI components, and the learning resources throughout the project-based learning process.

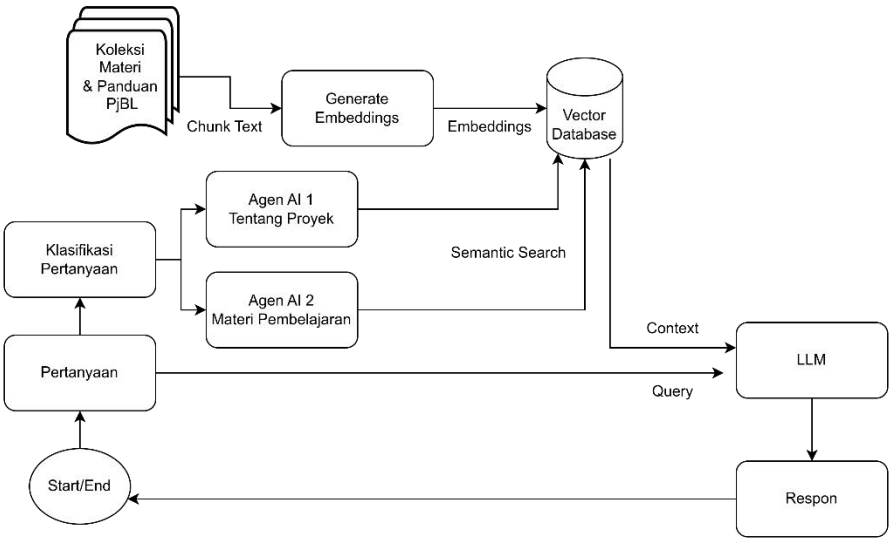

Figure 4. Workflow of the Virtual Mentor integrated with Retrieval-Augmented Generation Artificial Intelligence

To evaluate the effectiveness and usability of the Virtual Mentor system, an early user testing session was conducted involving a group of students who had previously engaged in project-based learning activities. The

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evaluation focused on several key aspects related to the system's core features, including response relevance, contextual guidance, usability, and student engagement. The results of this preliminary testing are summarized in the following table.

Table 1 Early User Evaluation Results of the Virtual Mentor System

No	Evaluation Aspect	Description of Evaluation Item	Mean Score (1–5)	Interpretation
1	Content Relevance	Accuracy and relevance of AI responses to student questions related to course materials.	4.6	Very Good
2	Project Idea Recommendation	The system's ability to provide helpful and contextually appropriate project ideas.	4.4	Very Good
3	Project Scheduling Assistance	Clarity and usefulness of the project timeline recommendations generated by the system.	4.3	Good
4	System Usability	Ease of interaction, navigation, and interface clarity during the learning process.	4.7	Excellent
5	Context Awareness	The AI's capability to adapt responses based on specific project-based learning contexts.	4.5	Very Good
6	Student Engagement	The extent to which students felt motivated and actively involved during the interaction.	4.2	Good
7	Overall Satisfaction	Students' overall perception of the system's effectiveness in supporting PjBL.	4.6	Very Good

Notably, the system's usability score of 4.7 aligns with previous research on RAG-enhanced educational agents, suggesting that retrieval-augmented approaches can significantly improve interactive learning experiences. For example, a pilot study by researchers who integrated RAG into a tutoring system reported similarly high levels of student engagement and motivation, emphasizing how RAG can provide timely, relevant, and credible responses grounded in course materials [6].

Moreover, our finding that students highly value real-time, context-aware responses is mirrored in the systematic survey of RAG in education, which highlights that RAG-powered interactive learning systems can adapt dynamically to learners' needs and provide up-to-date, domain-specific knowledge [5].

In addition, the usefulness of project-scheduling support in our system parallels the arguments made in literature that RAG-based intelligent tutoring frameworks can assist with structured learning paths by retrieving pedagogically relevant templates and resources. For instance, an intelligent tutoring system (LPITutor) evaluated in a study demonstrated that integrating RAG and prompt engineering improved response accuracy and relevance, leading to higher user satisfaction compared to standard LLM outputs [12].

These comparisons indicate that our Virtual Mentor not only embodies the strengths identified in prior RAG-enabled educational tools but also extends them into the specific context of project-based learning, combining idea generation and scheduling support in a unified system.

3.4 System Limitations and Future Improvements

Several limitations were observed during prototype evaluation:

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3.4.1 Limited Dataset Coverage.

The retrieval repository currently consists of course-specific materials and a small set of curated references. This restricts the breadth of contextual knowledge the system can access, potentially limiting idea diversity and cross-domain exploration.

3.4.2 Varying Retrieval Quality.

Although RAG improves response accuracy, retrieval quality is influenced by document structure, indexing quality, and query formulation. Some responses may become overly dependent on surface-level keyword matching rather than deeper semantic alignment.

3.4.3 Lack of Long-Term Adaptation.

The prototype adapts to user inputs within a single session, but long-term personalization (e.g., tracking learning progression across weeks) is not yet implemented.

3.4.4 Interface and Interaction Constraints.

The current chat-based interface supports core interactions but does not yet provide multimodal scaffolding such as visual progress charts, project templates, or concept maps that could improve clarity and engagement.

3.5 Future Improvements

Future development will focus on:

- expanding the retrieval corpus to include broader academic and interdisciplinary sources;
- integrating semantic retrieval and re-ranking techniques to improve contextual precision;
- implementing longitudinal learner modeling to support sustained, personalized guidance;
- enhancing the interface with multimodal dashboards and visualizations; and
- conducting larger-scale evaluations to validate system effectiveness across diverse PjBL contexts.

4. Conclusions

The development and evaluation of the Virtual Mentor System demonstrate its potential as an effective AI-based support tool for students engaged in project-based learning. By integrating Retrieval-Augmented Generation (RAG) and agentive AI, the system successfully provides three essential forms of assistance: answering content-related questions, recommending feasible project ideas, and supporting the creation of structured project schedules.

Findings from the early user evaluation show consistently strong performance across all indicators, with an average score of 4.47, reflecting high levels of content relevance, contextual responsiveness, usability, and overall satisfaction. These results indicate that the system not only improves access to accurate and context-sensitive information but also strengthens students' autonomy and project-management capabilities within the PjBL environment.

Overall, the Virtual Mentor System offers a promising direction for enhancing learning support in higher education by operationalizing RAG-based retrieval, multi-agent reasoning, and adaptive interaction. Its demonstrated effectiveness suggests that AI-driven mentoring can meaningfully complement instructional practices, streamline project planning, and improve student engagement.

Future studies should expand the scope of evaluation by involving larger and more diverse student cohorts to validate the system's effectiveness across different academic programs. Integration with institutional Learning Management Systems (e.g., Moodle) is also recommended to enable seamless access to course materials, improve retrieval quality, and support broader adoption in real classroom settings. Further refinement of the agent framework and personalization mechanisms may additionally enhance the system's long-term impact on project-based learning.

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