How to Build an AI Tutor that Can Adapt to Any Course and Provide Accurate Answers Using Large Language Model and Retrieval-Augmented Generation

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ABSTRACT: Artificial intelligence is transforming education through data-driven, personalized learning solutions. This paper introduces AI Tutor, an innovative web application that provides personalized tutoring in any subject using state-of-the-art Large Language Model (LLM). AI Tutor ingests course materials to construct an adaptive knowledge base tailored to the course. When students pose questions, it retrieves the most relevant information and generates detailed, conversational responses citing supporting evidence. The system is powered by advanced large language models and Retrieval-Augmented Generation (RAG) techniques for accurate, natural question answering. We present a fully-functional web interface and video demonstration that showcase AI Tutor's versatility across diverse subjects and its ability to produce pedagogically cogent responses. While an initial prototype, this work represents a pioneering step toward AI-enabled tutoring systems that can democratize access to high-quality, customized educational support.

Keywords: Intelligent Tutoring Systems, Large language model, Retrieval-Augmented generation, Adaptive education, Personalized learning

1. Introduction

The advent of artificial intelligence (AI) has instigated a transformational wave across various sectors, with education standing as a salient beneficiary. AI's unrivaled capacity to enable personalized and adaptive learning experiences has propelled intelligent tutoring systems to the forefront of modern educational paradigms (Kasneci et al., 2023). These systems, powered by AI, offer individualized feedback and interactive learning modules designed to cater to each student's distinct learning needs. Nonetheless, the challenge of developing AI tutors capable of delivering consistently accurate and dependable responses across diverse academic disciplines persists.

A notable hindrance to the reliability of AI in educational applications is the occurrence of 'information hallucination', a phenomenon where AI-generated responses, while appearing valid, deviate from factual accuracy (Nye et al., 2023). Such inconsistencies can undermine confidence in AI-centric educational systems (Kasneci et al., 2023). Furthermore, the customization of these systems to align with specific course content necessitates access to current and pertinent educational materials, a task often complicated by the multifaceted nature of academic disciplines.

To tackle these challenges, this paper introduces AI Tutor, a web application developed upon the sophisticated infrastructure of large language models (LLMs) and retrieval-augmented generation (RAG). AI Tutor is engineered to deliver accurate, contextually relevant responses by intelligently assimilating information from course-specific materials (Lewis et al., 2020). Our system signifies a substantial leap from traditional rule-based educational methodologies, amplifying the personalization potential of AI tutoring systems. The AI Tutor distinguishes itself with a user-centric web interface that streamlines the process of uploading course materials and submitting queries. It integrates robust vector embedding and storage systems for educational content, employs similarity-based retrieval algorithms to pinpoint relevant information, and leverages the OpenAI Assistants API, combining the strengths of LLMs and RAG for sophisticated answer generation. In addition, AI Tutor provides an option for students to download records of their Q&A sessions, thus enriching their repository of learning resources.

Our project has an ambitious goal: to build an AI tutoring system that gives accurate, personalized help for any school subject. We want to show that the latest AI technologies, known as large language models (LLMs) and retrieval-augmented generation (RAG), are more effective than the old-style tutoring systems that follow strict rules. At the core of our work is creating a smart system that can understand and use the materials from different courses to build a knowledge base tailored to students' needs. This is key to providing precise answers to students' questions and shows the system's strong grasp of the topics. We've also made a website that's easy to use, which shows off the wide range of skills our AI tutor has and how well it fits into the study process. This website proves that our system is adaptable

and focused on helping users, marking the AI tutor's role in changing the way we think about education. With this project, we're not just proving that LLMs and RAG work well in education. We're also showing how they can significantly change how we use AI to support learning, pointing towards a future where AI is an essential part of how we learn.

2. Related Work

AI's application in education spans a broad spectrum, from augmenting curriculum design to facilitating personalized learning experiences, engaging students, and boosting motivation. Moore, S. et al. (2023) delineate the role of AI as ranging from assistive to autonomous, predicting a shift from AI as a tool in the educator's arsenal to an independent teaching agent. Currently, AI plays a primarily assistive role, but the trend indicates a shift toward more sophisticated, AI-centric educational experiences. Bailey further explores the ethical, pedagogical, and social implications of embedding AI in learning, touching on privacy, bias, and creativity cultivation concerns.

In contrast to earlier systems, such as the PAT2Math developed by Jaques et al. (2013), which employed rule-based algorithms to guide learners through algebraic problem-solving, our AI Tutor system harnesses the latest advancements in AI to deliver a far more sophisticated and nuanced educational interaction. Where PAT2Math's rule-based engine excelled in providing immediate feedback by comparing student inputs to a set of predefined solutions, it was nonetheless constrained by the inherent limitations of its architecture, notably an inability to generate response for the answer that not existed in their database and also lack reasoning ability compare to large language model.

In the landscape of AI-enabled education, Gan et al. (2019) laid a significant groundwork with their proposed framework for an AI-based math tutor. This system uniquely leveraged a modified approach to Item Response Theory (IRT) to first gauge a learner's ability, subsequently supplying custom-tailored question and answer sessions rooted in a pre-stored mathematical database. Despite the system's innovative use of natural language processing to analyze the semantic relationship of questions, it presented certain limitations. Primarily, the system's adherence to a static question database constrained its answering flexibility, often leading to repetitive and predictable responses. Additionally, the system exhibited a low tolerance for linguistic errors, struggling with sentence structures marred by typos or poor grammar. This limited its ability to accurately parse and comprehend questions that were not part of its pre-existing bank, emphasizing a critical shortcoming of the mechanism.

In light of these limitations, our project turns to the latest advancements in large language models (LLMs). This state-of-the-art technology offers superior comprehension of natural language, allowing it to process student queries articulated in various manners effectively. The LLM also ensures the generation of natural, contextually appropriate responses, thus addressing and overcoming the limitations observed in earlier AI tutoring systems.

3. Technical Background

This section provides an overview of the main concepts and techniques used in this project, namely Large Language Models (LLMs), Retrieval Augmented Generation (RAG), embedding, vector storage, similarity search, and modified prompts. These concepts and techniques are essential for developing and evaluating an AI-based system that can generate accurate and relevant responses to natural language queries in the domain of education.

3.1. Large Language Models

Recent advancements in natural language processing have been spurred by Large Language Models (LLMs) (Lewis et al., 2020). These are powerful neural networks trained on vast amounts of text, capable of generating coherent and meaningful language. They are versatile, used in various tasks such as translation, summarization, dialogue, and question answering. LLMs employ transformer architectures, which use self-attention mechanisms to understand text better (Shin et al., 2020). To optimize their performance, these models are initially pre-trained on large datasets and then fine-tuned for specific tasks (Brown et al., 2020).

Among the notable LLMs are OpenAI's GPT models, Google's PaLM, and Meta's LLaMa. In our AI Tutor system, we use OpenAI's GPT-4-1106-preview model, launched in November 2023 (Devlin et al., 2019). This model's scale and sophisticated training methodology enable it to perform exceptionally well on natural language tasks. Interestingly, GPT-4 even outperforms humans on many academic exams such as SAT and GRE as can be seen in Figure 1 below. For instance, on the SAT Math exam, it scored 710 out of 800, beating 89% of human test takers (OpenAI GPT-4 Technical Report, 2023). This highlights the model's robust reasoning capabilities. By integrating GPT-4, our AI Tutor system can effectively understand course materials, interpret diverse student questions, find relevant information, and provide natural, contextual responses (Chang et al., 2023). This significant upgrade helps overcome the limitations of previous rule-based tutoring systems struggling with open-ended student inputs.

Figure 1. Comparative Performance: GPT-3.5 and GPT-4 Surpass Human Achievement in Academic Examinations
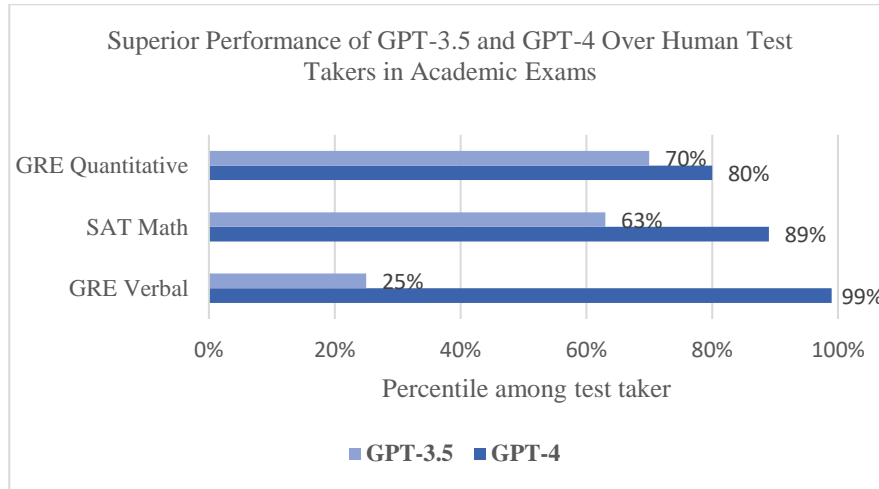

3.2. Retrieval Augmented Generation

Retrieval Augmented Generation (RAG) is a technique for enhancing the accuracy and reliability of LLM-generated responses by grounding the model on external sources of knowledge to supplement the LLM's internal representation of information (Lewis et al., 2020). RAG allows LLMs to access and incorporate relevant facts from an external knowledge base, such as user uploaded files, into their responses, instead of relying solely on their pre-trained parameters or hallucinating incorrect or misleading information (Cai et al., 2022). RAG consists of two main components: a retriever and a generator. The retriever is responsible for finding and ranking the most relevant documents or passages from the knowledge base given the input query. The generator is an LLM that takes the input query and the retrieved documents or passages as context and produces a response. The generator can also learn to select the best documents or passages from the retriever's output using an attention mechanism (Moore et al.,2023).

RAG has several benefits for improving the quality and trustworthiness of LLM-generated responses. First, it ensures that the model has access to the most current, reliable, and domain-specific facts, which can improve the accuracy and relevance of the responses. Second, it provides users with the sources of the model's responses, which can increase the transparency and verifiability of the model's claims. Third, it reduces the need for fine-tuning the model on new data and updating its parameters, which can lower the computational and financial costs of maintaining the model (Lewis et al., 2020).

4. Methodology

In this section, we describe the technical design and implementation of our AI Tutor system, which aims to provide accurate and intelligent tutoring customized to any course. We also explain how we integrated the OpenAI Assistants API, which provides the core functionality of our system. The overall architecture of our AI Tutor system is illustrated in the following Figure 1.

Figure 2. The AI Tutor Framework
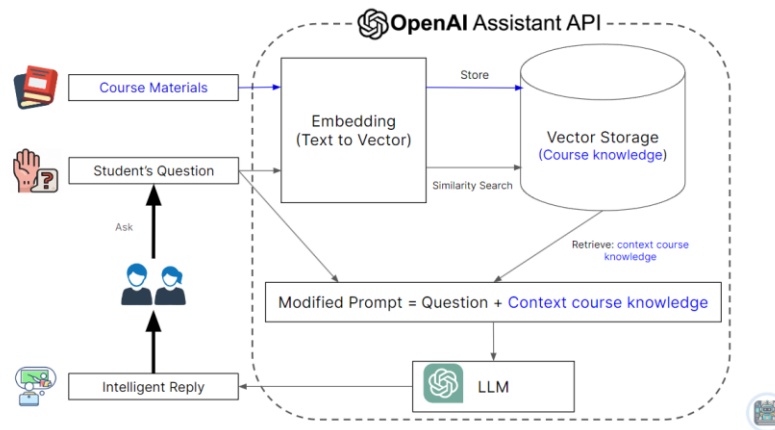
As shown in the Figure 2 above, our system consists of four main components:
- Course Materials: These are the domain-specific documents that provide the knowledge base for the AI Tutor. The user can upload any course materials in text format, such as lecture notes, slides, textbooks, etc. The system will store the course materials in a vector database and use them for retrieval and generation.
- Student's Question: This is the natural language query that the user inputs to the AI Tutor. The system will encode the question into a vector representation using a pre-trained embedding model.
- AI Tutor: This is the core component of our system that integrates the OpenAI Assistants API. The API provides the following features:
    - Embedding: The API uses a pre-trained embedding model to convert the text inputs (question and course materials) into vector representations. The assistants API use the OpenAI embedding
    - Vector Storage: The API stores the vector representations of the course materials in a vector database, which allows for efficient similarity search and retrieval.
    - Similarity-Based Retrieval: The API uses a similarity search algorithm to retrieve the most relevant course materials for the given question.
    - Retrieval-Augmented Generation (RAG): The API uses a large language model (LLM) that is augmented with a retrieval mechanism to generate the intelligent reply. The API supports various LLMs. The retrieval mechanism allows the LLM to access the relevant course materials and use them as context for generation. In this project, the we use the latest gpt-4-1106-preview trillion parameters model to empower the tutor which harness the ai power
    - Chat History Management: The API maintains a chat history for each user session, which allows the LLM to generate coherent and consistent replies. The API also allows the user to delete the chat history at any time.

The system's operational workflow is characterized by the following sequential steps:
- Material Upload: Users upload course materials, which are then vectorized using the API's embedding function and stored within the vector database.
- Question Submission: The student poses a question to the AI Tutor, which is encoded into a vector via the embedding feature.
- Response Generation: A modified prompt, composed of the student's question and the retrieved materials, is used to generate an intelligent response employing the RAG feature of the API. This response includes citations from the course materials, ensuring transparency and verifiability. Furthermore, the AI Tutor presents the intelligent reply to the student and updates the chat history to maintain the flow of the conversation.
- Session Continuation or Conclusion: Students have the option to continue the dialogue with additional questions, conclude the session, download a record of the chat history in HTML format for review, or delete the chat history for privacy.

The methodology applied in the development of the AI Tutor system is a testament to the integration of advanced AI with user-centric design, aiming to transform the educational landscape through personalized, responsive tutoring.

5. Demonstration

In this section, we present the demonstration of our AI Tutor project, which consists of two parts: the web app view and the Q&A session demo. We show how the AI Tutor works and how it can answer different types of questions based on the course materials. We also evaluate the performance and quality of the AI Tutor, such as the accuracy, relevance, naturalness, and citation of the answers.

5.1. Web App View

We developed a web app using Streamlit to showcase the functionality of our AI Tutor. The web app allows users to input their OpenAI API key, upload course materials in text format, and ask questions related to the course content. The web app also provides two buttons on the sidebar: one to delete all uploaded course materials, and another to generate a downloadable Q&A record in HTML format. The web app interface is shown in Figure 3.

Figure 3. The AI Tutor Web App Screenshot
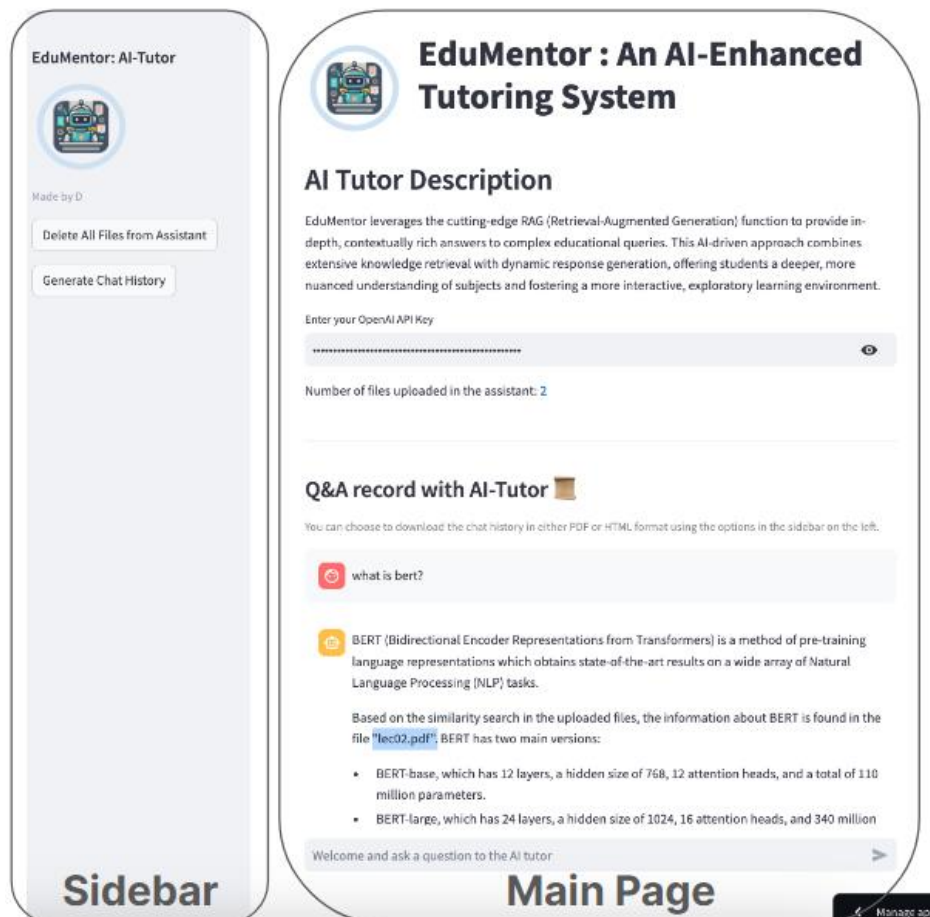

We created a video demo to illustrate the usage and features of our AI Tutor. The video demo shows how a user can upload course materials, ask questions, and view answers from the AI Tutor. The video demo also highlights the naturalness and citation of the answers, as well as the Q&A record generation. The video demo is available at: https://youtu.be/UH0SjqU5tVI?si=cVuBlwdOADq1q7gx.

5.2. Q&A Session Demo

To exhibit the capabilities of the AI Tutor in delivering precise and pertinent responses anchored in educational content, we initiated a Q&A session utilizing our web application. We uploaded a trio of pdf documents comprising the course materials for "Finance Theory I" sourced from MIT OpenCourseWare (https://ocw.mit.edu/courses/15-401-finance-theory-i-fall-2008/). Our inquiries delved into the core topics of the course, prompting the AI Tutor with questions like, "What are the six principles of finance? Use simple examples to explain to me." The AI Tutor's responses were impressively cogent, drawing directly from the uploaded material, and duly referenced the corresponding sources. This interactive dialogue is visually captured in Figure 4.
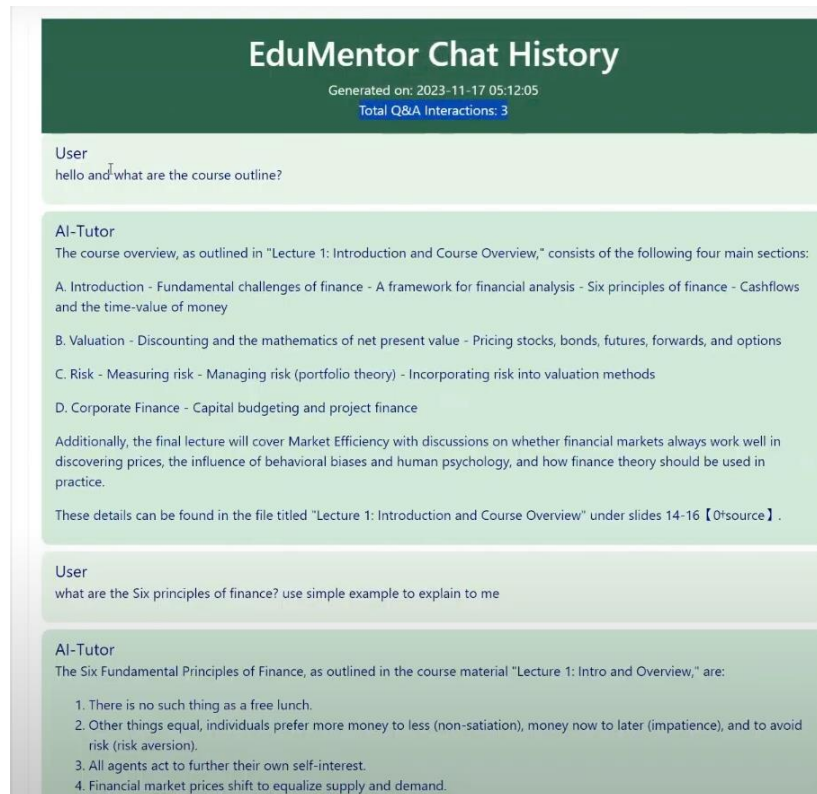
Figure 4. An Example of AI Tutor Q&A

AI Tutor Answer — Question related materials
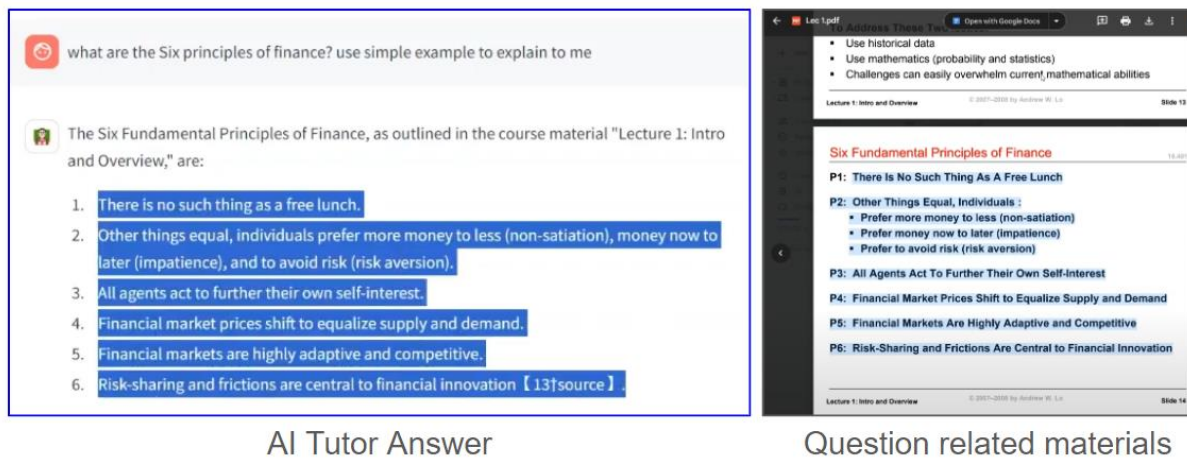
From the above Figure 4, we can see that our AI tutor performance have following highlights:
- Accuracy: The AI Tutor's responses were scrutinized for correctness and alignment with the posed questions, ensuring they adhered closely to the factual content of the course material
- Relevance: The pertinence of each answer was assessed, with a keen focus on the alignment with the correct answer, substantiated by direct citations from the related source materials.
- Naturalness: We observed the conversational quality of the AI Tutor's responses, gauging their human-like tone and approachability.
- Citation: The system was particularly evaluated on its ability to accurately cite the specific course materials that informed its answers. For instance, as illustrated in the aforementioned Figure 4, the AI Tutor effectively referenced the section titled 'Lecture 1: Intro and Overview' in relation to the queried concept.

An essential aspect of our AI Tutor is its commitment to sustained learning. Post each Q&A session, the system allows students to download a comprehensive record of the interaction. This feature is significant in the educational context, offering students the opportunity to revisit the discussion and review the responses at their own pace. The Q&A record serves as a personalized study guide, crafted to address the student's specific queries. It forms a valuable addition to the learner's resources, especially in the context of complex subjects that necessitate repeated engagement and a screenshot of the downloaded Q&A record is shown in Figure 5 below. Looking forward, we propose enhancing the AI Tutor's interactive dimension by incorporating visual aids, such as charts, tables, and diagrams, which could significantly bolster the comprehensibility and engagement of the responses.

Figure 5. An example of generated Q&A record downloaded (in html format)

EduMentor Chat History

Generated on: 2023-11-17 05:12:05

Total Q&A Interactions: 3

User
hello and what are the course outline?

AI-Tutor
The course overview, as outlined in "Lecture 1: Introduction and Course Overview," consists of the following four main sections:

A. Introduction - Fundamental challenges of finance - A framework for financial analysis - Six principles of finance - Cashflows and the time-value of money

B. Valuation - Discounting and the mathematics of net present value - Pricing stocks, bonds, futures, forwards, and options

C. Risk - Measuring risk - Managing risk (portfolio theory) - Incorporating risk into valuation methods

D. Corporate Finance - Capital budgeting and project finance

Additionally, the final lecture will cover Market Efficiency with discussions on whether financial markets always work well in discovering prices, the influence of behavioral biases and human psychology, and how finance theory should be used in practice.

These details can be found in the file titled "Lecture 1: Introduction and Course Overview" under slides 14-16【0†source】.

User
what are the Six principles of finance? use simple example to explain to me

AI-Tutor
The Six Fundamental Principles of Finance, as outlined in the course material "Lecture 1: Intro and Overview," are:

1. There is no such thing as a free lunch.
2. Other things equal, individuals prefer more money to less (non-satiation), money now to later (impatience), and to avoid risk (risk aversion).
3. All agents act to further their own self-interest.
4. Financial market prices shift to equalize supply and demand.

6. Discussion

In this project, we developed an AI tutor that can answer students' questions based on the course materials uploaded by the instructor. The AI tutor leverages a large language model (LLM) and a retrieval-augmented generation (RAG) technique to generate accurate and natural responses grounded in verified information. We demonstrated the functionality and versatility of our AI tutor through a web app and a video demo. In this section, we will discuss the strengths and weaknesses of our AI tutor, as well as the limitations and challenges of the techniques used in the project. We will also address the potential ethical and societal implications of deploying our AI tutor in educational settings. Finally, we will provide some recommendations for future improvements and extensions to the project.

6.1. Strengths and Weaknesses of the AI Tutor

One of the main strengths of our AI tutor is that it can adapt to any course by using the course-specific materials as the external data source for the RAG technique. This allows the AI tutor to provide tailored responses that are aligned with the course content and objectives. Moreover, the AI tutor can generate high-quality answers in any domain, as long as the domain knowledge documents are available and accessible. Another strength of our AI tutor is that it can produce natural and human-like responses by using the power of the LLM, which is trained on a large corpus of text and can capture the nuances and subtleties of natural language. Furthermore, the AI tutor can handle a variety of questions, such as factual, conceptual, or analytical questions, and provide appropriate citations for the retrieved information.

However, our AI tutor also has some weaknesses that need to be addressed. One of the weaknesses is that the AI tutor is not guaranteed to provide 100% accurate answers, as the LLM may still suffer from information hallucination or inconsistency. Therefore, the AI tutor's answers should be verified and validated by the instructor or other reliable sources before being accepted as correct. Another weakness is that the AI tutor's performance depends on the quality and clarity of the student's question, as well as the availability and relevance of the course materials. If the student's question is vague, ambiguous, or too broad, the AI tutor may not be able to provide a satisfactory answer. Similarly, if

the course materials are incomplete, outdated, or inaccurate, the AI tutor may not be able to retrieve the correct information or may provide misleading or erroneous answers.

6.2. Limitations of the Techniques Used in the Project

The techniques used in the project, namely the LLM and the RAG, also have some limitations and challenges that need to be considered. One of the limitations is that the LLM and the RAG are computationally expensive and require a lot of resources and time to train and run. This may pose a challenge for the scalability and affordability of the AI tutor, especially for low-resource settings or large-scale applications. Another limitation is that the LLM and the RAG are based on statistical models and probabilistic methods, which may not capture the full complexity and diversity of natural language and human knowledge. This may result in some limitations in the expressiveness, interpretability, and explainability of the AI tutor's answers. Moreover, the LLM and the RAG are still subject to some biases and errors that may affect the quality and reliability of the AI tutor's answers. For example, the LLM may inherit some social or cultural biases from the training data, or the RAG may retrieve some irrelevant information from the external data source some times.

6.3. Ethical and Societal Implications of Deploying the AI Tutor in Educational Settings

Deploying the AI tutor in educational settings may have some ethical and societal implications that need to be carefully examined and addressed. One of the implications is that the AI tutor may affect the role and relationship of the instructor and the student in the learning process. The AI tutor may complement or supplement the instructor's teaching, but it may also replace or undermine the instructor's authority or expertise. Similarly, the AI tutor may enhance or facilitate the student's learning, but it may also impair or discourage the student's critical thinking or creativity. Therefore, the AI tutor should be used as a tool or a resource, not as a substitute or a replacement, for the instructor or the student. Another implication is that the AI tutor may raise some privacy and security issues regarding the data collection and usage in the project. The AI tutor may collect and use some personal or sensitive data from the instructor or the student, such as the course materials, the questions, or the answers. This may pose some risks of data leakage, misuse, or abuse, which may violate the privacy or confidentiality of the instructor or the student. Therefore, the AI tutor should follow some ethical principles and guidelines, such as transparency, consent, accountability, and fairness, to ensure the data protection and respect of the instructor or the student.

6.4. Recommendations for Future Improvements

Based on the discussion above, we can provide some recommendations for future improvements and extensions to the project. One of the recommendations is to reduce the cost of the AI tutor by exploring some alternative options for the LLM and the RAG, such as open-source or low-resource models, or by using some third-party frameworks and libraries, such as Langchain or Chroma, to reduce the implementation costs. Another recommendation is to improve the user interface design of the AI tutor to enhance the user engagement and satisfaction, such as by adding some interactive or personalized features, such as feedback and user profile. A third recommendation is to implement more scalable solutions for the AI tutor, such as by using some cloud-based or distributed platforms, such as Google Cloud or Azure, to increase the availability and accessibility of the AI tutor. A fourth recommendation is to investigate the feasibility of automated quiz generation for the AI tutor, such as by using the context of course material to provide some formative assessment for the student's learning.

7. Conclusion

This paper introduced AI Tutor, a web application at the forefront of educational technology, utilizing the latest advancements in artificial intelligence to provide tailored tutoring for any course. The AI Tutor is underpinned by the most recent OpenAI Assistants API, released in November 2023, and is powered by the most sophisticated iteration of the GPT-4 model, ensuring that our system is both cutting-edge and robust. The innovation of AI Tutor resides in its unique ability to digest and utilize course materials provided by educators, forming an adaptable vector knowledge base. When a student poses a query, the system first employs vector similarity search to identify the most relevant

information within this specialized database. It then applies a powerful generative model to articulate responses that are not only accurate and contextually relevant but also enriched with citations from the source material. The evaluations reveal AI Tutor's effectiveness in producing relevant, factually consistent responses, showcasing the promise of integrating sophisticated LLMs with retrieval. This underscores AI Tutor's evolution beyond limitations of prior rule-based tutoring systems.

However, real-world deployment necessitates further enhancements, particularly in scalability. While the current prototype uses Streamlit's community cloud, migration to robust commercial platforms like Microsoft Azure or Google Cloud could strengthen stability for large-scale usage. Additional priorities include boosting interpretability, ethical rigor, and conducting user studies to gauge pedagogical impact. In essence, AI Tutor represents an important milestone in harnessing AI's benefits for education through an accessible, interactive platform. It lays a foundation for a new generation of intelligent tutors that can empower learners with personalized support tailored to their academic journeys. Realizing the full potential of such systems will require sustained research and responsible development. But the possibilities glimpsed by this initial effort highlight the transformative promise of AI in augmenting how we teach and learn.

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