GPT Pedagogy

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April 26, 2023

Abstract

GPT-3 and related technologies, while transformative, can be misused by students, hindering their learning potential. This paper presents a technical use case description for a GPT-3-based tool designed to foster transparency, active learning, and engagement between instructors and students in higher education. Our objective in designing this tool aligns with the fourth UN SDG,

> Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all [4].

We propose an asynchronous and adaptive learning tool that supports, rather than undermines, the educational process.

Our learning assistant, named *Mathesis* from the ancient greek work for learning, will be integrated in an Introduction to Biology course at RPI during the Fall 2023 semester. In collaboration with institute faculty members, we have gathered ample course material to fine-tune a GPT-3 [2] model. When integrated with our online user interface, this model can be used by students as a domain-knowledgeable and adaptive learning assistant. This personalized AI tutor aims to facilitate learning, increase transparency, and reduce student stress.

Our goal for *Mathesis* is to retain the conversational abilities of ChatGPT while fine-tuning the underlying large language model (LLM) with domain expertise. The current fine-tuned model can perform several tasks that achieve this goal. These include: the generation of course-relevant multiple choice and free response questions, the assessment of student responses, and the generation of tailored, critical, and constructive feedback to students. Future model iterations will leverage human-in-the-loop reinforcement learning, drawing from previous interactions with students and faculty to expand its proficiency as a learning tool.

We also aim for this model to be generalizable to other classes and disciplines in the future. The model will work especially well for courses where it is difficult to give personalized feedback to each learner in each class meeting time. This often happens in classes that have a high student to faculty ratio.

1 Introduction

Large language models (LLMs), such as OpenAI's Generative Pre-trained Transformer (GPT) series, have revolutionized the field of natural language processing (NLP) with their advanced language understanding and generation capabilities. These models are based on deep learning architectures called transformers, which enable the efficient processing of vast amounts of textual data. LLMs are trained on extensive datasets containing diverse information from websites, books, articles, and other sources, allowing them to grasp context and generate human-like responses. GPT-3, one of the latest iteration in the series, has shown remarkable performance in various tasks, including translation, summarization, and question-answering. While these models hold immense potential for applications across different domains, their use in educational settings has gained significant attention. By leveraging the proficiency of LLMs like GPT-3, we aim to develop an innovative learning tool that enhances student engagement and promotes a more personalized learning experience.

1.1 Our Targeted Approach

In partnership with the Teaching and Learning Collaboratory (TLC) at Rensselaer Polytechnic Institute (RPI) in Troy, NY, we have identified an Introduction to Biology class section in the Fall 2023 semester for the debut of our GPT-based learning management system. We believe *Mathesis* will significantly benefit students by providing them with relevant questions and detailed knowledge of course topics. This targeted approach reduces uncertainty and increases the model's usefulness to students by generating responses specific to the course material, avoiding misinformation or demotivation.

1.2 Significance

Customized learning assistants like *Mathesis* have the potential to reshape the educational landscape. We do not contend that AI models can replace faculty, rather that they can serve as learning aids to students. In this role, the model continuously assesses and reinforces student competency in course-relevant material by answering questions and providing feedback on self-administered assessments. The potential impact of these assistants is especially significant in courses with an elevated student-to-faculty ratio. In these classes, each student is afforded a limited amount of personalized instruction from the professor or their TAs. Automated learning assistants can provide students another avenue of learning from a domain-knowledgeable entity. This paradigm has the additional benefit of allowing faculty to prioritize their personalized instruction time on particular students in need of assistance beyond the capabilities of an automated assistant. Similar initiatives, such as Khan Academy's Khanmigo [1] model, offer comparable services to K-12 education through their online educational platform. We hypothesize that integration of LLM tutors in higher education will result in an elevated level of conceptualization of course material among affected students.

Our source code can be found at: *github.com/ITWSXInformatics/ChatGPT_Pedagogy_Group2_2023*
A demo video can be found at: *drive.google.com/file/d/139m_XDbhoRpS4L9yhUWEu-zSxkCSfSdE*

2 Project Use Case

2.1 Specifications

For the development of the use case for this project, it is important to detail several specifications that describe GPT Pedagogy in a more rigorous manner. One of these specifications is the list of the requirements of the project. To fulfil our objectives, the project has the following *functional requirements*:

- Be able to confidently and correctly answer any course-relevant question
- Be able to generate questions for students, based on key learning objectives
- Receive and evaluate student answers
- Provide useful feedback to students on their answers
- Allow instructors to customize question generation
- Allow instructors to evaluate class performance on key learning objectives

Along with these functional requirements, the project requires several *non-functional requirements*. Our project must also have:

- A GPT model fine-tuned to course-relevant material
- A user interface students and administrators use to interact with the model
- A login and authentication system to prevent unwanted access and to keep track of evaluations

Another important specification to consider is that of the entropy/uncertainty of the project. Overall, we have worked to minimize the total uncertainty of the project. It is important to note, however, that the GPT model will always introduce some amount of extra uncertainty.

One of the areas where we worked to minimize uncertainty is through the fine-tuning of the model on our own, customized, training data. The use of a GPT model introduces some uncertainty in user experience. However, we have minimized uncertainty associated with use of the model by employing fine-tuning and prompt engineering techniques. Fine-tuning enables confidence in our model's ability to provide accurate information on course-related concepts. Whereas prompt engineering tailors model outputs to fit within designed specifications which are amenable to integration within our user interface.

We also minimized uncertainty by careful user interface design. Our UI has two views corresponding to the student and administrator users. In both of these cases, our design was oriented towards a simple, straightforward interface. We worked to accomplish this through the use of a minimalist design. Users can choose to choose only a few tabs: the main chat and the lesson evaluations. The administrators have a similar view, with the addition of the ability to edit the questions that are displayed to students. In our design buttons, animations, and images are kept to a minimum. This allows users to focus key features of the website including evaluations or interactions with *Mathesis*.

The use case that we developed addresses what we expect to be the basic flow of the system, along with any reasonable alternate or exception flows. The goal of this system is the same as the project in general: to use an interface and pre-trained model to provide students with a flexible and helpful learning assistant for the *Introduction to Biology* course at RPI.

We have included the particular flows that we did in order to properly scope our use case. Our intention is to implement all relevant ways in which students and administrators interact with the system, while not including flows that may bloat our design of this early use case. Examples of such flows would be deliberate adversarial attacks to the system. While these attacks are a near certainty in a deployed system, the time constraints on this project has not allowed us to account for them in our working prototype. Due to this reason, we have set this, and similar edge cases, to be outside our implementation scope.

2.2 Semiotic Implementation Considerations

As mentioned above, one of our primary design goals of this project was to minimize uncertainty. In addition to the previously mentioned methods, we also minimized uncertainty through our usage of semiotics, cognitive principles, and the project architecture.

One of the ways in which we minimize uncertainty is through our placement of our signs. Many of the elements in the user interface lack symbols or icons. This is by design. As this project is currently in a prototype form, it would be unwise to begin using signs in places where they do not need to be. In place of these signs we instead have text descriptions. While this may be less visually appealing, it offers a lower uncertainty as many elements have their descriptions written on them. An example of a sign that we *do* use can be found in the 'send' icon for the chat functionality. This sign is an icon, specifically, as it does not physically resemble anything being sent. We chose this icon to be that of a paper airplane, as is standard across most massaging applications. Through the use of this, and other icons, we hope to make all functionality clear while maintaining familiarity. Another icon that we use in our interface is the *Mathesis* logo. This sign is also an icon, as it does not attempt to capture the appearance of our learning assistant, even if there was one. It is designed with a similarly minimalist style. Our goal with this sign is to give students something unique to associate with the project. Through this association, we hope that students will be more engaged with our site as it has a unique color palette, design, and character.

We also use both semiotics and cognitive principles in the chat and feedback functionalities of the project. Our design of the chat and feedback interfaces mirrors that of more mundane chat-focused applications. By modeling our interface in a similar manner to SMS communications, we create a familiar environment to both students and teachers. This was likely the rationale of ChatGPT's interface design, which mirrors these communications as well. The 'lesson quiz submission' view also mirrors other systems, such as RPI's learning management systems (LMS). In general, we create an environment that borrows many of the qualities that are present in other applications that are familiar to students. By using this familiarity, we hope that users will be able to immediately recognize the form and function of the interface, allowing for quicker acclimation.

2.3 Alignment and Feedback Considerations

Several considerations are specific to early adoption in the Introduction to Biology course at RPI. This course deals with several topics which could be scrutinized by students with disparate experiences, beliefs, and upbringings including: human evolution, origins of Earth, Covid-19, and climate change. While it is most likely impossible to robustly account for each of the various views on each topic, we have already made significant strides to fine-tune the underlying model to respect student's views while also making them aware of the current prevailing consensus in the biological literature. *Mathesis'* role is to educate, not to indoctrinate. For this reason, our model's behavior towards student's stated beliefs is trained to be both respectful and agnostic of doctrine. In the future, a topic blacklist may be curated to prevent students from asking the learning assistant questions misaligned with course concepts. Topics on this blacklist may involve disparate conspiracy theories prevalent in modern online discourse. When a question regarding one of these topics is asked, the response will be hard-coded to redirect the student's question to the human faculty member.

Our system is designed to be customizable and scalable to fit future needs of higher education. While we have partnered with a professor in the Biology department, there are other courses at RPI which may benefit from a personalized AI tutor like *Mathesis*. Our platform is designed to be amenable to a broad spectrum of course curricula. Each course at RPI can be subdivided into units, and each unit can be further divided into key learning objectives. The fine-tuned models are trained to be proficient question-answering systems per each stated key learning objective. Furthermore, significant supplemental documentation of the fine-tuning process will be made available for domain-knowledgeable models to be created for other courses. For some courses like calculus and physics, it may be necessary to incorporate more updated models, like GPT-4, which have image + text modality [5, 7]. This modality would enable students to upload images of their work to be assessed by the system.

Finally, our system will employ a student and faculty feedback component to allow continuous improvement of the resource. This ability will allow users to report issues or flag model outputs, suggest improvements, and contribute to the model's ongoing refinement. By providing users a voice in the future development of this project, we hope to make the *Mathesis* learning assistant more inclusive, accommodating, and adaptable to a wide range of student and faculty interactions.

3 Architectural Models

3.1 Conceptual Model

In our conceptual model, we outline the general structure of our project, its core components, and how those components relate to each other.

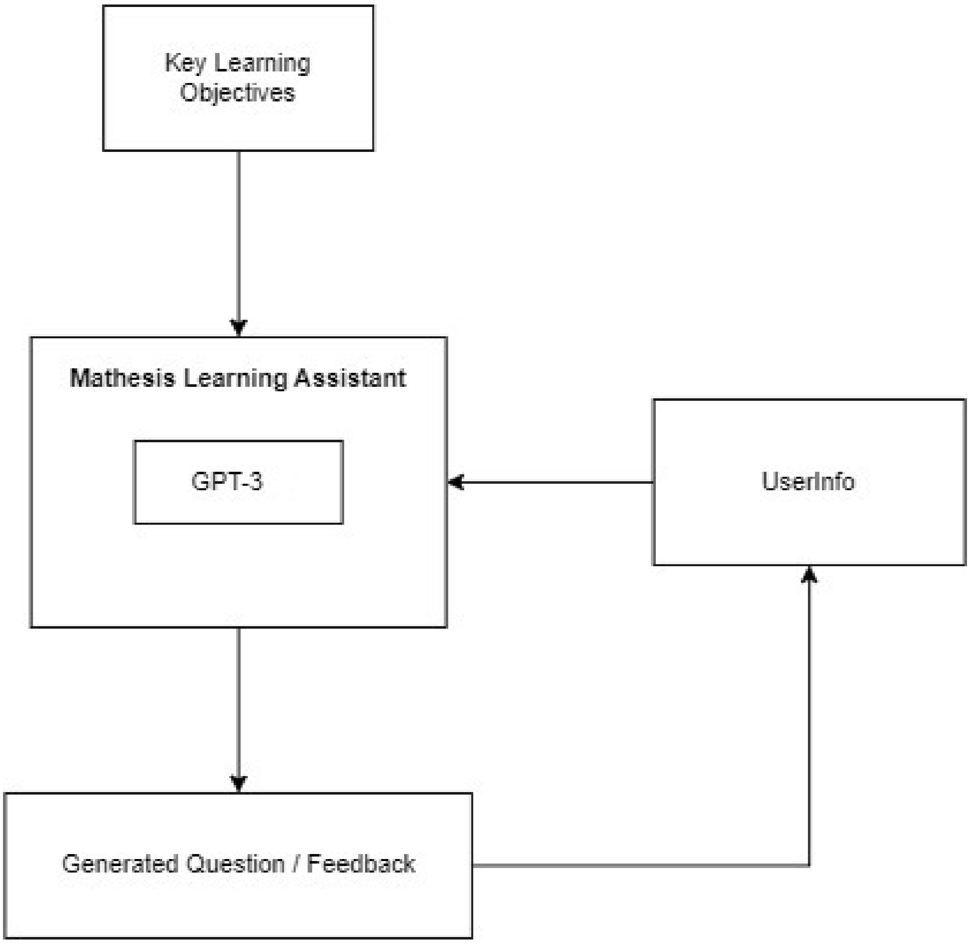

Figure 1: Conceptual Model

Mathesis The core of our project is our *Mathesis* learning assistant, powered by GPT-3. This is placed at the center of the diagram, symbolizing its foundational role. It is important to include this component in our diagram as it is the main generator of content for the project. This content can be anything from novel quiz questions to feedback for students. In our diagram, *Mathesis* is shown as a wrapper with a core of GPT-3. This is because our implementation is an extension and customization of OpenAI's model, created to achieve the project's specific goals. In our case, the base model provides the core language understanding and generation capabilities that the *Mathesis* Learning Assistant builds upon with its own knowledge and understanding.

Key Learning Objectives Also in our model, we include key learning objectives as an object. This object represents the collection of core course material that students are meant to learn. It is connected to our model, highlighting their guiding role in shaping the model's behavior through fine-tuning. These objectives ensure that the model focuses on the most important topics and concepts as defined by the faculty. The assistant generates questions and provides feedback on student's performance based on these key learning objectives.

Model Output In our diagram, we also include the products of the learning assistant. This is important to include because it shows what the model actually does to deserve its role as central to the function of the project. This output comes in the form of questions, generated from the learning objectives of the course, and useful feedback and corrections to the answers of students. This feedback also encapsulates the chat functionality of the model, where it provides feedback based on any question that the user asks of it.

User Information System Finally, the UserInfo MongoDB Database stores user information and their corresponding performance data for specific chapters. This will be useful to help gauge the quality of the questions that the model produces and the areas that the students may be struggling the most in. Both scenarios help to guide faculty into improving the course in some way.

3.2 Logical Model

Our logical model both maintains the objects and relations of the conceptual model and builds upon them through extra details about attributes and typing.

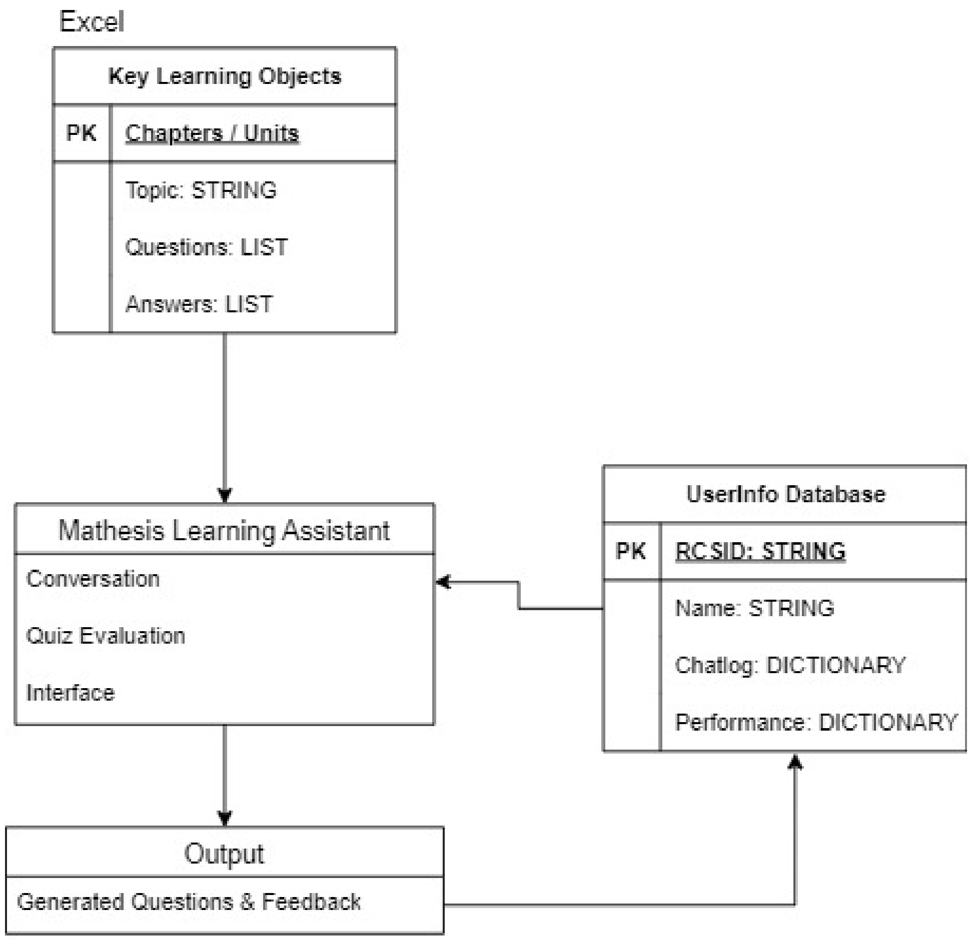

Figure 2: Logical Model

Mathesis and Output Our learning assistant comprises two main functionalities: Conversation and Quiz Evaluation. The model's conversational capabilities enable students to ask questions related to the learning topics, expanding their knowledge before formal evaluation. *Quiz Evaluation* is a functionality that grades chapter quizzes for students and records their performance. The 'Generated Questions

& Feedback' item in the Output object represents the quiz question generation process and the responses provided by the conversation functionality of the *Mathesis* Learning Assistant. The 'Interface' object comprehensively represents the entire application, encompassing all its components and functionalities. This includes the administrative view within the *Mathesis* Learning Assistant, which offers a specialized perspective tailored for administrators to have an overview of students' performance.

Key Learning Objectives For the faculty, the key learning objectives are stored in Excel sheets/CSV files that contain the units, topics, questions, and answers that go into the internal representation that will guide our learning assistant. Internally, this information is represented by a JSON file. Within this file, we store each lesson, the core concepts that the lesson aims to teach, and any questions that *Mathesis* generates based on those topics.

User Information System The UserInfo Database, with a student's RCS ID as the primary key, stores student information including name, past chat logs, and performance. This information is stored, ready to be put to use by the faculty. In the web interface, faculty have the ability to download a summary of student performances in either a CSV or Excel format.

4 Prototype Implementation

Over the course of the project, we made several important decisions on how to best implement our prototype design. These decisions involved areas where we improved our project by selecting the best model for the core of *Mathesis* as well as some important decisions we made regarding the scope of the project and how to handle out-of-scope paths.

4.1 Model Choice

One of the biggest references that we used in this decision-making process was the OpenAI Python API documentation [5]. This documentation details each of the models that we can use, their capabilities, and their drawbacks. One example of this comes in the type of model that we use. As our primary model, we use their *text-davinci-003* model. We have found that this model is a good balance between cost, quality, and flexibility. Da Vinci is the most advanced of the *text-** models. It offers similar quality to ChatGPT and has the added bonus of being available for file-tuning. Using this feature helps to lower the uncertainty of our information system, as mentioned above. An option that we did not decide to use as our primary model is *gpt-3.5-turbo*. This model is the model behind ChatGPT itself; it is cheaper, but has the drawback of not being pre-trainable. Due to these factors, we decided to keep using *text-davinci-003* after the announcement of *gpt-3.5-turbo* that came mid-way through the project. This decision helps us to fulfil the first four of our functional requirements while keeping our overall goal in mind.

Table 1: Model Comparison[6]

Model	**Parameters**	**Price (Per 1000 Tokens)**
ChatGPT	175B	$0.002
Da Vinci	175B	$0.02
Curie	13B	$0.002
Babbage	6.7B	$0.0005
Ada	2.7B	$0.0004

4.2 Alternate and Exception Flows

Another important decision that we made was our decision to exclude particular alternative or exception flows from our design. From the beginning of this project, we have been aware that large language models, like the GPT series, can both be incredibly helpful and somewhat volatile. Notably, we considered the possibility that users could perform adversarial attacks on the model. While these attacks would only affect that particular student, it is important to make sure our model provides all students with an appropriate learning environment, regardless of their actions. This decision was influenced primarily by the *DAN* [8, 3] (Do Anything Now) exploit and its many iterations. This exploit allows users to convince the ChatGPT model to ignore its alignment and safety training. Attacks like these would likely also be able to bypass the fine-tuning of *Mathesis*. We partially confirmed this assumption by testing similar exploits on GPT models. Our evaluation suggests that students could attempt something similar if they wished to do so. At present, we have decided to not focus on measures specifically preventing this type of attack. The reason for this is the relatively quick patches OpenAI sends out when exploits are discovered, combined with the difficulty of the problem. Our hope is that we will not have to change the non-functional requirements of the project, especially as OpenAI continues to work against the issue. Regardless, we do have future plans to mitigate these risks. Chief among which is hard-coding an extra alignment layer that checks for misaligned topics. When encountering prompts of this nature, the model will respond in a manner that redirects the conversation to a safer topic.

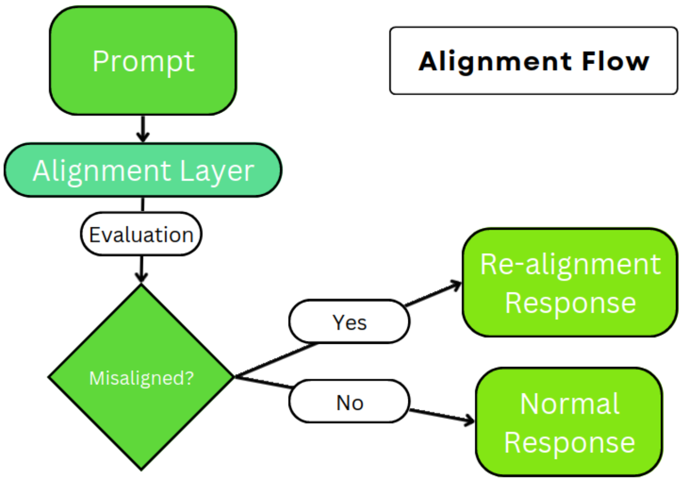

Figure 3: The *Mathesis* Re-alignment Flow

5 Conclusion

5.1 Future Work

In our future work in this project, we expect to both finalize the attributes of the project that we have included in its current scope and to expand the projects scope to cover more edge cases.

We aim to better handle reasonable edge cases by assisting students with navigating the new system, managing adversarial attacks, and further automating the model training process on new datasets. These enhancements will help students adapt to the *Mathesis* assistant and its learning platform, deter them from using the model for unintended purposes, and create a conducive environment for professors who wish to integrate their courses into the learning system in future semesters.

A member of our team will continue to monitor and maintain the *Mathesis* learning assistant as it is integrated into our pilot program in Introduction to Biology. This member will assist in user support and training during the semester and coordinate with the course's faculty member to facilitate a seamless integration. During and after the conclusion of our pilot semester, we will generate metrics which assess the competency of students to achieve the course's key learning objectives and compare with a control section of the course taught by the same faculty member. We hope these metrics, and the student and faculty feedback resulting from our pilot program will indicate to the RPI community that personalized AI tutors can be successful in promoting student engagement and comprehension.

5.2 Closing Thoughts

Our project has the potential to make a significant impact on higher education, specifically in facilitating personalized learning experiences for students. By providing a knowledgeable and adaptive AI learning assistant, we aim to promote active engagement, reduce stress, and ensure a transparent learning environment for both students and instructors.

The success of *Mathesis* in the Introduction to Biology course at RPI will serve as a stepping stone for its future integration into various other university courses. We believe that personalized AI tutors can be particularly beneficial in courses where providing individualized feedback to each student can be challenging due to high enrollment numbers or limited instructor resources.

By aligning our project with the fourth UN SDG, we aim to contribute to the global goal of ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all. We envision *Mathesis* becoming a scalable and adaptable platform that can be integrated into different educational frameworks, fostering a culture of continuous lifelong learning and improvement.

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Appendices

A Use Case Document

Use Case Name: GPT Pedagogy: Mathesis

Goal:

Develop a model, *Mathesis*, that maintains its conversational abilities, while embedding additional knowledge about faculty defined key learning objectives. This model will generate a series of topic-relevant questions, evaluate the answers of those questions, and give useful feedback or counterexamples to the student.

Summary:

Students can log in and can start chatting with our agent as it responds in real time with auto-generated responses. They can then proceed with their learning experience and discover gaps in their knowledge through their chat and through quizzes. This leads to better overall learning outcomes.
Faculty can log in and start viewing a summary of student responses to knowledge. Through this, they can pinpoint gaps in the collective student knowledge, drawing unbiased conclusions, and making necessary changes of pace for later lectures. This then improves the quality and consistency of lectures, leading to a better teaching experience.

Actors:

Students, Faculty, Server, *Mathesis* model, Database

Preconditions:

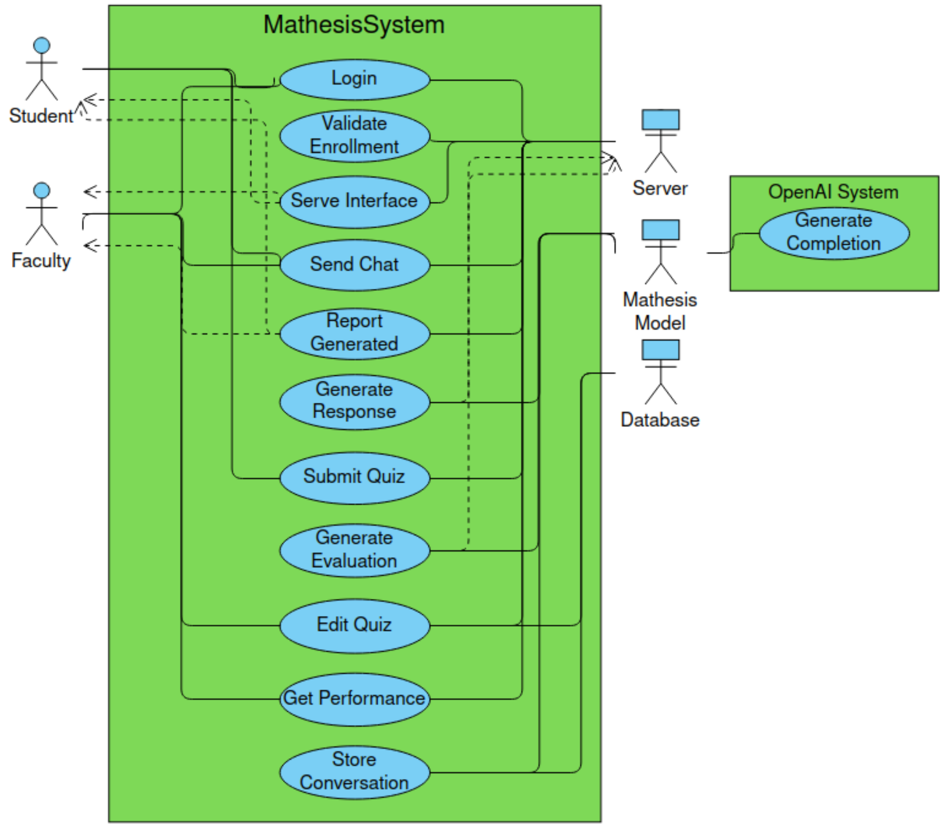
- The User has a valid RPI ID.
- The User is enrolled in the class either as the professor or student.
- The User is connected to the internet.
- The Server is running.
- OpenAI is accessible.
- DataBase is accessible.

Triggers: • User sends a request to load the homepage. • User sends a chat request to the model. • User selects a lesson from the list. • User submits a quiz from a lesson. • Faculty user submits a request to generate a new question. • Faculty user saves a quiz configuration • Faculty requests student performance report.
Basic Flow: 1. The user logs in via their RPI account. 2. Server checks if the information matches and if the user is enrolled in the class or not. 3. Server create response to the user. 4. Users interprets the response and sends a request to the server. 5. Server interprets the result and sends a request to OpenAI API. 6. OpenAI sends the generated result back to the server. 7. Server pushes the response back to the user and the database. 8. User interprets the response. 9. Database records the response and terminates the use case.
Alternate Flow: 1. A faculty user logs in via their RPI account. 2. Server checks if the information matches and if the faculty is enrolled in the class or not. 3. Faculty member requests the generation of a new question for a lesson quiz. 4. *Mathesis* generates the selected question and it is returned to the UI. 5. Faculty member removes quiz questions, inserts generated qustions, or both. 6. Faculty saves the lesson quiz to the database. 7. Database records the new quiz and terminates the use case.
Exception Flow: 1. The user logs in via their RPI account. 2. Server checks if the information matches and if the user is enrolled in the class or not. 3. User performs actions beyond the normal usage of *Mathesis*. 4. *Mathesis* detects malicious behavior. 5. User interaction redirected and actions are taken to either mitigate or terminate this incident.

Postconditions:

- Students have gained further course knowledge.
- Students have their knowledge tested with results recorded.
- Faculty has observed student performance.
- Faculty has modified lessons to account for students' knowledge.

Activity Diagram:



Questions and Answers:

- What role does the success of *Intro to Biology* trial play in this use case?

  The success of Mathesis in the *Introduction to Biology* course at RPI will serve as a stepping stone for its future integration into various other university courses.

- How can faculty/professors draw conclusions from student responses?

  The student feedback report will contain important information about which students struggle the most on certain topics along with the areas that the class as a whole is the least knowledgeable in. This will hopefully help faculty to decide how to best allocate their time during course lectures or assignments.