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Generative AI and Learning: Using Retrieval-Augmented Generation (RAG) for C++ Tutoring

**Abstract:**

By utilizing advancements from the field of AI, we aim to develop a tutoring app that answers the questions of intro-level C++ programming students, while creating a framework to expand into other academic areas. A Retrieval-Augmented Generation (RAG) approach will provide targeted feedback, dynamically generating context-specific responses by interfacing with a locally hosted AI.

Our goal is to minimize the risk of oversaturated or hallucinated responses. By processing incoming questions from users and communicating with the AI model, a RAG method ensures that the answers generated by the backend are both concise and relevant to the search. The front end will allow students to easily input their questions and view immediate feedback, ultimately enhancing the interactive learning experience. The functionality will be custom-built, while the graphic design from a previous personal project will be used. Combined, these systems will create a user-friendly application that provides students with clear and direct responses to their specific queries.

Overall, the project aims to create a scalable and efficient tutoring tool. Not only would this tool improve students’ understanding of C++ programming concepts, but it could be integrated into other educational platforms. Unlike the VS Code extension Continue or other similar tools, our project is designed as a two-part web application for easy integration into current LMSs (Learning Management Systems). The desired outcome is an engaging, adaptive, and accessible learning environment that can be extended to additional subjects and environments in the future.

**Paper:**

The objective of our project is the design and implementation of an AI-based tutor app that addresses introductory-level C++ programming questions. By using a Retrieval-Augmented Generation (RAG) approach to providing targeted feedback, our goal is to develop a basic, but effective AI framework that facilitates learning. Instead of relying on a pre-stored database of answers, the system will dynamically generate context-specific responses by interfacing with a local Llama3 AI model through Ollama’s local REST API.

The backend, implemented in Python, will serve as the engine of the application. It will process incoming questions from users and communicate with the Llama 3.2 model via the REST API, ensuring that the answers generated are both concise and relevant. This design minimizes the risk of oversaturated or generic responses, providing students with clear and direct explanations tailored to their queries.

We chose to use Retrieval-Augmented Generation because it solves many of the outstanding issues that exist with generative AI. One of generative AI’s largest and most well-known flaws is that of hallucination, where the AI fabricates information with no factual basis. Retrieval-Augmented Generation has been shown to improve code generation and summarization ***Citation Needed***. By implementing Retrieval-Augmented Generation, we intend for this app to draw from a stricter data pool, thus limiting the AI’s answers from straying into hallucination and solving a key potential problem with the use of AI as a tutor.

(*beginning of introduction section)*

The value of our project is in its ability to provide an introductory computer science student with a course-specific learning tool. The app is not intended to replace textbooks or teachers, but to help support currently established methods of education. By focusing on specific material as the basis for our tutor app’s responses, we can add support to the development of problem-solving skills for these students, enabling a stronger knowledge of the material. The app also provides students with active, accurate support outside a tutor’s or professor’s available hours.

Furthermore, we chose C++ as the focus of our tutor app because it is a foundational programming language to the software engineering process. It is important for a beginner to understand the more complex syntax of C++, before they can effectively learn topics such as pointers, memory management, data structures, and algorithms. The building blocks of these data types are laid in an introductory course. The learning curve for C++ is steeper than higher-level languages such as Python. These advanced concepts are more tedious to grasp early on. If a student has access to an accurate, effective tutor app, they will be able to learn the material much more effectively.

Our tutor app also solves another problem, bridging an important gap for many students: the financial one. Personal tutors can be very expensive. Most students can’t afford to pay a human tutor $50-$200 per hour for guidance. For students who are enrolled in schools with high class populations, it may be hard to get tutoring help from other students or faculty. Our tutor app would be a great supplement to traditional teaching utilities such as textbooks and class lectures, making extended support possible as they establish their basic skills.

Retrieval-Augmented Generation is the cornerstone of our project. It is a generative AI process that combines the power of Large Language Models with a curated supply of information. Retrieval-Augmented Generation supplies the AI with contextual information from a data store that is related to a user query. It then uses this context to inform and guide the generative process, giving the AI a stronger knowledge of the topic at hand. (Lu, Yiu, 2.3) (citing references format?)

Online education already exists, but traditional online resources may not be effective for some students and may not offer the best examples early on in their coding education. Some newer students can struggle finding pertinent information without a clear overview of the problem. By using Retrieval-Augmented Generation, the program will dynamically adjust to each unique question, providing students with a personalized response to each question and empowering them with answers that help build a broader understanding.

Retrieval-Augmented Generation has the unique capability to draw on current class materials. By sourcing information from traditional educational resources, such as a textbook, this approach remains consistent informationally, while delivering it in a more engaging, personal way for each student. Using relevant coding examples can often be a more efficient method in reaching inexperienced students, allowing them to better digest the textbook information.

This app can also help build confidence by approaching the information in an unthreatening way. Eliminating the fear of being judged by a tutor or faculty member, students are free to explore answers to their questions in an effective and comfortable environment. By freely pursuing basic questions, students can build their understanding and confidence to ask more precise questions of an instructor. This serves to lower barriers for new students and facilitate quicker, more stress-free progress and eventual mastery of the basics of C++ programming.

*(beginning of related works section)*

Computer Science is currently facing educational obstacles. The reliance on software in all aspects of modern society is growing, causing increased interest in software careers. Schools are seeing record undergraduate enrollment in Computer Science. At the same time, they are facing a both a lack of qualified faculty and varied curriculum challenges. The combined force of these factors is stressing Computer Science education. As Ma, Martins, and Lopes pointed out, “Providing individualized support to many students in introductory courses, especially regarding mastery of complex material, has been challenging.” A strategic use of AI could further the educational reach of the faculty that now exist, reducing the need for an instructor’s direct involvement in simpler questions.

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Previously, some traditional online methods of learning introductory computer science material have been things such as Python Tutor, which helps students visualize runtime data structure changes during program execution. A similar tool, Visual Algo helps students visualize algorithms through animation. These are good tools and help provide good insight into programming, data structures and algorithms, they don’t offer support in other topics that are included in an introductory class.

Beginning computer science students need to be able to learn and review the intro material because many of them may not have a working knowledge of computer concepts such as files and memory (something something kids these days and their darn phones). Basically, the Ma, Martins, and Lopes research looked at a pool of 455 students at UC-Irvine, and they deployed five RAG Man tutor apps to assist the students with their supplemental homework assignments. The tutor apps were designed to not give solutions but to guide the students in taking the next step towards solving their questions.

Furthermore, the results of the Ma study were positive to say the least. Although there was a larger percentage (44% vs. 42%) of A grades in the 2023 class that didn’t use AI tutors vs. the 2024 class that did, 3% less students received F’s, 5% more received Bs in 2024, which is significant. The very basis of continuing the computer science education tract was ensured, arguably by the RAG Man tutor deployment. About student feedback, it was mostly very positive as well.

There’s no question our app aims to help alleviate the gap between the obstacles of computer science education and ensuring the development of new competent, successful computer science students. Another study by Wang and Ramon **(Quantitative Evaluation of Using Large Language Models and Retrieval-Augmented Generation in Computer Science Education)** quantified the performance of different AI models and how effective they were by a cost-effective analysis for instructors.

Moreover, they found that advanced model Large Language Models did outperform open-source models in Q&A tasks. However, the performance gap wasn’t significant enough to justify the cost-benefit of using locally hosted open-source models. The needs of the instructor/students should be considered in this regard.

In addition to being cost effective, an open-source model using Retrieval-Augmented Generation made a great impact as well. They found that implementing Retrieval-Augmented Generation enhanced the ability of the Large Language Models to answer questions and provide concise feedback. They also found it particularly noticeable when the model was integrated with course materials, allowing them to close the gap with the likes of GPT-4, for example.

These studies, and other similar ones emphasize how future research should aim to measure student feedback and student engagement. The paper **(Can Small Language Models with Retrieval-Augmented Generation Replace Large Language Models When Learning Computer Science?)**  shows that SLMs can provide enhanced data privacy and control and provide enriched learning experience for students. It’s imperative that instructors keep their course materials secure and in-line with organizational policies.

Our tutor app would help a student or instructor, institution with limited resources as it would be a cost-efficient tool for learning. Creating essentially a personal assistant for computer science students is very promising based on the results of prior research. This Retrieval-Augmented Generation method would be more engaging and productive than current resources, such as Stack Overflow, Python Tutor, etc. Hallucinations would be minimized, which contrasts with basic ChatGPT models where roughly 20% of responses are hallucinated.

Undoubtedly the Retrieval-Augmented Generation tutor app provides pressure free, efficient, personalized tutor experience for introductory students. The ability given (Giving the ability to?) to the Large Language Model or Small Language Model to draw on trusted course materials is extremely beneficial to the incoming student. If we continue to prioritize the feedback and interactions of the students, we can further enhance these awesome (ok this might be too much) learning tools.

*(beginning of solutions/implementation section)*

It’s clear that our main goals are to facilitate learning and minimize the hallucinations made by generative AI. The latter goal is propelled by our tutor app’s Retrieval-Augmented Generation methodology. Again, the retrieval-augmented generation combined with the Llama 3.2 AI model delivers personalized, contextually relevant and concise answers to students’ questions. This approach will minimize hallucinations.

The Retrieval-Augmented Generation pipeline begins with the indexing of the collection of data/documents that are being leveraged as the source of relevant material. In our case we used the ZyBooks text, chapters one through six to supplement the generated answers. The whole process of Retrieval-Augmented Generation begins when we index the collection with ChromaDB, a vector database that will store the documents paired with their embeddings. The embeddings are small, semantic (mathmatic, array of float numbers, might need to make a reference to an article on this) representations for similarity searches.

We chose ChromaDB because it is able to seamlessly integrate with Python, through a library. Is known for its efficiency. ChromaDB became the preferred choice. The indexing phase is crucial to facilitate accurate matches to the user queries.

Moving onto the next step, the retrieval stage. When the student makes a query, the query is matched with the most relevant data in the vector database (It does this by getting the embedding of the user question and then finds the stored document whos embedding is mathmaticly closest). Next, the augmentation occurs. So, the retrieved information is combined with the user’s query to create an augmented input that will be sent to the Llama AI model. ( It should be noted it is also combined with other context, such as the message history between the user and the bot, as well as the user’s code) The enhanced context will enable the Large Language Model to generate a more concise response.

Lastly, the generation occurs with an answer that integrates the Llama model’s generation capacity with the supplied relevant context. The answers seem more calibrated and centered around the students’ query.

The first step to minimizing hallucinations is the indexing stage. We chose the first six chapters of the ZyBooks online text, which is used in our CSC-108 Intro to Computer Science course here at Quinsigamond Community College. The indexing happens before the runtime of the Retrieval-Augmented Generation itself. Indexing builds a strong foundation for the retrieval of concise data. (Seems duplicate)

Next the data is processed into chunks using Langchain and then converted into numerical vector embeddings by importing Langchain\_Ollama (More accurate to say it is sent to Ollama or the llama model to have the embeddings generated). Using Ollama’s built in embedding function provides better performance and stability for the app. Then the embeddings are indexed in ChromaDB, the vector database. ChromaDB offers fast similarity search and semantic retrieval. (Too fancy, need to convey that it is able to find similar information in a document better than a relational DB like SQL)

The indexing pipeline sets up before runtime ~~and ensures the accurate retrieval of data~~. The retrieval process is the basis for concise responses. The retrieval uses the indexed information stored in ChromaDB and employs the embeddings to find the most relevant information for each user query.

Basically, when a student submits a query, the retrieval functionality processes the text into a vector embedding, using the same embedding function we used in the indexing stage. This ensures that the query embeddings and indexing embeddings reside in the same space and are similar in context.

The query embedding is then passed to ChromaDB, where the semantic search takes place. ChromaDB efficiently identifies and retrieves the most relevant chunks to the query. So, it’s this combination that creates the accuracy and precise context needed to help the student. This remedies the typical downfall of generative AI where it just generates an answer from metadata without concise context. Again, the retrieval process builds the foundation for the optimal educational experience for the student. It creates a beginning-user-friendly environment.

Furthermore (Used way too much), the retrieved content is then inserted into a structured prompt along with the original user query. The prompt would be a guideline or tone for the Large Language Model to follow. This augmented prompt is then sent to the Llama 3.2 model, and a response is generated based on the contextual data. The result is the student receives an accurate answer that is grounded in the course material (and other context). Thus, avoiding hallucinations. Also, system prompts allow it to be guided against responding with hallucinations if the model doesn’t know the answer or doesn’t have enough information. This is an important part of the process as well.

*(beginning of the section about the modularity of the backend)*

*I have not checked past this, I just got sent it and have no time today to look at it.*

Also, one of our goals (*needs to be added to abstract?)* was to create a tutor app that could facilitate other courses and subjects for future work. Our goal was to have an interchangeable backend that can be integrated easily with other subject matter, if that subject matter data is in .txt format. Basically, we can use the RAG tutor for any subject or course and still maintain consistent, efficient experience for the students.

The main components of our backend operate independently of the C++ material so that we can use it for other subjects quickly and efficiently. Our RAG pipeline uses LangChain for text processing, langchain\_ollama for generating semantic embeddings, and ChromaDB for vector-based storage. The combination of these tools creates a formidable RAG pipeline that is totally flexible in the subjects it can cover and be used as a tutor. Instead of embedding specific rules for C++ education, the backend will use any .txt material that a tutor or instructor provides the system. The texts are divided into chunks, each chunk is transformed into an embedding vector that represents its semantic content. These vectors are then stored in ChromaDB, providing efficient retrieval when a student submits a question.

Furthermore, any user can convert course textbooks, lecture notes, or supplementary materials into standardized .txt files. These files should be segmented by chapters or topics/ideas to facilitate contextual chunking. This subdivision is critical because it preserves the proper context and ensures that the retrieved content directly relates to the student’s/user’s query.

Next, using LangChain, the text files are taken in and split into semantically coherent chunks. Langchain\_ollama then generates embeddings from these chunks, which are stored along with metadata into ChromaDB. This process requires no adjustments to the backend code, which remains the same regardless of the subject matter.

The next phase includes when a user submits a question, the backend converts the question into an embedding using the same model, ensuring compatibility with the indexed content. A semantic similarity search is executed in ChromaDB, and the most relevant text chunks are retrieved. These retrieved chunks are then augmented with the original question to construct a concise prompt for the LLM. Lastly the LLM generates a response that is concise and relevant to the user’s question.

The backend gets its functionality through a REST API, which makes it simple to be integrated into learning systems such as Canvas or Blackboard. Whether the LS uses a web interface or some other interface, the API endpoints take care of queries and responses without any further changes required from the LS. The modularity ensures that teachers, professors, and tutors can employ the backend easily regardless of the learning system.

**Furthermore, this modularity offers significant advantages in terms of scalability. Upgrades to the embedding model or improvements in the vector database can be implemented centrally, benefiting all courses that use the system. This ability to serve multiple subjects with the same core engine reduces redundancy and enhances the overall reliability of the tutoring system. (check this paragraph)**

Finally, the flexibility of our backend allows it to be used with other course materials if they are in a structured .txt format. Simple integration is made possible by the REST API and the other interchangeable components. Additions to the tutor app could include more advanced feedback systems for the students, which seems to be a focus of some of the RAG tutor research that I cited earlier in this paper. The more we can measure the performance of the application, then the more we can improve upon its functionality. One of the main ways to do that is to efficiently get detailed feedback from the students.