Detailed Project Plan

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1. Project Background

1.1 Introduction to Traditional Classrooms and Their Limitations

The current educational landscape is often criticised for being unable to offer students personalised learning experiences (Zhang et al., 2023). In traditional classrooms, the inability to accommodate a wide range of learning paces and styles tends to leave some students feeling left behind, while others may end up being understimulated (Zhang et al., 2023). This disparity is further evidenced by the fact that in Mathematics, merely 28% of Indonesian students achieved at least Level 2 proficiency, compared to the OECD average of 76%. There is an urgent need to elevate the academic proficiency for underperforming students in Indonesia and many other nations worldwide. This effort should aim not only to reach the OECD average but potentially surpass it, thereby enhancing these countries' overall educational competitiveness and global standing. Nevertheless, despite their best efforts, teachers are usually unable to provide individualised attention to each student due to a variety of reasons, including large class sizes. In Indonesia, the student-teacher ratio in primary education was 16:1 in 2018, which, while not extreme, still poses challenges for personalised instruction. These factors could lead to gaps in students' understanding and retention of subjects (Tularam, 2018), potentially contributing to Indonesia's lower-than-average performance in key educational metrics as reported by the OECD.

Traditional teaching methods are typically unidirectional, similar to one-way streets (Tularam, 2018). This setup frequently results in passive learning environments where students are expected to absorb information rather than actively engage with the material (Tularam, 2018; Nindam, 2023). Additionally, conventional education systems often struggle with addressing each student's unique characteristics and needs, leaving many unmotivated and disengaged (Alshammari, 2020; Zhang et al., 2023). Furthermore, large class sizes only worsen these issues by making it difficult for teachers to effectively cater to individual student needs (Shen et al., 2020).

1.2 Existing Solutions and Their Limitations

Currently, there are several solutions available that aim to tackle these challenges. These include one-on-one tutoring services like TutorMe, online learning platforms such as

Coursera or Khan Academy, and AI-powered learning solutions like Socratic by Google, Khanmigo by Khan Academy and Century Tech. While these options have their benefits, they also come with significant limitations.

Many of these solutions lack deep integration with school-specific curricula and syllabi, which raises concerns about how effective they can be in supporting institutional learning objectives. Data privacy and security issues are also very significant concerns, especially when dealing with younger students' information. Moreover, these platforms often fail at providing comprehensive progress tracking aligned with institutional standards which makes it difficult to accurately gauge student performance. Furthermore, although generic artificial intelligence (AI) solutions might be innovative, they do not always capture the nuances required by individual schools' requirements. Lastly, there is often a lack of seamless integration between AI tutoring systems and existing school infrastructure, creating potential barriers to adoption and effective use.

1.3 KGV's Motivation and Our AI Solution

ESF King George V School (KGV) is seeking to optimise classroom dynamics and enhance individualised learning experiences. Their primary motivation comes from the desire to free up teachers' time, allowing them to work more effectively with small groups and interact with individual students during class. KGV recognizes the need for additional support to carry some of the curriculum load, particularly in Years 10 and 11 where students are preparing for their GCSE syllabus. The school aims to pilot an innovative solution that can assist in delivering personalised education while maintaining the crucial role of human teachers. In response to KGV's specific requirements, we are introducing the KGV AI Tutor, an AI-powered tutoring system designed to address these challenges and enhance the overall learning experience.

A key feature of our project is its integration with existing school systems and syllabi, ensuring that the AI tutor complements rather than disrupts current educational practices already in place today. Our solution ensures strict adherence to data privacy and security standards, both of which are critically important in today's digital learning environment. The system is designed to be customisable enough so it meets unique requirements from different educational institutions, regardless of their location, curricula, and more. By leveraging advanced AI-Retrieval technology, we can create a system that is adaptable enough for each student's learning pace and style, providing continuous support, maintaining retention through active recalling, and offering valuable insights back to teachers through on-demand learning reports. The scope of our project currently involves Years 10 to 11 of ESF King George V School’s curriculum, specifically following the Pearson Edexcel International GCSE (9-1) Science Double Award syllabus, where we will be performing various pilot tests on some of their classes.

This innovative approach not only addresses KGV's specific requirements but also transcends constraints found within traditional classrooms, creating more effective personalised learning experiences overall (Shiau et al., 2012; Cai, 2023). The KGV AI Tutor addresses core issues around personalised teacher support educational efficiency, paving the way forward into an inclusive, effective future-oriented education landscape. This project's ambition to revolutionise the current educational paradigm directly correlates with the urgent global need to enhance academic proficiency for underperforming students, thereby bolstering the educational competitiveness and global standing of nations like Indonesia and others worldwide.

2. Project Objective

The KGV AI Tutor Project's primary objective is to develop and implement an artificial intelligence-powered tutoring system that enhances the learning journey for students while supporting educators in their teaching roles. This innovative system is designed to cater to the Pearson Edexcel International GCSE (9-1) Science Double Award syllabus, covering the three fields of natural science: Biology, Chemistry, and Physics.

2.1 Primary Objectives

2.1.1 Personalized Learning Environment

The system aims to create an adaptive learning environment that caters to each student's unique pace and style of learning. By incorporating various teaching techniques and using proactive recall methods, the KGV AI Tutor focuses on areas where students might be struggling.

2.1.2 Improved Teaching Effectiveness through Data Insights

By providing on-demand data insights about student progress and potential learning patterns, the system empowers teachers to make informed decisions. This allows for better teacher’s allocation of time and resources.

2.1.3 Advanced AI Technology Implementation

The project employs Retrieval-Augmented Generation (RAG) methods for accurate subject-specific information delivery. It focuses on building a secure system that protects student data and provides a user-friendly interface for students and teachers.

2.1.4 Scalable System Development

The project develops a scalable system, initially focused on the Science Double Award syllabus. The design allows for future expansion to other subjects, grade levels, and schools, enabling broader application across educational institutions.

2.2 System Features

The following subsections outline the core functionalities that drive the KGV AI Tutor's innovative approach to education.

2.2.1 Chatbot

At the heart of the KGV AI Tutor is a chatbot system utilising the Large Language Model with Retrieval-Augmented Generation (LLM-RAG) as its backbone, where information retrieved comes from verified data sources such as school textbooks. Students will have access to different chatbots for various subjects and can create multiple chats within each chatbot, facilitating more focused and accurate information retrieval.

2.2.2 Smart Quiz

A key feature of the system is the "Smart Quiz," accessible anytime from the sidebar. This feature supports reinforcement learning by helping students retain mastery and track their progress based on syllabus statements. The continuously updated student database provides data for the LLM to generate both multiple-choice questions and structured questions, adapting to each student's learning journey.

2.2.3 Mastery Exercises

To ensure comprehensive coverage of the syllabus, the KGV AI Tutor incorporates mastery exercises for each syllabus statement within the sub topics. These exercises, all structured questions, are generated by the LLM based on the student's database to assess their syllabus statement mastery. Students must successfully complete all exercises related to each sub-topic before moving on to the next main topic, ensuring a balanced class progress.

2.2.4 Report Generation Tool

For educators, the system offers an on-demand report generation tool. This feature provides a comprehensive summary of students' current learning progress, specifically their mastery of syllabus statements, whenever requested by the teacher. This data-driven approach allows for more effective teaching by enabling instructors to better allocate their time and resources towards students who need extra support.

2.2.5 Study Preference Assessor

To further personalise the learning experience, the KGV AI Tutor includes a student questionnaire section. This feature gathers insights into students' learning styles and interests, enhancing the chatbot system for a more tailored educational experience.

3. Project Methodology

From start to finish, we will implement our project using an agile development approach, specifically following the Scrum framework to ensure efficient, iterative development and continuous improvement. This methodology allows for flexibility and continuous improvement based on internal and external feedback from various technical stakeholders. Our extensive methodology will include the following:

3.1 Requirements Gathering and Project Initiation

We will have an initial meeting with KGV School to define and refine detailed requirements and specifications based on the needs of students, teachers, and the school. Furthermore, we will also lay down the comprehensive project plan with clear milestones and intended deliverables.

3.2 Research

We will conduct thorough research on existing RAG (Retrieval-Augmented Generation) solutions and best practices within the educational technology sector. This phase will include:

1. *Literature Review:*
   We will:
   - Conduct a comprehensive analysis of academic papers focusing on:
     - Retrieval-Augmented Generation (RAG) implementations.
     - Latest developments in large language models, with a particular focus on striking an optimal balance between high performance and cost-efficiency.
     - Text chunking methodologies to determine the most effective approach for our specific use case.
     - Advanced prompt engineering techniques to enhance language model performance while minimising resource utilisation.
2. *Technology Stack Assessment:*
   We will:

- Research and compare various embedding models (e.g., BAAI General Embedding, text-embedding-ada-002, BERT) for optimal knowledge representation.
- Evaluate different vector databases (e.g., Pinecone, Weaviate, FAISS, Chroma) for efficient information retrieval.
- Assess Local LLM options (e.g., Llama, Mistral) and their suitability for the project given resources constraint

3.3 Development

Building up on top of the extensive research conducted, this phase will focus on development of our project, which will include:

1. *Version Control and Collaboration*

   We will:

   - Use Git for version control, with GitHub as our remote repository platform.
   - Utilise GitHub's project management tools for issue tracking and milestone management.
   - Employ pull requests and code reviews to ensure code quality and knowledge sharing among team members.

2. *Tools and Technologies:*

   We will:

   - Utilise the following technologies:
     - Frontend: Next.js for a responsive and efficient React-based user interface. TailwindCSS will be leveraged to create easily-customisable components.
     - Backend: FastAPI for a high-performance Python web framework.
     - Database: PostgreSQL for relational data storage.
     - Vector Database, LLM, Embedding Model: Determined in the research phase mentioned in the above.
     - Cloud Infrastructure:
       - Amazon Web Services (AWS) for hosting and scalability.
       - S3 for document storage.
       - ECS (Elastic Container Service) for containerized deployment.

    - Model Deployment: Use Lightning AI for efficient model serving and scaling.

3. *Design and Implementation*

   We will:

   - Preprocess (include vectorization) all data sources (e.g. textbooks) to enhance data retrieval accuracy.
   - Utilise a modular architecture to develop the AI tutor system, allowing for easier maintenance and scalability.
   - Implement the core LLM-RAG chat system as the foundation and extend it to the Exercise and Report Generation section once the core system is completed.
   - Develop additional features such as the report generation tool for the teachers and incorporate a reinforcement learning approach.

4. *Testing and Quality Assurance*

   We will:

   - Perform alpha testing with a small group of students to gather initial feedback and identify potential issues that could arise from the system.
   - Perform beta testing with a larger group of students and teachers to ensure system stability, safeness and effectiveness in a more diverse environment.

5. *Security and Data Protection*

   We will:

   - Use data minimization techniques, only sending necessary information to the LLM:
     - Strip out personally identifiable information (PII) before processing.
     - Use pseudonyms or unique identifiers instead of actual student names.
   - Implement end-to-end encryption for all data transmissions.
   - Use AWS CloudTrail for monitoring and recording account activity.

3.4 Assessment

Once the product has been successfully developed and passed all the tests outlined in the above, we will focus on assessing the impact as well as various documentation to help support teachers and students navigate through the application. This phase will include:

1. *Documentation and Training*

We will:

- Develop comprehensive documentation for the system, including user manuals and technical documentation.
- Create training materials for teachers and students to ensure effective adoption of the AI tutor.

2. *Evaluation and Reporting*

   We will:

   - Establish key performance indicators (KPIs) to measure the success and impact of the AI tutor.
   - Regularly evaluate the system's performance against these KPIs and prepare progress reports.
   - Conduct a final evaluation at the end of the project to assess overall impact and identify areas for future improvement.

By following this methodology above, we aim to deliver a high-quality, effective AI tutoring system that meets the needs of KGV school while maintaining flexibility to adapt to changing requirements and feedback throughout the development process.

4. Project Milestones and Schedule

We will outline the tentative schedule of the project, which will include the expected outcome at various stages of the project on a monthly basis, incorporating the methodology outlined in the above.

Time	Milestones
27 June 2024	- Initial consultation with KGV's technical team to gather and clarify the client's specific needs and expectations for the project.
23 September 2024	- Presented preliminary design concepts and proposed functionalities to KGV School, seeking additional project clarification.
30 September 2024	- Deliverables of Phase 1 [Due: 1 October 2024] ● Detailed Project Plan ● Project web page
30 October 2024	- Execute a comprehensive research phase, encompassing an in-depth literature review and the formulation of a targeted technological stack. - Initiate the preliminary development cycle, focusing on core system components, like the LLM-RAG, etc.
30 November 2024	- Continue system development, emphasising the integration of reinforcement learning capabilities to enhance student engagement. - Refine the user interface, incorporating an interactive exercise module.
30 December 2024	- Continue system development, incorporating various security measures, as well as further refinement of the system, and front end interface. - Conduct initial alpha testing with a select cohort of students, soliciting comprehensive feedback to guide further improvements.
13 January 2025	- First presentation

26 January 2025	- Deliverables of Phase 2 ● Preliminary implementation ● Detailed interim report
28 February 2025	- Continue system development, with emphasis on report generation features for teachers and other functionalities. - Continued refinement of the product
31 March 2025	- Finish the core system, and layout of the product. - More work done on report write up. - Documentation and training provided to the teachers and students.
21 April 2025	- Beta testing with a larger group of students and gathering feedback. - Deliverables of Phase 3 ● Finalised tested implementation ● Final report
22 April 2025	- Final presentation
30 April 2025	- Project exhibition

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