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ChatPLT: An intelligent tutoring system for teaching Physics in Higher Education

Abel Naya-Forcano[1, 2], Miguel Garcia-Bosque[1, 2], Esther Cascarosa[1, 3], Francisco Aznar[1, 4], Carlos Sánchez-Azqueta[1, 5], Santiago Celma[1, 2], Concepción Aldea[1, 2].

[1]Group of Electronics Didactics with ICT Technologies (DIELTIC), University of Zaragoza, Spain, [2]Department of Electronics Engineering and Communications, University of Zaragoza, Spain, [3]Department of Specific Didactics, University of Zaragoza, Spain, [4]Centro Universitario de la Defensa - Academia General Militar, Spain, [5]Department of Applied Physics, University of Zaragoza, Spain.

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Abstract

The application of artificial intelligence (AI) has attracted great interest in higher education, highly influenced by the development of information and communication technologies. Integrating artificial intelligence into learning ecosystems is one of the biggest challenges for higher education.

In this work, an intelligent tutoring system based on AI has been designed but with control of the possible responses. For this, a first diagnostic phase was carried out that determined the selection of initial material that will be used by the neural network or classifier algorithm, so that the teacher has control of the answers offered, limiting the sources of information used. Subsequently, this selection of documents is part of the input, together with the question in a large language model (LLM) ChatGPT-type conversational network. All developments have been done using open access resources. It is the first stage of a project to obtain a predictive analysis of each learning studding.

Keywords: *Artificial intelligence; autonomous learning; intelligent tutoring.*

1. Introduction

With the rapid advances in technology and science, new paradigms have emerged in Education. These involve the Information and Communication Technologies (ICT) and artificial intelligence (AI) as pedagogical resources.

The realizations of ICTs that present the greatest educational potential are those that facilitate the presence of instructors in the student's learning process, providing immediate and relevant support (Sánchez-Azqueta, 2019). In particular, they emerge as a privileged tool to accomplish

the monitoring, supervision, guidance, and support that the teacher can and should provide for the student's work and autonomous learning (Zúñiga, 2012; Olmo, 2012). In this way, the tasks of supervising and tutoring the student's activity can be carried out without the need to coincide with them in space and time.

In turn, AI is transforming every facet of our lives, from communication to the workplace, and it is being proclaimed as a tool that can be used to enhance and advance all sectors of our lives (Górriz et al., 2020). In the field of education, the use of AI technologies or application programs is expected to revolutionize the dynamics of learning, teaching, or decision-making, particularly taking into account the great influence of ICTs in education in the last years (Alajmi et al., 2020). As a consequence, the use of AI in higher education (HE) has risen quickly in the last 5 years (Chu et al., 2022a;b), with a concomitant proliferation of new AI tools.

In the literature, we can find numerous works exploring both the challenges and threats, as well as the opportunities that AI presents in this context (Crumpton et al., 2023; Ouyan et al., 2022). In this work, we will focus on the opportunities that AI can provide in higher education rather than the ethical and legal challenges that must be faced when implementing such a strategy.

Among the exploratory works, Borge (2016), regarding AI and its application in the educational field, propose as main advantages that AI can automate basic activities in education, such as the grading system, and that students can receive personalized learning. Integrating AI into learning ecosystems is one of the greatest challenges for higher education.

In this work, we propose the development of an AI-based tool that enables more personalized, flexible, and engaging learning, allowing not only to respond to what is being learned but also to how it is being learned.

2. Intelligent tutoring systems (ITS)

Educational technologies provide opportunities for personalized learning, tailored to individual styles. In turn, the implementation of virtual tutoring systems offers educational support that is more accessible from the student's perspective. The automation of administrative processes improves the operational efficiency by freeing up time and resources. Alongside the optimization of academic management through AI, it enables teachers to have quality time at their disposal. Among the various applications of AI in higher education, we will focus on those targeting students. This category includes adaptive/personalized learning systems or recommendation systems, virtual FAQ assistants, and the automation of repetitive tasks and progress analysis.

The identification of concepts that students find difficult to understand is a key element in constructive learning and also allows for the development of specific intervention actions. In

line with the above, one of the most critical issues is how to facilitate access to such interventions at the moment and in a way that is relevant to the students.

Academic tutoring serves as a tool for this purpose. Its mission should be to individualize and personalize teaching for the student seeking it: expanding and deepening information, resolving doubts and difficulties, etc. This ongoing guidance by the teacher allows for determining the level of success in various assigned tasks, adjusting initial objectives if necessary, and guiding autonomous learning. It should also foster a personal relationship between teacher and student, provide professional guidance, motivation towards the subject, and facilitate assessment.

An update of this tool is necessary to achieve an effective classroom intervention in the current technological scenario. This new form of academic tutoring, compatible with face-to-face (F2F) interactions, provides students with the advantages of availability and on-demand repeatability, allowing for ubiquitous learning in the emerging new learning environments. Among the new didactic tools to strengthen education, we have intelligent tutoring systems (ITS), which are designed to enhance learning both inside and outside the classroom, replicating the effectiveness of human tutoring in digital tools.

An ITS is a computational system designed to provide instruction and intelligently support the teaching-learning processes through the interaction with the student (Arias et al., 2009). An intelligent tutor, therefore, "is a software system that uses AI techniques to represent knowledge and interacts with students to teach it" (Minn, 2022; Ouyang et al., 2022).

Nevertheless, it should not only create a digital profile of a student and provide them with a personal tutor; the primary objective of ITS should be the identification of the learning level in a specific area to offer support in the teaching-learning process to stimulate students. This work presents the development of an AI-based ITS as the first stage of a process that elaborates a predictive analysis of the student.

3. Proposed AI application

Intelligent tutoring systems have coexisted with conventional methodologies for some time, in the form of seminal intelligent tutoring systems like cognitive tutors (Anderson et al., 1995) or AutoTutor (Graesser et al., 2004); or the ASSISTments program, which combines intelligent tutoring with assessment to provide real-time feedback (Heffernan and Heffernan, 2014). Nevertheless, it has been in recent years, with the advent of AI in our lives, that intelligent tutoring systems have been claimed to have the potential to become key tools to enhance the teaching-learning process. In this respect, it has to be noted that the most widely used AI implementations to provide contextual responses, such as those expected for a tutoring tool, like ChatGPT, still suffer from a lack of accuracy or even mistakes in the responses provided, which demands its users to be proficient in the topics for which information in sought. Therefore, it is

advisable to develop scaled versions of those tools, specific for certain topics, with the control of the instructors, both in the selection of sources to extract information for the answers, as well as in the supervision of the answers provided. In addition, this allows to add tools to carry out a predictive analysis of the learning process of the students so that the information given can be tailored to his/her needs, in an open-access and free way.

One of the main concerns of educators should not be whether students use AI applications fraudulently, but rather the quality and timeliness of the responses they obtain within the framework of the subject. AI can provide questionable information, it can generate incorrect information or be influenced by biases present in the data with those who were trained. It is crucial that teachers should act as professional managers of AI resources for the benefit of students. It is also important to consider that AI responds to a process that simulates human intelligence to solve problems by learning from the surrounding data, and its effectiveness depends on how its tools are used.

In this work, an Intelligent Tutoring System based on AI has been designed, but with control over the possible responses which increases the reliability of the answers received and that the questions asked allow students' doubts to be analyzed to continue improving the AI system. It also represents the first phase of a project where a predictive analysis of each student's learning can be obtained.

3.1. Participants and scope

Participants are the students enrolled in the course Physical Techniques I, which is part of the second academic year of the Bachelor degree in Physics at the authors' institution. The course aims to provide basic skills in metrology and electronic instrumentation for the measurement of physical magnitudes. In Physical Techniques I, students must be able to analyze basic electronic circuits, determine specifications and tolerances for a measurement, and design the full setup to carry out a measurement, calculating the contribution of every stage to the uncertainty. In this subject, students face basic concepts of Electronics and, in particular, Circuit Theory for the first time, are asked to analyze an electronic circuit using the complex variable *s*, to find out tolerances and specifications for the equipment, to design conditioning stages to carry out measurements, and calculate their contribution to the final uncertainty. Furthermore, the laboratory sessions require the utilization of several instruments that students are not used to manipulate. As a consequence, students often need guidance by the instructors. This project seeks to identify which are the theoretical concepts that appear to be the most difficult to understand by the students in the framework of the course Physical Techniques I.

3.2. Methodology

As detailed above, this project seeks to identify which are the theoretical concepts that appear to be the most difficult to understand by the students in the framework of the course Physical Techniques I. To achieve this, we worked on a previous project where an extensive survey had been conducted, covering both general aspects of the student's situation and their perception of the subject and concepts addressed (Sánchez-Azqueta, 2019). The specific concepts presented in the new survey were primarily based on a prior selection made according to inquiries from previous years in F2F academic tutoring sessions. Contents related to conceptual errors detected in the correction of written tests were also included, which were sometimes not identified by students as errors, as they did not appear to have apparent complexity. These contents influenced the selection of initial material that our neural network or classification algorithm will use, ensuring that the teacher has control over the responses by narrowing down the sources of information employed.

Once a broad (ideally unlimited) set of reference documents is selected (including classroom notes, articles, open-access books, etc.), the classification algorithm generates a selection based on the user's question. Subsequently, this selection of documents becomes part of the input, along with the question, in a conversational network large language model (LLM) like ChatGPT. Since training the network is not the goal of the work, a pre-trained network from an open-access repository is utilized (Crompton and Burke, 2023). The developed information processing scheme can be seen in Figure 1 and the ChatPLT user interface in Figure 2.

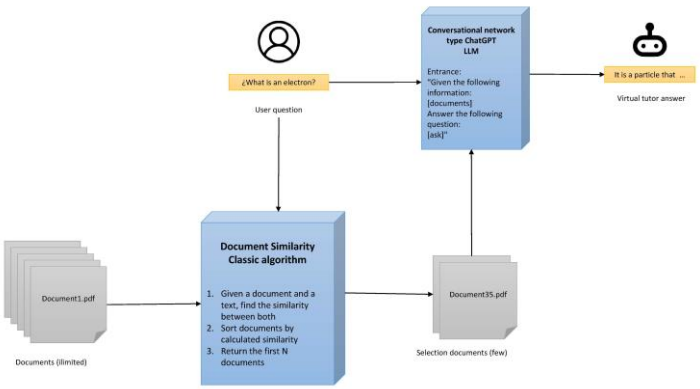

Figure 1. Block diagram of the virtual tutor AI based

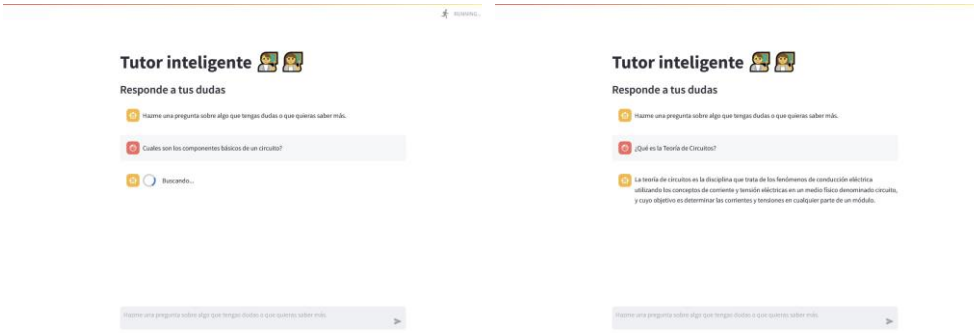

Figure 2. ChatPLT user interface

4. Description of the ITS developed

As can be inferred from Figure 1, this application has two clearly differentiated elements. On the one hand, Ollama [https://ollama.ai/] is used to load and execute a publicly available model designed for the retrieval-augmented generation task (RAG). The second part is the classification algorithm, where we use LlamaIndex [https://www.llamaindex.ai/] and, most particularly, an out-of-the-box vector store database to extract and store the information of the documents (or excerpts). Vector databases work by transforming text into vectors that 'identify' their contents. By transforming the input text into another vector, it can be quickly and efficiently compared with the stored ones to rank and return the most similar documents.

One of the benefits of LlamaIndex, a Python framework specifically designed to implement ChatGPT-like apps and interact with multiple LLM related components, is that both Ollama and vector store are already included. Everything is done in the background and the code just needs to initialize and configure the elements, and provide the folder with specific and controlled documentation. To conclude, StreamLit [https://streamlit.io/] is used to generate a user interface for the application, in this case for the students of the subject.

A preliminary test has been carried out by analyzing the responses to 40 different questions related to the documents fed to the application. These responses have been classified in three different categories according to their accuracy. As it can be seen in Table 1, 31 questions (77.5%) have yielded correct answers, 8 questions (20%) have yielded answers with missing or incorrect information and 1 one question (2.5%) have yielded an incorrect response. These results show that, although the accuracy of the application is not perfect, it could have a great potential.

Table 1. Analysis of the responses to 40 different questions.

Category	Number
Satisfactory responses	31
Missing or incorrect information	8
Incorrect or unrelated answers	1
Total questions	**40**

5. Expected results and Conclusions

In this phase of the project, the first two stages have been covered: the identification of challenging concepts and the development of an AI-based tool with accurate bibliographic references using reliable sources that caters to specific needs of the students. The next phase is currently underway, focusing on introducing the tutor to the students as a complementary tool to their learning, especially in preparation for the June exams. This will be a dynamic process that will contribute to building a more refined and tailored database, along with the gradual introduction of improvements to the tool's functionality. Finally, the project will expand to include the development for implementation in the next course, focusing on analyzing the evolution of the students' profiles to enable predictive analysis and timely interventions.

The way our students acquire information nowadays differs significantly from consulting the bibliography recommended by the professor. Internet and YouTube are often the usual sources due to the way they interact with technology, and, of course, the use of ChatGPT. We believe that integrating AI as a useful tool in the educational environment should be part of the teaching responsibility, assessing the sources and references our students use to give greater value to the generated responses. Leveraging the power of the tool to add value to this interaction, such as personalizing the learning experience, is crucial.

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