Authors' accepted manuscript
Article published in IEEE Conference on Education and Training in Optics and Photonics (ETOP), 2025.
The final published version available at https://doi.org/10.1109/ETOP64842.2025.11030638

CoulombCompagnon: An Intelligent Tutoring System for Enhancing Electromagnetic Concepts Understanding in Engineering Education

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***Abstract*— This paper introduces CoulombCompagnon, an intelligent individual tutoring system designed to enhance the comprehension of complex electromagnetic concepts among electrical engineering students. Utilizing AI-driven adaptive learning techniques, this system provides a customized bank of exercises and conceptual resources specifically made to meet individual student needs. Integrated personalized feedback mechanisms gather data on student performance, enabling educators to pinpoint and address challenging areas. This facilitates the creation of personalized problem sets for each student, effectively bridging the gap between theoretical knowledge and practical application while deepening their understanding of electromagnetic principles.**

Keywords — intelligent tutoring system, electromagnetism education, AI in learning, adaptive learning, problem-solving skills, engineering education

I. Introduction

As technology rapidly evolves, the landscape of engineering education is undergoing a profound transformation, becoming increasingly complex and demanding [1-3]. This evolution presents significant challenges, particularly in conceptually dense fields like electromagnetism that rely heavily on abstract theories [2]. Traditional teaching methods often struggle to effectively convey these complex concepts, resulting in significant learning gaps and blocking practical application of essential knowledge [1, 2]. In response to these challenges, the CoulombCompagnon project was launched at École de Technologie Supérieure (ÉTS), Canada, aiming to leverage advanced artificial intelligence to revolutionize the learning environment. This initiative seeks to foster a more personalized and adaptive educational experience to meet the diverse needs of students.

CoulombCompagnon is designed specifically to enhance the learning experience in key electromagnetism courses, such as Electromagnetism (ELE312) and Electromagnetic Waves (ELE413). These courses cover fundamental topics like Maxwell's equations, wave propagation, and Coulomb's law, which are essential for any future electrical engineer. The system incorporates an intelligent individual tutoring system that utilizes AI-powered adaptive learning techniques [3-5], providing a rich bank of exercises and conceptual resources tailored to individual learning styles and needs.

II. Methodology

A. Evaluation of Learning Needs

The first step in developing the CoulombCompagnon platform focused on identifying the specific learning needs of students in electromagnetism. Educators observed that students often struggled with abstract concepts and practical applications, as reflected in their academic performance. These observations laid the groundwork for identifying areas of difficulty. To gain deeper insights, we collected data on students' understanding of electromagnetic principles and their problem-solving skills. This process involved reviewing grades, gathering qualitative feedback from both students and educators, and analyzing interactions with existing educational tools. The data revealed common conceptual misunderstandings and gaps in learning, necessitating targeted interventions.

Based on these findings, we designed educational resources to address these challenges. These resources include accessible materials explaining fundamental electromagnetic principles, interactive simulations to visualize complex theories, and carefully crafted problem sets aimed at reinforcing both theoretical understanding and practical skills. Initially, we leveraged problems already used in existing courses to provide a familiar starting point for students to practice their problem-solving skills.

B. Development of Educational Content

Building on insights from the evaluation phase, the next step involved developing tailored educational content that directly addressed the identified needs. This content was centralized on a newly created website featuring a variety of resources, including class presentations, formulas, step-by-step guides, and illustrative visuals. One of the platform's key features is its integration with the OpenAI API, which allows students to ask in-depth questions about formulas, problem-solving steps, and their interconnections.

The platform is designed to evolve continuously, with planned additions such as interactive concept maps and a communication module to facilitate peer support. Future enhancements include AI-generated problems that dynamically adapt to individual learning needs, offering students a personalized educational experience. To make content easily

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accessible, problems are tagged with relevant formulas and concepts, enabling students to efficiently search for and work on customized problem sets.

C. Platform Creation

The CoulombCompagnon platform was developed using Django, chosen for its flexibility and scalability, alongside OpenAI's API to generate adaptive learning content tailored to individual needs. The platform features distinct, intuitive interfaces for both students and instructors, ensuring a user-friendly experience that caters to their specific roles.

For students, the platform offers direct access through Moodle and comprises three core modules: conceptual resources, a problem-solving exercise bank, and practical application modules. The Intelligent Tutoring System (ITS) customizes the learning process based on individual performance, tracks progress, and adapts content dynamically to address each student's unique needs. Students can practice a wide range of problems, engage with interactive learning tools, and receive feedback that enhances their understanding of complex concepts.

For instructors, the platform provides dedicated access where they can integrate their own problems, resources, and teaching materials. This functionality allows professors to contribute tailored support and align the platform's content with specific course requirements. Educators can also monitor student performance through the ITS, gaining insights into learning patterns and identifying areas requiring additional focus. This feature helps refine teaching strategies and ensures the platform remains a powerful tool for both teaching and learning.

The deployment of CoulombCompagnon on AWS and Heroku ensures robust and scalable access, accommodating the growing user base and evolving educational needs. By combining adaptability, instructor customization, and student-focused learning, the platform serves as a comprehensive educational tool, fostering a more engaging and effective learning experience.

The platform was developed in French to align with the language requirements and institutional policies of ÉTS.

D. Preliminary Test

Student performance data from the ELE312 and ELE413 courses was collected during the preliminary testing phase. This allowed us to assess the platform's impact on learning outcomes, specifically students' comprehension of electromagnetic concepts and problem-solving skills. Surveys and feedback from students and educators were used to identify areas for improvement, enhancing the platform's functionality and optimizing the learning experience. These insights were incorporated into iterative updates to ensure the system met both teaching and learning needs effectively.

E. Enrichment of the Problem Bank

To diversify the range of problems offered, efforts were made to enrich the problem and solution bank using OpenAI resources. This initiative introduced a broader array of scenarios and challenges suitable for various skill levels. The process involved developing and testing AI algorithms capable of generating new problems and solutions, which were rigorously validated to ensure their relevance and appropriate difficulty. These enriched resources were then added to the platform, expanding the range of tools available for students to deepen their understanding and practice critical skills.

F. Analysis of Learning Outcomes

The final phase involves analyzing learning outcomes by collecting statistical data on students' problem-solving abilities and engagement with the platform. Usage and performance data will be analyzed to identify areas where students face the most difficulty. These findings will guide necessary pedagogical adjustments to enhance learning effectiveness.

Detailed reports will be compiled for educators, providing insights into areas of success and recommendations for improvement. This feedback loop ensures the platform remains dynamic and responsive, continuously refining both the ITS and teaching practices. By aligning these insights with instructional strategies, CoulombCompagnon fosters a more effective, data-driven approach to teaching electromagnetism, benefiting both students and educators alike.

III. Results

A. Platform

The CoulombCompagnon platform has achieved significant milestones in its development, focusing on creating a comprehensive and interactive learning environment for electromagnetism courses. A robust bank of problems has been developed, drawing directly from existing practical sessions and lecture materials, ensuring alignment with the curriculum and relevance to students' learning needs.

To support a wide range of learners, the platform introduces five levels of assistance, designed to progressively guide students toward mastering complex electromagnetic concepts (see Figure 1):

1. **Preliminary questions (Question préliminaire):** Students are asked to reflect a little bit about the different concepts and formulas that will be useful in solving the problem. This section aims to ensure that students understand which tools and methods they should use to answer the question. By placing this section first, we make sure that the students have all the necessary information to understand and then solve the problem instead of doing the opposite.
2. **Algebraic expressions (Formules):** Key equations and expressions are provided to simplify problem-solving, giving students a clear starting point without overwhelming them with complexities.
3. **Step-by-step methodological guidance (Étapes):** Problems are broken down into manageable steps, offering students a structured approach to tackle even the most challenging topics, improving their analytical skills and confidence
4. **Access to class resources (Ressources):** Students can consult class presentations, PowerPoint slides, and textbooks directly on the platform, connecting theoretical

concepts with practical applications and reinforcing their understanding.

5. **AI-powered assistance (AI)**: Leveraging the integration of OpenAI, the platform provides tailored suggestions, solutions, and explanations, offering students dynamic support as they engage with the material. Both students and educators can validate the accuracy of AI-provided responses. Correct solutions are saved to the system's database for future reference, while incorrect or unsatisfactory answers prompt further clarification, ensuring continuous refinement of the learning experience.

The integration of AI-powered assistance in CoulombCompagnon represents a significant step toward creating a responsive and adaptive learning environment. However, it is widely recognized that AI tools, including OpenAI, may provide incorrect or misleading responses when questions are not asked with sufficient precision. To address this limitation and ensure the reliability of the assistance provided, the platform narrows the scope of AI interaction by structuring questions based on the specific concepts required to solve a particular problem.

In practice, students interact with the AI tool through predefined question templates or guided prompts directly linked to the context of the problem they are solving. These prompts ensure that the AI focuses on delivering accurate and relevant information by anchoring its responses to specific electromagnetic concepts, such as Maxwell's equations, wave propagation, or Coulomb's law. For example, instead of asking a general question about solving a problem, students can query how a particular formula is applied or request clarification on a specific step in the solution process.

By framing the AI interaction within the context of each problem, CoulombCompagnon minimizes the risk of inaccurate or irrelevant responses, ensuring that students receive precise guidance aligned with their learning objectives. Additionally, the platform encourages students and instructors to validate the responses provided by the AI. Validated answers are saved in the system's database, enriching its resources for future learners, while unsatisfactory responses can be refined through iterative interactions, ultimately enhancing the overall reliability and utility of the AI-powered assistance.

Detailed solution manual (Réponse(s) complète(s)) is created in the style of traditional solution guides. This resource serves as an invaluable reference, enabling students to independently review complete solutions and understand the rationale behind each step.

By combining these elements, the platform creates a dynamic, student-centered learning environment. It not only supports individual progress but also promotes collaborative validation and improvement, ensuring that the problem bank and solutions evolve to meet the needs of both current and future learners.

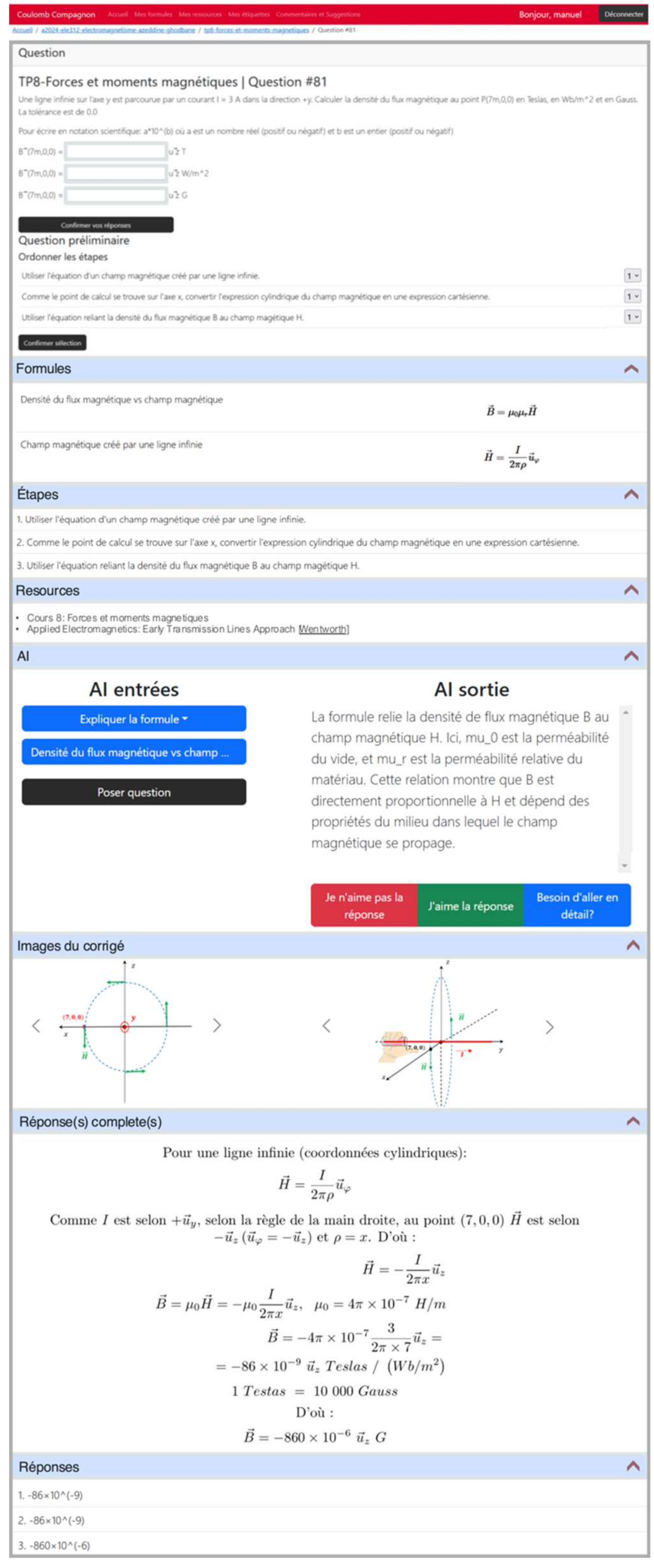

Figure 1A screenshot from the platform showcasing an example problem along with step-by-step guidance for finding the solution.

B. Initial Feedback

The CoulombCompagnon platform has been evaluated by a group of 50 students at ÉTS, offering valuable insights into its usability, accessibility, and impact on their learning experience in electromagnetism. The majority of students rated the user interface as good or very good, with most finding the platform's resources, such as formulas and slides, easily accessible.

Comments frequently highlighted the ease of navigation and straightforward access to learning materials.

None of the students reported technical difficulties, indicating that the platform operated reliably during the initial testing phase. Most participants agreed that the provided resources were sufficient to understand concepts and solve exercises, though some suggested adding more detailed explanations of calculations, mathematical rules, and additional visual aids like schematics.

The integration of AI-powered assistance was positively received, with many students describing it as useful or very useful for clarifying complex concepts. While some students noted they did not extensively use this feature, others appreciated its potential to enhance their understanding.

Suggestions for improvement included expanding the platform to increase the number of visual aids and providing more detailed step-by-step explanations for problem-solving. Some students recognized the platform as a work in progress and expressed patience and optimism for future updates.

Overall, the platform received an average satisfaction score of 7.9 out of 10, with most students expressing a willingness to recommend it to their peers. This score reflects the platform's strengths in design, functionality, and educational value, while also pointing to areas where further refinement could enhance its effectiveness. The feedback provides a strong foundation for future development, ensuring that CoulombCompagnon continues to grow as a valuable learning tool for electromagnetism.

IV. Discussion

CoulombCompagnon addresses several challenges in electromagnetism education by providing a structured and adaptive learning environment. The system's AI-driven approach ensures that students receive timely and relevant feedback, helping them overcome conceptual difficulties. The integration of interactive elements, such as concept maps and peer communication, fosters a more engaging and supportive learning experience.

Future developments include expanding the problem bank, enhancing the AI's feedback capabilities, and introducing collaborative learning modules to encourage knowledge sharing among students. These improvements aim to further bridge the gap between theoretical learning and practical application, ensuring that students are well-prepared for real-world engineering challenges.

V. Conclusion

CoulombCompagnon represents a significant advancement in the use of intelligent tutoring systems in engineering education. By leveraging AI and adaptive learning techniques, the platform enhances students' understanding of complex electromagnetic concepts, improves problem-solving skills, and fosters a deeper engagement with the material. As we continue to refine and expand the system, we anticipate even greater impacts on student learning outcomes and overall academic success.

Acknowledgment

M.Z. thanks Décanat des études of ÉTS.

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