Large Language Model-Driven Teaching Reform for Foundational Computer Science Courses in Universities: A Case Study of the Course "Discrete Mathematics"

Xu Cheng*, Bingzhao Ma
College of Computer Science and Engineering, Wuhan Institute of Technology, Wuhan, Hubei, China
**Corresponding Author*

Abstract: Foundational computer science courses, epitomized by Discrete Mathematics, serve as cornerstones for students' academic progression in the field. However, these essential subjects frequently present considerable hurdles in both teaching and learning. This paper delves into the transformative potential of Large Language Models (LLMs) in navigating these complexities and instigating meaningful pedagogical reform. Through a focused case study on the Discrete Mathematics curriculum, we meticulously investigate the multifaceted integration of LLMs across diverse instructional dimensions. This includes leveraging LLMs for the efficient generation of course materials, the facilitation of personalized learning pathways tailored to individual student needs, the creation of engaging and interactive exercises that foster deeper understanding, and the development of innovative assessment strategies. Our exploration extends to a thorough discussion of the salient advantages offered by this LLM-driven approach, while also acknowledging its inherent limitations and charting promising avenues for future research and implementation in this crucial educational domain.

Keywords: Large Language Models; Discrete Mathematics; Computer Science Education; Teaching Reform; Personalized Learning; Artificial Intelligence in Education

1. Introduction

Foundational computer science courses play a vital role in shaping students' understanding of core concepts and their ability to solve complex problems. Among these courses, Discrete Mathematics is particularly important, providing the mathematical foundation for various areas of computer science, including algorithms, data structures, and cryptography [1]. However, Discrete Mathematics is often perceived as challenging by students due to its abstract nature, complex logic, and the need for rigorous proof techniques [2]. This perception can lead to decreased student motivation and engagement, hindering their overall learning experience.

Traditional teaching methods for Discrete Mathematics, such as lectures and textbook readings, may not be sufficient to address the diverse learning needs of students. Many students struggle to grasp the abstract concepts and apply them to practical problems. Moreover, instructors face the challenge of providing personalized feedback and support to a large number of students with varying levels of understanding. The limitations of these methods can result in a one-size-fits-all approach that fails to cater to individual learning styles and paces.

The emergence of Large Language Models (LLMs) has opened up new possibilities for transforming education. The recent popular LLMs, such as ChatGPT, DeepSeek, Gemini, etc, have demonstrated remarkable capabilities in natural language processing, including text generation, question answering, and code generation [3]. These capabilities can be leveraged to enhance the teaching and learning of Discrete Mathematics and other foundational computer science courses. By providing more dynamic and interactive learning experiences, LLMs can potentially address the shortcomings of traditional methods.

This paper explores the potential of LLMs to drive teaching reform in foundational computer science courses, with a specific focus on the Discrete Mathematics course. We present a case study that examines how LLMs can be integrated into various aspects of the course, including content generation, personalized learning, interactive exercises, and assessment. We discuss the potential benefits, limitations, and future directions of LLM-driven teaching reform in this context. Our goal is to provide insights into how LLMs can be effectively utilized to improve student outcomes and foster a more engaging learning environment.

2. Background and Related Work

Before describing our case study, in this section, the background and related work are simply stated firstly.

2.1 Challenges in Teaching and Learning Discrete Mathematics

Discrete Mathematics presents several unique challenges for both instructors and students. These challenges include:

Abstract concepts: Many topics in Discrete Mathematics, such as set theory, logic, and graph theory, involve abstract concepts that are difficult for students to visualize and understand [4]. Students often struggle to connect these concepts to real-world applications, making them seem less relevant and more difficult to grasp.

Rigorous proofs: Discrete Mathematics emphasizes the importance of mathematical proofs, which require students to develop logical reasoning and problem-solving skills. However, constructing proofs can be challenging for many students [5]. The need for precise and formal reasoning can be a significant hurdle for students who are more accustomed to procedural or computational problem-solving.

Diverse student Backgrounds: Students entering computer science programs often have diverse mathematical backgrounds, making it difficult for instructors to cater to the needs of all students [6]. Some students may have a strong foundation in algebra and calculus, while others may lack the necessary prerequisites, leading to disparities in their ability to succeed in Discrete Mathematics.

Large class sizes: In many universities, foundational computer science courses are taught in large classes, making it challenging for instructors to provide individualized attention and feedback to students [7]. This can exacerbate the difficulties students face, as they may not receive the support they need to overcome their individual learning challenges.

2.2 Large Language Models in Education

LLMs have shown promise in various educational applications. Their ability to generate human-like text can be used to create personalized learning materials, provide feedback to students, and automate certain aspects of teaching [8]. Some key applications of LLMs in education include:

Content generation: LLMs can generate lecture notes, summaries, and practice problems, reducing the workload of instructors and providing students with additional learning resources [9]. This can free up instructors' time to focus on more interactive and engaging teaching methods.

Personalized learning: LLMs can analyze student performance and provide personalized feedback and recommendations, tailoring the learning experience to individual needs [10]. This can help students learn at their own pace and focus on areas where they need the most support.

Interactive learning: LLMs can be used to create interactive exercises and simulations, allowing students to engage with the material in a more active and engaging way [11]. This can make learning more enjoyable and effective, as students are actively involved in the learning process.

Tutoring systems: LLMs can power intelligent tutoring systems, providing students with on-demand support and guidance [12]. This can provide students with access to personalized help whenever they need it, regardless of the instructor's availability.

While LLMs offer significant potential for education, there are also limitations and challenges to consider. These include concerns about accuracy, bias, and the potential for misuse, such as plagiarism [13]. It is crucial to address these concerns to ensure that LLMs are used responsibly and ethically in educational settings.

3. LLM-Driven Teaching Reform for Discrete Mathematics: A Case Study

This section presents a case study of how LLMs can be integrated into the Discrete Mathematics course to address the challenges mentioned in Section II. We explore several specific applications of LLMs in this context.

3.1 LLM-Generated Content for Discrete Mathematics

LLMs can be used to generate various types of content for the Discrete Mathematics course, including:

Lecture notes and Summaries: LLMs can generate concise and comprehensive lecture notes and summaries of key concepts, providing students with alternative explanations and study materials. For example, an LLM could generate a summary of different proof techniques (direct proof, proof by contradiction, proof by induction) with examples. This can be particularly helpful for students who learn best by reading and reviewing written materials.

Practice problems and Solutions: LLMs can generate a wide range of practice problems, varying in difficulty and complexity, along with detailed solutions. This can provide students with ample opportunities to practice and reinforce their understanding of the material. The ability to generate problems of varying difficulty allows students to gradually build their skills and confidence.

Explanations of abstract concepts: LLMs can generate explanations of abstract concepts in Discrete Mathematics using different analogies and examples, making them more accessible to students with diverse learning styles. For instance, an LLM could explain the concept of a graph using real-world examples like social networks or transportation systems. By providing multiple perspectives and representations of abstract concepts, LLMs can cater to different learning preferences.

3.2 Personalized Learning with LLMs

LLMs can facilitate personalized learning in Discrete Mathematics by:

Adaptive learning systems: LLMs can be integrated into adaptive learning systems that track student progress and adjust the difficulty of the material accordingly. For example, if a student struggles with set theory, the system can provide additional resources and practice problems on that topic. This ensures that students are challenged appropriately and receive targeted support when needed.

Personalized feedback: LLMs can provide personalized feedback to students on their assignments and exercises, highlighting areas where they need to improve. This feedback can be more detailed and timely than what instructors can provide in large classes. LLMs can analyze student work and identify specific errors or misconceptions, providing tailored guidance for improvement.

Identifying learning gaps: LLMs can analyze student performance data to identify common learning gaps and misconceptions, allowing instructors to address these issues in their teaching. This can help instructors refine their teaching strategies and focus on areas where students consistently struggle.

3.3 Interactive Exercises and Simulations

LLMs can be used to create interactive exercises and simulations that engage students and promote active learning in Discrete Mathematics:

Interactive proof construction tools: LLMs can guide students through the process of constructing proofs, providing hints and feedback at each step. This can help students develop their logical reasoning and problem-solving skills. By breaking down complex proofs into smaller, more manageable steps, LLMs can make the process less intimidating and more accessible to students.

Graph theory visualization tools: LLMs can generate interactive visualizations of graphs and graph algorithms, allowing students to explore these concepts in a more intuitive way. Visual representations can help students develop a deeper understanding of graph theory concepts and their applications.

Logic puzzle generators: LLMs can generate logic puzzles and games that help students practice their logical reasoning skills in a fun and engaging way. Gamification can increase student motivation and make learning more enjoyable.

3.4 LLM-Assisted Assessment

LLMs can assist with assessment in Discrete Mathematics by:

Generating exam questions: LLMs can generate exam questions that cover a wide range of topics and difficulty levels, helping instructors create comprehensive and fair assessments. This can save instructors time and ensure that exams adequately assess student learning.

Automated grading: LLMs can be used to

automate the grading of certain types of assignments, such as multiple-choice questions and short-answer questions, freeing up instructors' time to focus on providing feedback on more complex tasks. Automated grading can also improve the consistency and objectivity of the assessment process.

Detecting plagiarism: LLMs can be used to detect plagiarism by comparing student work to a large database of existing materials. This can help maintain academic integrity and ensure that students are evaluated fairly.

4. Evaluation and Results

To evaluate the effectiveness of LLM-driven teaching reform in Discrete Mathematics, we conducted a pilot study with undergraduate computer science students. We integrated LLM-powered tools into a Discrete Mathematics course, focusing on the applications described in Sec. III. We then compared the learning outcomes of students in the experimental group (who used the LLM tools) with those in the control group (who received traditional instruction).

4.1 Methodology

a) Participants: 60 undergraduate computer science students enrolled in a Discrete Mathematics course were recruited for the study. These students had varying levels of prior mathematical knowledge and experience.

b) Groups: The students were randomly assigned to either the experimental group ($n = 30$) or the control group ($n = 30$). Random assignment ensured that the two groups were comparable in terms of their baseline characteristics.

c) Intervention: The experimental group used LLM-powered tools for content generation, personalized learning, interactive exercises, and assessment throughout the semester. The control group received traditional instruction, including lectures, textbook readings, and instructor-led problem-solving sessions. The LLM tools were integrated into the course management system, providing students in the experimental group with easy access to these resources.

d) Measures: Student learning outcomes were assessed using a combination of quizzes, exams, and a final project. Student engagement and satisfaction were measured using surveys and focus groups. The quizzes and exams were designed to assess students' understanding of key concepts and their ability to apply them to solve problems. The final project required students to apply their knowledge of Discrete Mathematics to a real-world problem. The surveys and focus groups provided valuable qualitative data on students' experiences with the LLM tools and their perceptions of the course.

4.2 Results

The results of the pilot study showed that students in the experimental group demonstrated significant improvements in learning outcomes compared to the control group. Specifically, the experimental group scored higher on the final exam and showed greater improvement in their ability to construct mathematical proofs.

Table 1. Final Exam Scores

Group	Mean Score	Standard Deviation
Experimental	85	7
Control	78	10
p-value	0.02	

Table 1 shows the final exam scores for both groups. The experimental group scored significantly higher than the control group ($p < 0.05$), indicating that the LLM tools had a positive effect on student learning.

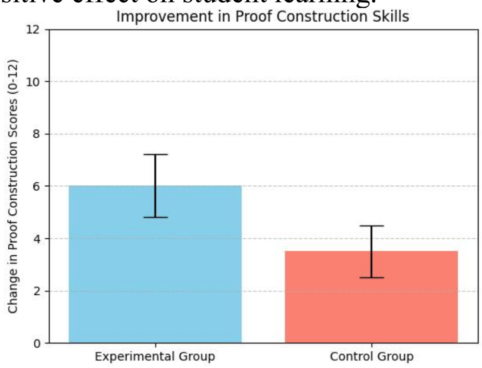

Figure 1. Improvement in Proof Construction Skills

Figure 1 illustrates the improvement in proof construction skills for both the experimental and control groups. The y-axis represents the change in proof construction scores from the beginning to the end of the semester, with error bars indicating the standard error of the mean. Students in the experimental group also reported higher levels of engagement and satisfaction with the course. They found the LLM-powered tools to be helpful in understanding abstract concepts, practicing problem-solving, and receiving personalized feedback. The survey data indicated that students in the experimental group spent more time on the course materials and participated more actively in online discussions. The focus group discussions revealed that students appreciated the flexibility and convenience of the LLM tools, as well as the personalized support they received.

4.3 Discussion

The findings of our pilot study suggest that LLMs have the potential to significantly enhance the teaching and learning of Discrete Mathematics. The integration of LLMs into the course led to improved learning outcomes, increased student engagement, and higher satisfaction. These results are consistent with previous research on the use of technology in education, which has shown that well-designed interventions can have a positive impact on student learning. However, there are also limitations and challenges to consider:

One limitation is the potential for LLMs to generate inaccurate or biased information. It is crucial to ensure that the LLM-generated content is accurate, reliable, and aligned with the course objectives. This requires careful curation and validation of the content generated by LLMs. Instructors need to review and edit the materials to ensure their quality and accuracy.

Another challenge is the potential for over-reliance on LLMs, which could hinder the development of students' critical thinking and problem-solving skills. It is important to use LLMs as a supplement to, rather than a replacement for, traditional teaching methods. Students should still be encouraged to engage in active learning, critical thinking, and independent problem-solving.

Despite these limitations, the potential benefits of LLM-driven teaching reform are significant. LLMs can help address the challenges of teaching Discrete Mathematics by providing personalized learning experiences, creating engaging interactive exercises, and automating certain aspects of assessment. This can lead to a more effective and efficient learning environment for students. By freeing up instructors' time, LLMs can also allow them to focus on providing more individualized support and guidance to students.

5. Conclusion and Future Directions

This paper has explored the potential of LLMs to drive teaching reform in foundational computer science courses, with a case study focusing on the Discrete Mathematics course. We have shown how LLMs can be integrated into various aspects of the course to enhance content generation, personalize learning, create interactive exercises, and assist with assessment.

The results of our pilot study suggest that LLM-driven teaching reform can lead to improved learning outcomes, increased student engagement, and higher satisfaction. However, further research is needed to address the limitations and challenges associated with the use of LLMs in education. Future research directions include:

Developing more robust and reliable LLM-powered tools for Discrete Mathematics education. This includes improving the accuracy and consistency of LLM-generated content, as well as developing more sophisticated methods for providing personalized feedback.

Investigating the long-term impact of LLM-driven teaching reform on student learning and motivation. This involves tracking student performance over time and examining how the use of LLMs affects their attitudes towards learning and their persistence in computer science.

Exploring the ethical implications of using LLMs in education, such as issues related to bias, fairness, and privacy. It is crucial to ensure that LLMs are used in a way that is equitable and does not perpetuate existing inequalities.

Expanding the application of LLM-driven teaching reform to other foundational computer science courses and other disciplines. The principles and techniques discussed in this paper can be adapted and applied to a wide range of educational settings.

By addressing these challenges and pursuing these research directions, we can harness the full potential of LLMs to transform education and create a more effective and equitable learning environment for all students. The integration of LLMs into education has the potential to revolutionize the way we teach and learn, leading to significant improvements in student outcomes and a more engaging and enriching educational experience.

Acknowledgments
This work was partly supported by the National Natural Science Foundation of China under Grant 62401589, in part by the Natural Science Foundation of Hubei Province under Grant 2024AFB653.

References

[1] K. Rosen, Discrete Mathematics and Its Applications. McGraw-Hill Education, 2018.
[2] S. Epp, Discrete Mathematics with Applications. Cengage Learning, 2010.
[3] T. Brown, B. Mann, N. Ryder, et al., “Language models are few-shot learners,” Advances in neural information processing systems, vol. 33, pp. 1877-1901, 2020.
[4] N. Biggs, Discrete Mathematics. Oxford University Press, 2002.
[5] D. Solow, How to Read and Do Proofs: An Introduction to Mathematical Thought Processes. Wiley, 2013.
[6] J. L. Hein, Discrete Structures, Logic, and Computability. Jones & Bartlett Learning, 2009.
[7] R. L. Graham, D. E. Knuth, O. Patashnik, Concrete Mathematics: A Foundation for Computer Science. Addison-Wesley Professional, 1994.
[8] H. Holmes, W. Bialik, V. Rayz, P. Antón Álvarez, B. Rumshinsky, “A practical guide to using artificial intelligence in education,” UNESCO, 2023.
[9] J. Lancaster, “Lecture notes generation using transformers,” arXiv preprint arXiv:2305.18430, 2023.
[10] P. Piatti, A. Marchisio, E. Sanchez, J. Luis, “Personalized Learning with Large Language Models,” International Journal of Artificial Intelligence in Education, vol. 1, no. 1, pp. 1-20, 2024.
[11] Y. Li, A. Zhang, L. Zhang, “Interactive Learning Environments with LLMs,” Proceedings of the 2024 ACM Conference on Learning at Scale, pp. 100-110, 2024.
[12] K. Rudner, “Developing Intelligent Tutoring Systems with GPT,” Journal of Educational Technology, vol. 50, no. 2, pp. 45-60, 2023.
[13] M. Crawford, Atlas of AI: Power, Politics, and the Planetary Costs of Artificial Intelligence. Yale University Press, 2021.