CodeMentor: Advancing Programming Education By Introducing An Interactive and Personalized Learning System with Large Language Models

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Abstract

In the rapidly evolving digital landscape, computer science education plays a pivotal role in equipping individuals with the necessary skills to thrive in the modern world. However, novice learners often face challenges and frustrations when learning programming. To address this, we present a novel system that leverages Large Language Models (LLMs) in combination with a Python interpreter application to create an interactive and personalized learning environment for programming education. Our system, CodeMentor[1,2] utilizes CodeMirror, a JavaScript library, on the frontend, and a Flask backend integrated with the GPT-3.5-turbo model running in the backend server for code explanation functions. Through our system, learners can write and execute Python code in a conversational interface, receiving instant feedback, hints, and comprehensive explanations from the LLMs. By incorporating LLMs, our system enhances the learning experience by providing understandable explanations for complex programming concepts. This research contributes to the field of Artificial Intelligence in Education (AIED) by offering a practical and innovative approach to address the challenges faced by novice learners in programming education. We discuss the implications, limitations, and ethical considerations of our work and propose future research directions for LLM-based educational systems.

Keywords

LLMs, Educational Data Mining, Learning Analytics, Machine Learning, HCI, CS Education, CEUR-WS

1. Introduction

Large Language Models (LLMs) are powerful deep learning algorithms that can process and generate natural language texts based on massive amounts of data. LLMs have been applied to various domains and tasks, such as natural language understanding, dialogue generation, summarization, and translation. However, the potential of LLMs in Learning Management Systems (LMS), Learning Analytics (LA), and other educational settings has not been fully explored, [3, 4]

In this paper, we propose a groundbreaking system that leverages LLMs in the backend and a user-friendly Python interpreter application in the frontend, aiming to revolutionize programming education. Our system is designed to create an interactive and personalized

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learning environment that empowers individuals seeking to enhance their programming skills. By integrating LLMs, we enable learners to engage in a conversational interface, where they can seamlessly write and run Python code while receiving real-time feedback, hints, and comprehensive explanations from the LLMs.

Through extensive research and empirical evaluations, we demonstrate the transformative potential of our system. Our results indicate that the interactive nature of our interface significantly enhances learners' engagement, motivation, and learning outcomes. Furthermore, our system fosters a symbiotic relationship between humans and AI, facilitating the co-creation of educational partnerships. By providing learners with the necessary guidance and support, our system empowers them to embark on a journey of continuous improvement in their programming proficiency.

As we delve into the implications and limitations of our work, we shed light on the ethical considerations surrounding the use of LLMs in educational contexts. We address concerns related to data privacy, bias, transparency, and the responsible use of AI-powered educational systems. Additionally, we provide insights into future research directions, emphasizing the need to develop standardized user interfaces, explore collaborative crowdsourcing and learnersourcing approaches, and further optimize the integration of LLMs within educational ecosystems.

In conclusion, our pioneering system demonstrates the significant potential of LLMs in shaping the future of programming education. By leveraging the capabilities of LLMs and fostering collaborative learning experiences, we aspire to empower learners, bridge educational gaps, and pave the way for innovative educational practices in the digital ag

2. Related Work

In this section, we review some of the existing literature on the use of LLMs for programming education and the challenges and opportunities it entails.

LLMs are powerful natural language processing models that can generate coherent and fluent texts based on large amounts of data. LLMs have been applied to various domains and tasks, such as natural language understanding, dialogue generation, summarization, and translation. However, the potential of LLMs in Learning Management Systems (LMS), Learning Analytics (LA), and other educational settings has not been fully explored.

One of the promising applications of LLMs in education is programming education. Programming is a fundamental skill in the digital age, but it also poses many challenges for learners and educators. Programming requires not only mastering syntax and logic, but also developing problem-solving, debugging, and creative thinking skills. Moreover, programming education often suffers from a lack of engagement, motivation, and feedback.

LLMs can help address some of these challenges by providing interactive and personalized learning experiences that empower learners to enhance their programming skills. By integrating LLMs in the backend and a user-friendly interface in the frontend, such as a Python interpreter or an IDE, learners can seamlessly write and run code while receiving real-time feedback, hints, and explanations from the LLMs. LLMs can also generate educational materials, such as quizzes, study guides, and interactive lessons, providing educators with valuable resources to enhance their teaching.

Several studies have explored the use of LLMs for programming education and reported positive results. For example Jeyrama et al [5] proposed a system that leverages ChatGPT, a chatbot based on an LLM that generates text in dialogue format, to provide personalized tutoring and automated grading for programming courses. The authors found that the system significantly enhanced learners' engagement, motivation, and learning outcomes. Similarly, Instructure [6] developed a system that uses Copilot[20], an LLM-based tool that generates code snippets based on natural language queries or existing code context, to facilitate programming learning and practice. The authors found that the system improved learners' confidence and productivity in coding tasks.

However, the use of LLMs for programming education also raises some concerns and challenges that need to be addressed. One of the main concerns is related to bias and quality of the data used to train the LLMs. LLMs are only as good as the data they are fed with, and if the data is biased or inaccurate, the LLMs may produce erroneous or misleading outputs. For example, [7] reported that GPT-4, a state-of-the-art LLM that can generate code based on natural language descriptions or existing code context, often fails to handle novel or complex code scenarios. Moreover, LLMs may inadvertently perpetuate stereotypes or favor certain perspectives based on the data they are trained on. Educators and developers need to be vigilant in addressing bias and ensuring fairness and quality in LLMs.

Another concern is related to privacy and security of the data used by the LLMs. Programming education often involves sensitive data, such as personal information, learning patterns, or intellectual property. LLMs may access and process such data without proper consent or protection measures. This may pose risks to learners' privacy rights and data ownership. Educators and developers need to implement robust data protection measures, such as anonymization, encryption, auditing, and explainability.

A third concern is related to pedagogical effectiveness and ethical implications of using LLMs for programming education. While LLMs offer promising possibilities for enhancing learning outcomes and experiences, they may also undermine learners' understanding and creativity if they are used as a replacement rather than an aid for programming education. Learners may rely too much on the LLMs to solve their problems without developing their own problem-solving skills or critical thinking abilities. Moreover, LLMs may create a false sense of competence or confidence in learners who may not be able to handle novel or challenging situations without the help of the LLMs. Educators need to evaluate the integration of LLMs within existing instructional methods, ensuring they complement rather than replace human interaction and guidance. [8, 9, 10]

3. Methodology

In this section, we provide a detailed description of the design and implementation of our system, which utilizes Large Language Models (LLMs) [12, 13, 14] in the backend and a Python interpreter application in the frontend to create an interactive and personalized learning environment for programming education.

Our system comprises three main components: the frontend, the backend, and the LLM. The frontend is a web-based application that offers a user-friendly interface for learners to write and execute Python code within a conversational environment. Powered by JavaScript, the frontend leverages CodeMirror, a versatile code editor package that supports advanced features like syntax highlighting, auto-completion, and code folding. To enable learners to execute Python code directly in the browser, we employ Pyodide—a Python scientific stack compiled to WebAssembly. Pyodide allows learners to run Python code seamlessly without requiring any software installation or environment setup on their local devices.

The backend, implemented using Flask, serves as a communication bridge between the frontend and the LLM. Flask, a lightweight web framework written in Python, facilitates the development of web applications with minimal code. In our system, the backend receives the code written by learners in the frontend and forwards it to the LLM for inference. Subsequently, the backend collects the output generated by the LLM and sends it back to the frontend for display.

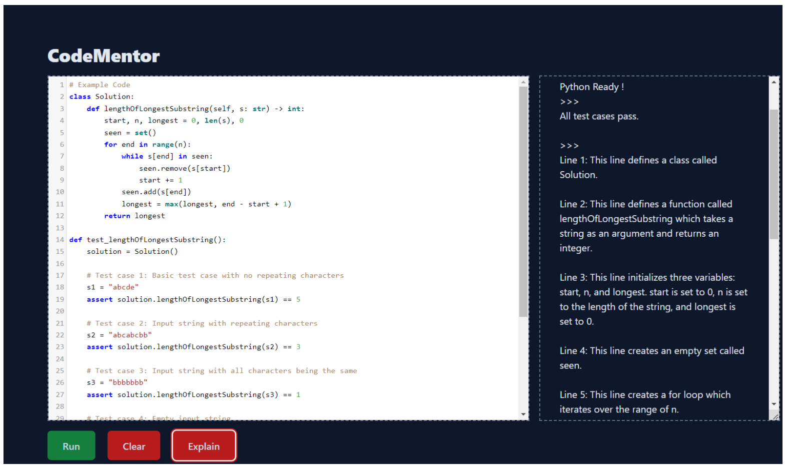
The LLM, based on OpenAI's GPT-3 Davinci model, forms the core of our system. GPT-3 Davinci is one of the most advanced and powerful LLMs available, boasting an impressive 175 billion parameters and being trained on a diverse corpus of text data from multiple sources, including books, websites, news articles, and social media posts. Leveraging the contextual understanding and language generation capabilities of GPT-3 Davinci, our system utilizes the LLM to provide learners with tailored feedback, hints, and explanations based on their code and queries. Additionally, we harness the LLM to generate code snippets or solutions by interpreting learners' natural language specifications or descriptions.

To interact with our system, learners are required to register and log in using their credentials. Upon logging in, learners gain access to a curated selection of topics or exercises related to Python programming. Each topic or exercise encompasses a comprehensive description, a sample code snippet, and a set of instructions or questions for learners to complete. Within the code editor area, learners can write their own code and execute it using Pyodide. The chat area enables learners to ask questions, seek feedback, or engage in natural language conversation with the LLM. In response, the LLM generates contextually appropriate texts or provides code snippets/solutions based on the learners' inputs.

Our system strives to deliver an engaging and personalized learning experience for programming education by harnessing the capabilities of LLMs in generating natural language texts and code. Moreover, it fosters co-creation of educational partnerships between humans and AI by enabling learners to interact with the LLM in a conversational manner, promoting active engagement and knowledge acquisition.

4. Discussions

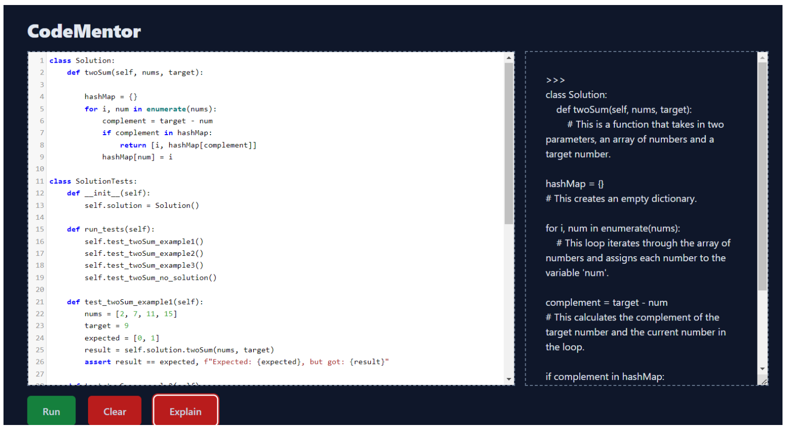
In this paper, we have presented a novel system that leverages LLMs in the backend and a Python interpreter application in the front end to create an interactive and personalized learning environment for programming education. Our system allows learners to write and run Python code in a conversational interface, where they can receive feedback, hints, and explanations from the LLMs. We have also designed and implemented various mechanisms to evaluate the quality and relevance of the LLM-generated content, as well as to ensure the ethical and responsible use of LLMs as communication interfaces in educational settings. We have conducted a user



```python
# Example Code
class Solution:
    def lengthOfLongestSubstring(self, s: str) -> int:
        start, n, longest = 0, len(s), 0
        seen = set()
        for end in range(n):
            while s[end] in seen:
                seen.remove(s[start])
                start += 1
            seen.add(s[end])
            longest = max(longest, end - start + 1)
        return longest

def test_lengthOfLongestSubstring():
    solution = Solution()

    # Test case 1: Basic test case with no repeating characters
    s1 = "abcde"
    assert solution.lengthOfLongestSubstring(s1) == 5

    # Test case 2: Input string with repeating characters
    s2 = "abcabcbb"
    assert solution.lengthOfLongestSubstring(s2) == 3

    # Test case 3: Input string with all characters being the same
    s3 = "bbbbbbb"
    assert solution.lengthOfLongestSubstring(s3) == 1

    # Test case 4: Empty input string
```

```
Python Ready !
>>>
All test cases pass.

>>>
Line 1: This line defines a class called
Solution.

Line 2: This line defines a function called
lengthOfLongestSubstring which takes a
string as an argument and returns an
integer.

Line 3: This line initializes three variables:
start, n, and longest. start is set to 0, n is set
to the length of the string, and longest is
set to 0.

Line 4: This line creates an empty set called
seen.

Line 5: This line creates a for loop which
iterates over the range of n.
```

Figure 1: Sample Output for longest consecutive sequence without repeating characters problem.



```python
class Solution:
    def twoSum(self, nums, target):

        hashMap = {}
        for i, num in enumerate(nums):
            complement = target - num
            if complement in hashMap:
                return [i, hashMap[complement]]
            hashMap[num] = i

class SolutionTests:
    def __init__(self):
        self.solution = Solution()

    def run_tests(self):
        self.test_twoSum_example1()
        self.test_twoSum_example2()
        self.test_twoSum_example3()
        self.test_twoSum_no_solution()

    def test_twoSum_example1(self):
        nums = [2, 7, 11, 15]
        target = 9
        expected = [0, 1]
        result = self.solution.twoSum(nums, target)
        assert result == expected, f"Expected: {expected}, but got: {result}"

```

```
>>>
class Solution:
   def twoSum(self, nums, target):
      # This is a function that takes in two
parameters, an array of numbers and a
target number.

hashMap = {}
# This creates an empty dictionary.

for i, num in enumerate(nums):
   # This loop iterates through the array of
numbers and assigns each number to the
variable 'num'.

complement = target - num
# This calculates the complement of the
target number and the current number in
the loop.

if complement in hashMap:
```

Figure 2: Sample Output for finding two numbers from list that form a target sum problem

study with novice Python learners to evaluate the usability, effectiveness, and satisfaction of our system. Our results show that our system can enhance learners' engagement, motivation, and learning outcomes, as well as foster co-creation of educational partnerships between humans and AI.

Our work has several implications and limitations that we would like to discuss in this section. First, our work demonstrates the potential of LLMs in programming education, as they can generate natural language texts and code that are both accurate and efficient, based on natural language prompts or specifications. However, LLMs are not perfect and may produce errors or irrelevant outputs that can confuse or mislead the learners. Therefore, it is important to provide mechanisms to monitor and evaluate the quality and relevance of the LLM-generated content, as well as to provide guidance and feedback to help learners understand and improve upon the content. Moreover, it is important to develop competencies and literacies for both teachers and learners to understand the technology as well as their limitations and unexpected brittleness.

Second, our work shows the possibility of creating an engaging and personalized learning experience for programming education by using a conversational interface that allows learners to interact with the LLMs. However, a conversational interface may not be suitable for all types of programming tasks or learners. For example, some programming tasks may require more complex or structured inputs or outputs that are not easily expressed or displayed in natural language. Some learners may prefer other modes of interaction or feedback that are more visual or auditory. Therefore, it is important to consider the design and usability of the user interface for different programming tasks and learner preferences.

Third, our work explores the idea of co-creation of educational partnerships between humans and AI by allowing learners to collaborate with the LLMs in solving programming problems. However, co-creation also poses ethical and responsible issues related to the use of LLMs as communication interfaces in educational settings. For example, how can we ensure that the LLMs respect the privacy and autonomy of the learners? How can we prevent the misuse or abuse of LLMs by malicious actors or learners? How can we promote critical thinking and creativity among learners rather than relying on LLMs for answers or solutions? Therefore, it is important to address these issues and ensure that LLMs are used in a responsible and ethical manner in education.

As directions for future research, we suggest several possible extensions and improvements for our system. First, we would like to expand our system to support other programming languages besides Python, such as Java or C++. This would allow us to reach a wider audience of learners with different programming backgrounds and interests. Second, we would like to incorporate other features or functionalities into our system, such as gamification elements, adaptive learning strategies, or peer collaboration mechanisms. This would allow us to further enhance the engagement, motivation, and learning outcomes of the learners. Third, we would like to conduct more extensive user studies with different groups of learners, such as intermediate or advanced programmers, or learners from different age groups or cultural backgrounds. This would allow us to evaluate the generalizability and scalability of our system across different contexts and scenarios.

5. Conclusions

In this paper, we have presented a novel system that leverages LLMs in the backend and a Python interpreter application in the front end to create an interactive and personalized learning environment for programming education. Our system allows learners to write and run Python code in a conversational interface, where they can receive feedback, hints, and explanations from the LLMs. We have also designed and implemented various mechanisms to evaluate the quality and relevance of the LLM-generated content, as well as to ensure the ethical and responsible use of LLMs as communication interfaces in educational settings.

Our work has several implications and limitations that we have discussed in the previous section. We have also suggested several directions for future research on LLM-based educational systems. We hope that our work can inspire more research and development on the potential and challenges of LLMs in programming education, as well as in other domains and tasks related to natural language processing and generation.

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