

Digital transformation in engineering education: Exploring the potential of AI-assisted learning

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This research explored the potential of artificial intelligence (AI)-assisted learning using ChatGPT in an engineering course at a university in South-east Asia. The study investigated the benefits and challenges that students may encounter when utilising ChatGPT-3.5 as a learning tool. This research developed an AI-assisted learning flow that empowers learners and lecturers to integrate ChatGPT into their teaching and learning processes. The flow was subsequently used to validate and assess a variety of exercises, tutorial tasks and assessment-like questions for the course under study. Introducing a self-rating system allowed the study to facilitate users in assessing the generative responses. The findings indicate that ChatGPT has significant potential to assist students; however, there is a necessity for training and offering guidance to students on effective interactions with ChatGPT. The study contributes to the evidence of the potential of AI-assisted learning and identifies areas for future research in refining the use of AI tools to better support students' educational journey.

Implications for practice or policy

- Educators and administrators could review the usage of ChatGPT in an engineering technology course and study the implications of generative AI tools in higher education.
- Academics could adapt and modify the proposed AI-assisted learning flow in this paper to suit their classroom.
- Students can review and adopt the proposed AI-assisted learning flow in this paper for their studies.
- Researchers could follow up on the application of ChatGPT in teaching and learning: teaching quality and student experience, academic integrity and assessment design.

Keywords: ChatGPT, generative AI, digital transformation, engineering education, AI-assisted learning, personalized learning, adaptive learning

Introduction

Digital transformation is revolutionising various industries, and education is no exception (Dąbrowska et al., 2022; Oliveira & de Souza, 2022). In the field of education, there is a growing interest in harnessing the potential of artificial intelligence (AI)-assisted learning to enhance the teaching and learning experiences (Berry et al., 2020; Costan et al., 2021). AI technologies offer promising opportunities to optimise engineering courses, enabling students to gain a deeper understanding of complex concepts and develop practical skills through personalised and interactive learning experiences (Alnaqbi & Fouda, 2023; Emenike & Emenike, 2023). This paper aims to explore the potential of AI-assisted learning in engineering courses and its implications for digital transformation in engineering education. By examining the current landscape, discussing the benefits and challenges and showcasing real-life examples, this study aims to shed light on the transformative power of AI in engineering education and inspire educators to embrace innovative approaches that can better prepare future engineers for the demands of a rapidly evolving technological landscape.

Generative AI tools, like ChatGPT, utilise advanced natural language processing and machine learning algorithms to understand and generate human-like responses in real time (Alnaqbi & Fouda, 2023; Benuyenah, 2023). This capability opens exciting possibilities for interactive and adaptive learning environments where students can engage in dynamic conversations, ask questions and receive instant feedback from AI-powered virtual assistants (Gašević et al., 2023; Geerling et al., 2023). These AI tools

can offer personalised guidance, facilitate problem-solving, and provide additional resources to support students' individual learning needs (Baidoo-Anu & Owusu Ansah, 2023; Fergus et al., 2023).

The birth of generative AI tools represents a significant shift in education, moving away from traditional one-size-fits-all approaches towards a more student-centred and immersive learning experience (Gregorcic & Pendrill, 2023). By leveraging the power of AI, educational institutions can tap into vast amounts of data and educational resources to create intelligent systems that adapt to students' preferences, learning styles and progress (Karaali, 2023; D. Liu & Bridgeman, 2023; Ong & , 2023). This personalised approach to education has the potential to unlock students' full potential and improve learning outcomes (Halaweh, 2023).

Although AI-assisted learning has been extensively studied in fields such as medicine, business and social sciences, there is a lack of research on its application in programming and engineering courses (Emenike & Emenike, 2023; Gilson et al., 2023; Ivanov & Soliman, 2023). It is important to test generative AI tools, like ChatGPT, in these domains as they may encounter unique challenges. The technical nature of programming and engineering requires precise understanding and tailored feedback (Khan & Abid, 2017). Investigating the performance of ChatGPT in these courses helps identify its limitations and guides the development of specialised AI models. This research is essential for ensuring effective AI support in programming and engineering education (Dwivedi et al., 2023; Shoufan, 2023).

In this study, we evaluated the potential of using ChatGPT as an AI-assisted learning tool for students in an introductory course on embedded systems. We completed 15 selected questions of various types, assessed the responses from ChatGPT and distilled them as lessons learned for further investigation. Although AI-assisted learning has shown promise in various educational domains, its effectiveness in the context of technical subjects like embedded systems remains largely unexplored (Alnaqbi & Fouda, 2023; Johnke et al., 2023). By investigating the use of ChatGPT in this specific course, we sought to assess its ability to provide valuable insights, personalised support and interactive learning experiences to students. This experiment sheds light on the potential benefits and limitations of ChatGPT as an AI tool in the field of embedded systems education, paving the way for innovative and enhanced learning approaches in technical disciplines (Emenike & Emenike, 2023).

This study makes two key contributions. Firstly, it addresses a research gap by evaluating the potential of ChatGPT as an AI-assisted learning tool in a specific course – Introduction to Embedded Systems (Lodge et al., 2023). This expands the knowledge of AI-assisted learning in technical subjects. Secondly, more broadly, the study advances innovative and personalised learning approaches in engineering education, providing insights for educators and researchers in similar fields. The findings inform the development of tailored AI systems and instructional strategies, enhancing student learning outcomes in technical disciplines.

Related works

Peer-assisted learning

Peer-assisted learning (PAL) includes different teaching methods like near-peer teaching, where higher-year students teach lower-year students, and peer-to-peer teaching, where students at the same level take turns as tutors and tutees (Brierley et al., 2022). From a pedagogical perspective, peers serve as supplementary educators to support faculty lecturers in significantly enhancing students' comprehension of course materials (Edwards & Bone, 2012). Beyond their role as instructors, peer tutors can also act as motivators for tutees, helping them achieve a deeper understanding of course content and fostering the development of interpersonal and social skills (Wadoodi & Crosby, 2002).

In the dynamics of peer interaction, peer feedback and peer assessment emerge as pivotal pedagogical strategies. They nurture a culture of reflective practice and continuous improvement. The reciprocal nature of feedback and assessment in PAL fosters a sense of ownership and responsibility towards

collective learning goals. Additionally, cooperative learning strategies further enrich the learning environment by promoting active engagement, problem-solving and critical thinking among peers (Li & Stone, 2018).

PAL is a highly effective study technique that taps into the collaborative potential of students, resulting in enhanced learning outcomes (Fogarty et al., 2022). One of the key advantages of PAL is its ability to foster a deeper understanding and retention of knowledge (Nortcliffe et al., 2022). Through engaging in discussions and exchanging ideas with their peers, students are exposed to different perspectives and interpretations of the subject matter (B. Liu et al., 2021). Furthermore, when students take on the role of teaching or explaining concepts to their fellow peers, it solidifies their own understanding, reinforcing their grasp of the subject and improving long-term retention (Blake & Liou-Mark, 2014).

In engineering education, the collaborative and problem-solving-oriented nature of PAL resonates well with the inherent demands of engineering courses. The shared exploration of engineering concepts, principles and practices under the PAL framework cultivates a conducive learning environment. It not only enhances the understanding of engineering principles but also fosters the development of essential skills such as teamwork, communication and problem-solving, which are indispensable in the professional realm of engineering (Power & Dunphy, 2010)

In addition to academic benefits, PAL also nurtures valuable communication and interpersonal skills (Gonglewski & Baker, 2021). Collaborative learning activities, such as group discussions, presentations and joint projects, stimulate critical thinking, encourage active problem-solving and facilitate a broader comprehension of the material being studied (Ryder et al., 2017). These skills are not only crucial for academic success but also transferable to real-world scenarios, where effective collaboration and communication are highly valued in both professional and personal contexts (Alpay et al., 2010).

However, there are some problems with PAL (Johns-Boast & Flint, 2013). PAL comes with its share of challenges that educators need to address for its successful implementation (Glassey & Russo Abegao, 2018). Discrepancies in knowledge and learning abilities among students can hinder effective explanations and pace within the group (Johns-Boast & Flint, 2013). Group dynamics and conflicts may arise, impacting the learning environment, and educators should foster a positive atmosphere with conflict resolution strategies (Blake & Liou-Mark, 2014). Overdependence on peers can hinder independent thinking, and time management can pose challenges in coordinating collaborative activities. By recognising and proactively managing these issues, PAL can be optimised to create an inclusive and supportive learning environment (Brake & Curry, 2016).

AI-assisted learning

AI-assisted learning integrates AI technologies into education to enhance the learning experience (Lai, 2021). Through personalised learning pathways, AI analyses student data and tailors instruction to meet individual needs. Intelligent tutoring systems provide personalised guidance and feedback, while adaptive learning platforms adapt to students' progress and offer real-time recommendations (Wu et al., 2022). AI automates grading and assessment processes, freeing up time for educators to provide targeted feedback. Virtual assistants and chatbots powered by natural language processing support student enquiries and foster independent learning (Chen et al., 2022). Additionally, AI generates educational content and provides data-driven insights for instructional improvement (Zou et al., 2023). Although ethical and privacy considerations must be addressed, AI-assisted learning has the potential to revolutionise education by personalising instruction, enhancing engagement and optimising learning outcomes (Cheng et al., 2020).

AI-assisted learning has been implemented in various ways to enhance education. Adaptive learning platforms like Khan Academy and Duolingo use AI algorithms to personalise content and exercises based on individual student needs (Lai, 2021). Carnegie Learning's Cognitive Tutor is an intelligent tutoring system that provides personalised instruction and feedback (Aleven et al., 2023). Automated essay scoring systems such as Turnitin utilise AI to assess and grade essays efficiently (Moodley & Nhavoto, 2023).

Chatbots and virtual assistants like IBM Watson Assistant and Microsoft's Xiaoice offer personalised support and guidance to students (X. Liu et al., 2022). These real-world examples demonstrate the diverse applications of AI in education, empowering learners with personalised learning experiences, efficient assessments and interactive tools for improved outcomes (Glassey & Russo Abegao, 2018; Strzelecki, 2023).

Although there has been extensive application of general AI technologies in higher education across various disciplines, including science, mathematics, arts, language, engineering (including computer courses), health and medical fields, business and management (Chu et al., 2022), few studies have focused on generative AI chatbots specifically in higher education (Qadir, 2023). For instance, Wang et al. (2023) engaged in an insightful investigation into the interaction dynamics between students and AI in English as a Foreign Language learning. Their study delineated distinct patterns of interaction and posited that a deeper engagement with AI-supported learning can considerably enhance the personalised guidance afforded by AI. Although set in a language learning context, the implications of their findings resonate with the broader theme of fostering a productive interaction between students and AI tools in engineering education, where language and code often intertwine.

Given that many engineering courses incorporate programming components, it is crucial to review studies that have applied generative AI tools in teaching programming courses. In fact, the early version of ChatGPT, GPT 3.0, was used in teaching programming and offered improvement for programming productivity (Baidoo-Anu & Owusu Ansah, 2023). Recently, after being allowed to use ChatGPT 3.5 in the classroom, students from Object-Oriented Programming agreed that it can support problem-solving, improve critical thinking skills, aid in debugging and boost their self-confidence (Yilmaz & Karaoglan Yilmaz, 2023). Therefore, it is not surprising that many universities plan to adopt not only AI chatbots but also advanced programming tools like GitHub Copilot in teaching programming courses (Lau & Guo, 2023). Sun et al. (2022) delved into a critical aspect of AI application in education – the explainability of generative AI models in the context of coding. By employing scenario-based design, they uncovered users' explainability needs for generative AI in software engineering tasks such as natural language to code translation, code translation between different languages and code auto-completion. Their exploration accentuates the importance of understanding the operations of generative AI models, which is crucial for harnessing AI capabilities in an educational setting, especially in code-related tasks, which are inherent in engineering courses.

This study aimed to expand beyond programming courses and investigate the usage of ChatGPT in a course involving hardware components – Introduction to Embedded Systems.

Methodology

To conduct this study, we selected an engineering course in the Bachelor of Engineering programme at a university in a South-east Asian country. It is worth mentioning that ChatGPT is not officially available in the country; however, there is clear evidence of significant usage by students from universities (Linh, 2023; SGGP, 2023; Spencer, 2023). Introduction to Embedded Systems aims to introduce first- and second-year students to the concept of embedded systems and teach them how to design using both hardware and software. We chose this course primarily due to its popularity as one of the most common courses in electronic, electrical, computer and robotics-based engineering programmes. By optimising the course development and delivery, it can further assist early-year students in building a strong foundation for later relevant technical courses in their studies. Additionally, the course requires students to work with electronic boards and measurement hardware, providing an opportunity to explore the applicability of ChatGPT in a context that goes beyond the traditional programming content of engineering course. Some questions and exercises in the course require definite solutions that can be operated on the hardware, which is a useful indication to inform learners of the end goals and instruct them to keep trying generative AI tools until they succeed.

This study utilised ChatGPT 3.5, hereafter referred to as ChatGPT for conciseness. Although the free version of ChatGPT is not available in the country, the paid version, ChatGPT Plus, is open for registration. Since we cannot require students to use the paid version, the study involved only the lecturer in charge, who subscribed to ChatGPT Plus. The decision to select ChatGPT-3.5 over ChatGPT-4.0 was intentional, as it anticipates that when the tool becomes accessible to the public, students are more likely to opt for the free version. The qualitative insights gathered from the lecturer's use of ChatGPT, through observational methods and reflective discussions, provided a foundational understanding of how AI-assisted learning could be employed in embedded systems education. Although the findings are primarily from the lecturer's perspective, they form a basis for the ongoing study involving student participants, aimed at further exploring the practical implications and benefits of AI-assisted learning in this context.

To systematically examine and document the capability of ChatGPT, we developed an AI-assisted learning flow for learners, as described in Figure 1. Firstly, questions and exercises that were not ChatGPT applicable, such as tasks involving graphical illustration or personal information were not used. An initial prompt with contexts and description was important, and hence the proposed flow recommended that users spend more effort on this step. There were three levels of validation: checking for answers in the context of the question, validating the actual code manually, and finally verifying the accuracy of the code by deploying it on an electronic board used in this course (i.e., Arduino Uno). For each level, if the answers were not satisfactory, we rephrased the questions, added more details and descriptions, provided contexts and even needed to challenge ChatGPT until an acceptable answer was received. For theory-based questions, the validation was completed by comparing the answers from ChatGPT with existing solutions or sources provided by the lecturer. It is critical to mention that between attempts, for many cases, users might go through the process of manually analysing and troubleshooting the issues or errors. This is an important step for learners to achieve the learning outcomes through practice. As part of the submission process, besides a technical report, the flow recommends that students include a reflective journal to provide a detailed account of their utilisation of ChatGPT to accomplish the task. This document will aid lecturers in evaluating how AI tools are used specifically.

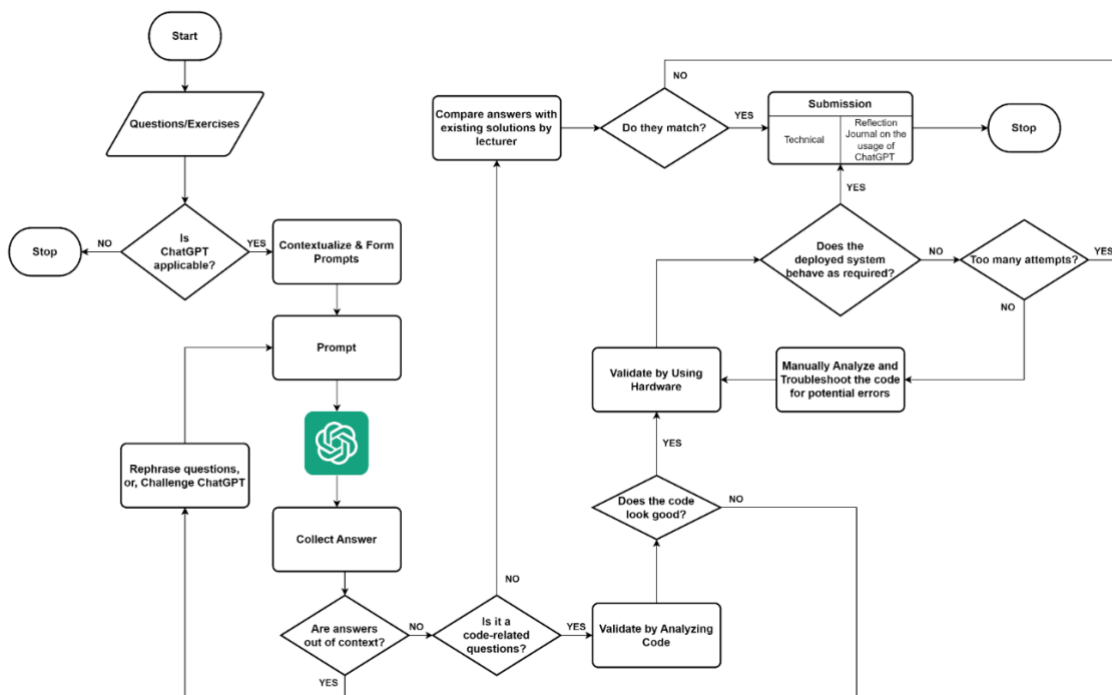


Figure 1. Proposed flow of using ChatGPT in assisting learning

We identified and produced prompts for 15 questions and exercises from the class materials. We categorised them into various levels, as indicated in Table 1. They ranged from simple and straightforward

tasks to more complex ones with hardware verification required. As ChatGPT accepted only text-based inputs as of the version we tested on 24 May 2023, we rephrased the questions to improve their context. We completely rewrote any original questions with either description or requirements involving graphical illustrations. Finally, we incorporated a selection of assessment questions and exercises (Category 4) that followed a similar flow as in tutorial questions. We modified the assessment questions presented in this paper to conceal the original questions while maintaining sufficient detail to test the capability of ChatGPT in providing solutions. The inclusion of questions in Category 4 was essential in evaluating whether existing assessments needed to be redesigned to ensure they were ChatGPT-proof, if necessary.

Table 1

Categories of questions and exercises

No.	Category	Description
1	Theory questions: definition, categorisation, critical analysis and calculation	These questions are designed to assess students' understanding of specific definitions. Students are evaluated based on their ability to demonstrate, explain and critically analyse the provided information.
2	Programming questions: code snippets for a simple requirement, a full code for complex tasks or specifications	These questions require students to write either a small code snippet or a complete code (100–200 lines of code) in the C programming language to fulfil a given requirement. These questions allow for the assessment of programming skills, including the appropriate use of programming syntax, relevant central processing unit registers and values.
3	Exercises: Complex full code to accomplish a task executable on an actual electronic board, which may involve measurements	These exercises involve developing full code that can be executed on an electronic board. The verification might involve some measurements using laboratory instruments. Specifically, this course utilises the Arduino (2021) board, a well-known embedded platform widely used for studying, and industries over the past 20 years.
4	Assessment programming exercise	The exercises in this category are more sophisticated requiring slightly longer solutions and combine knowledge and skills from various weeks instead of one, as in Category 3. These exercises ask students to validate their solutions using hardware verification and measurement.





In this study, the course's primary lecturer (with 10 years of developing and teaching such a course) acted as the main user in the flow described in Figure 1. Unedited answers were collected, assessed and questions would be revised where necessary. The whole process was repeated for all 15 questions and exercises. In addition to completion of the flow, for each question, we analysed the answer in terms of their alignment with the context, accuracy, potential for assisting learners and their potential impact on the course's development and delivery from the perspective of the lecturer. Finally, we report and discuss the results in the Findings and discussion section.

Findings and discussion

Questions and ChatGPT responses

In this section, we present three sample questions and analyse the structure of the answers from ChatGPT (see Table 2). The question indexes are taken from the full list of question (Table A1 in Appendix A). We also conducted some demonstrations to showcase the usage of ChatGPT (detailed in Appendix B).

Table 2
 Sample questions and answers from ChatGPT

No.	Screenshot of questions and responses from ChatGPT
3	<p data-bbox="336 376 991 421">  What are two features from the thermostat example above that made them to be an embedded system</p> <p data-bbox="336 483 1129 506">  Two features of the thermostat example that classify it as an embedded system are:</p> <ol data-bbox="395 533 1054 808" style="list-style-type: none"> 1. Specific Functionality: The thermostat is designed with a specific purpose, which is to control the temperature in a building. It performs dedicated tasks related to temperature monitoring, processing sensor data, and controlling heating or cooling equipment. The embedded system is tailored to fulfill this specific functionality efficiently and reliably. 2. Integration into a Larger System: The thermostat is integrated into a larger system, such as a heating, ventilation, and air conditioning (HVAC) system or a smart home automation system. It interfaces with other components or devices, receives input from temperature sensors, and communicates with the heating or cooling equipment to maintain the desired temperature. The embedded system's functionality is tightly integrated and interacts with the broader system it is a part of. <p data-bbox="395 835 1018 913"> These two features highlight the specialized nature and purpose of embedded systems. They are designed to perform specific tasks, often with real-time requirements, and are integrated into larger systems to fulfill their intended function effectively.</p>
10	<p data-bbox="336 992 1086 1048">  For the above program, if I wanna to measure the output waveform using a Virtual Bench, how can I connect? Which wires do I need to connect to which pin?</p> <p data-bbox="336 1144 1075 1200">  To measure the output waveform of the LED using a Virtual Bench, you can connect the Virtual Bench's probes as follows:</p> <ol data-bbox="395 1227 1078 1346" style="list-style-type: none"> 1. Connect the ground (GND) probe of the Virtual Bench to the ground (GND) pin of the Arduino board. 2. Connect the channel 1 (CH1) probe of the Virtual Bench to the pin where the LED is connected (in this case, pin 13). <p data-bbox="395 1373 1107 1458"> This setup will allow you to measure the voltage waveform of the LED on pin 13 using the Virtual Bench. Make sure to set the Virtual Bench to the appropriate voltage range and time scale to capture the blinking LED waveform accurately.</p>

15

Prompt(Question/Exercise)

R Write a register-based program for Arduino Uno using the Atmega328p Microcontroller. The program interfaces with a single button connected to PORTD2, which is configured as an external interrupt pin (INT0) with a pull-up resistor configuration. Additionally, there is an LED connected to PORTB0 with source configuration.

The program's functionality is as follows: when the button is pressed, an external interrupt request is triggered and sent to the microcontroller. The program responds to this interrupt by controlling the LED to generate a specific pattern only one time then stop. The pattern consists of three intervals where the LED remains on for 1 second and then turns off for 1 second. This is followed by two intervals where the LED is on for 0.5 seconds and then off for 0.5 seconds. Finally, the LED is turned off completely.

To accurately manage the time delays for the mentioned intervals, the program utilizes the Timer 1 interrupt with a suitable scaling range. Additionally, it employs the external interrupt with falling edge detection to handle the button press effectively.

a.Coding answer

Certainly! Here's a register-based program for Arduino Uno using the Atmega328p Microcontroller that fulfills the mentioned requirements:

```

cpp
Copy code

#include <avr/io.h>
#include <avr/interrupt.h>

volatile uint8_t pattern_counter = 0; // Counter to track the pattern state

void setup()
{
    DDRB |= (1 << PORTB0); // Configure PORTB0 (LED) as an output
    PORTD |= (1 << PORTD2); // Enable internal pull-up resistor on PORTD2 (B
    EICRA |= (1 << ISC01); // Set INTO to trigger on falling edge
    EIMSK |= (1 << INT0); // Enable external interrupt INT0
    TCCR1B |= (1 << CS12) | (1 << CS10); // Set Timer 1 prescaler to 1024
    sei(); // Enable global interrupts
}

void generatePattern()
    
```

b.Coding explanation

This program sets up the Arduino Uno to work with the Atmega328p microcontroller. It configures PORTD2 as an external interrupt pin (INT0) with a pull-up resistor configuration for the button input. PORTB0 is configured as the LED output. When the button is pressed, the external interrupt is triggered, and the program generates the specified LED pattern. The pattern consists of three intervals where the LED is on for 1 second and then off for 1 second. This is followed by two intervals where the LED is on for 0.5 seconds and then off for

Question 3 (Category 1) is a theory text-based question. ChatGPT was able to list significant characteristics of a particular technical term. Users can extract the texts from the answers and check their accuracy by comparing with the solution from the class notes.

Question 10 (Categories 3 & 4) demonstrate an example when users consult ChatGPT for how to set up their measurement equipment and perform the task to confirm the accuracy of the provided code. Such a setup can be seen in Figure 2. This approach is essential for students to confirm if they have finally achieved the functional specification, as indicated in Figure 1.

Question 15 (Category 4) demonstrates an example when users consult ChatGPT on a coding question. The answer includes a code window with a “Copy” button allowing users to transfer to their target integrated development environment (see Figure 3). Additionally, an accompanying short code explanation can be used to explain the construction of the code. The code explanation is the significant tool for instructing users about the code.

Question 15 is an assessment-level exercise; it requires students to code and complete the requirements using knowledge gained from multiple course topics and showcase workable hardware. We rewrote the

description of the system from a shorter version in the original class note, where graphical illustrations are translated into descriptive texts.

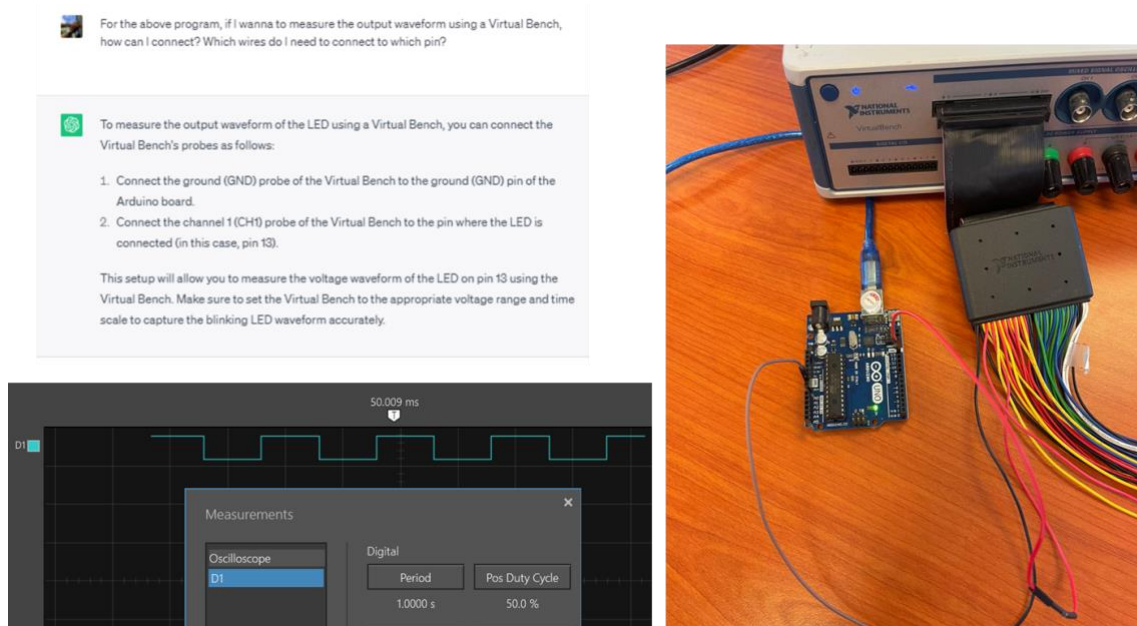


Figure 2. Instructions on how to set up measurement provided by ChatGPT (top left), the actual setup (right), and the resulting waveform confirming the system is working

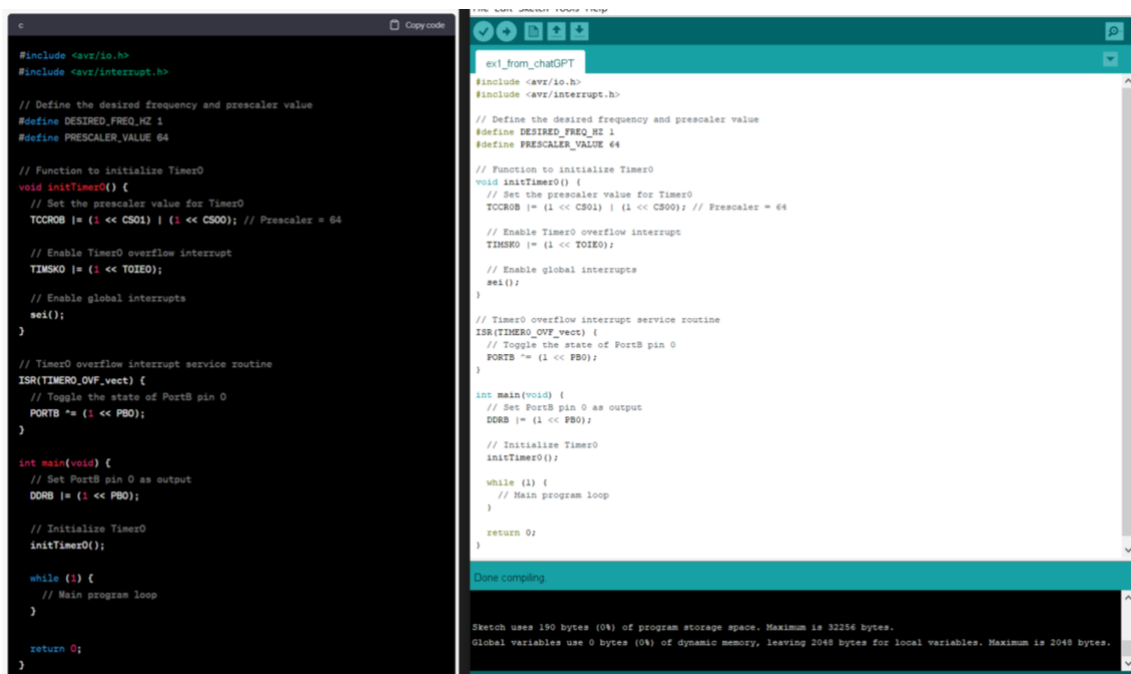


Figure 3. A sample code generated by ChatGPT being transferred to the Arduino integrated development environment and compiled successfully (i.e., syntax error-free)

Evaluating the answers provided by ChatGPT

In this section, we will discuss the lecturer's evaluation of the usability of the answers provided by ChatGPT for the course. The evaluation is provided for the first two iterations of each answer. We

developed and used the rating in Table 3 to systematically assess the answers from Table A1 (Appendix A). The final rating is summarised in Table 4.

Table 3
Definition of evaluation rating

Rating	Description
I (invalid)	The answer is not relevant or out of context, which needs rephrasing, recontextualising and redoing.
A (applicable)	The answer is clear and correct.
C (close)	The answer is clear and close, but changes in prompts are still required (via rephrase, more context or challenging ChatGPT).
M (misleading)	The answer is clear, but the code contains misleading information (e.g., value of variables is unrealistic). Users must provide context, challenge ChatGPT to correct the misleading information in the next iteration.
F (functional)	The answer is clear, the final code is functional on the designated hardware and meets the requirements.
U (unsuccessful)	The answer cannot be reached after so many attempts.

Table 4
Evaluation of ChatGPT answers

Question or prompt no.	Category	Evaluation rating
1	1	A
2	1	A
3	1	A
4	1	A
5	1	A
6	1	A
7	2	A
8	2	C
9	2	C
10	3	M
11	3	A
12	3	C
13	3	C
14	4	C
15	4	C

Following are brief discussions on the above results:

- First, there are no I (invalid) rating for any prompts. This could be explained by the prompts from the lecturer being specific enough and full of context. This, however, should be expected from students in their first trials.
- ChatGPT can produce good results for standard theory questions in the form of a definition (2, 5 & 11), identification (3 & 4) and multiple-choice question (6).
- Because of their hardware-specific nature, the answers for most of the coding and calculation questions are close but need refinement. For complex questions (14 & 15), there are multiple follow-ups and challenges to ChatGPT.
- Measurement question 10 initially produced a misleading answer. After some rephrasing, ChatGPT was able to produce better instructions for users. This can be seen from minutes 2:11 to 3:50 in the demonstration video mentioned in Appendix B.
- Although the code generated by ChatGPT was acceptable, our study suggests that learners still need to make minor edits in the code to guarantee successful hardware verification.
- All the questions above were eventually answered either A for theory questions or F for coding-related questions after multiple attempts and refinements.

Discussion

The first recommendation of this research is that lecturers should examine their courses against the usage of ChatGPT, as we have done in this study. As ChatGPT was able to produce a skeleton of the solution in the selected embedded system course, this demonstrates our assessments must be redesigned to maintain academic integrity. This should be applicable for all lecturers, even those who might not include ChatGPT in course delivery. Techniques for designing ChatGPT-proof assessments can be explored (Jacobs, 2023; Sayers, 2023).

On the positive side, this study highlights the significant potential of ChatGPT as an effective tool for assisting students in an introductory course on embedded systems. The AI-powered capabilities of ChatGPT, such as providing valuable insights and personalised support, offer promising opportunities for enhancing the learning experience. However, it is important to note that the results obtained from ChatGPT can vary depending on the prompts or wording used as input. This variability can lead to inconsistent or unexpected answers, which may potentially upset students who rely heavily on ChatGPT for assistance.

Moreover, this study emphasises the need to renovate the course structure to incorporate not only core engineering topics but also additional activities focused on training students to effectively use ChatGPT. For instance, lecturers can offer hints or suggestions on the keywords, questions or prompts that yield more accurate and helpful answers. This renovation in course design will allow students to develop the skills necessary to utilise ChatGPT as a valuable tool for their learning and hence harness its full potential. The goal is to improve the learning experience, promote a deeper understanding of the subject matter and enhance their overall learning outcomes.

This research also highlights the demand for further investigation and future studies in this area to address the variations in results based on different prompts or wording used with ChatGPT and the potential impact on student satisfaction and effectiveness. This research opens opportunities for future exploration and improvement in the design and implementation of AI-assisted learning systems, ensuring their optimal utilisation and addressing the concerns and struggles that student may face.

Drawing from our research and conclusions, subsequent studies could adopt our methodology to explore the potential of generative AI in enhancing AI-supported learning for advanced embedded system courses. Moreover, ChatGPT is a generative AI that has been trained on a huge data set that includes many subject areas. Therefore, future studies could utilise our approach and investigate AI-assisted learning in other disciplines, such as economics, business or communications.

Addressing the challenges in evaluating students' responses generated with AI assistance, particularly in grading the accuracy, relevance, coherence and overall quality, necessitates a comprehensive approach. One pivotal aspect is the development of robust assessment rubrics tailored to the context of incorporating AI tools like ChatGPT. These rubrics should ensure a consistent and equitable evaluation for all students, regardless of their choice to use AI assistance. The integrity and fairness of assessments are paramount, requiring a thorough investigation and possibly an iterative development process to ensure they adequately address the nuances brought about by AI-assisted learning.

Additionally, alongside technical submissions, we propose the inclusion of a reflective journal as part of students' submissions. This journal would serve as a platform for students to articulate their process of using the AI tool, the challenges faced and the steps taken to verify the accuracy and relevance of the AI-generated responses. By evaluating students' reflective journals, lecturers can gain insights into the students' engagement with the AI tool, their critical thinking process and the learning outcomes achieved. This, in turn, can aid in assessing the overall quality and relevance of the AI-assisted responses. Moreover, alternative assessment methods such as oral presentations or technical demonstrations can also provide a more holistic understanding of students' comprehension and application of the course material in an AI-assisted learning environment.

In addition to the above valuable lessons, there are some implementation techniques from the lecture's perspective, including the following:

- An AI-assisted learning flow (as illustrated in Figure 1) can be customised for various subjects and disciplines.
- In addition to designing good prompts, learners must be able to critically evaluate the answer generated. In an actual course, students should conduct extra studies outside of ChatGPT to verify the answers, as ChatGPT can hallucinate. This should be the subject of intensive research.

Conclusion

In conclusion, the incorporation of ChatGPT or generative AI in education appears to be unavoidable. This study aimed to explore the potential of using ChatGPT as an AI-assisted learning tool in an introductory course on embedded systems. Findings suggest that students can use ChatGPT as a companion for their learning, enhancing both their learning and teaching experiences. However, it is important to gradually integrate this tool with additional modules to provide students with quick fact-checking skills, ensuring they can maximise the tools' impact. This research addresses a gap in the literature by evaluating the use of AI-assisted learning in a technical subject, contributing to the field of embedded systems education. Additionally, it advances innovative and personalised learning approaches in engineering education, providing insights for educators and researchers in similar fields.

Author contributions

Thanh Pham: Conceptualisation, Investigation, Writing - original draft, Writing – review and editing; **Binh Nguyen:** Data curation, Formal analysis, Writing – review and editing; **Son Ha:** Data curation, Formal analysis, Writing - review and editing; **Thanh Nguyen Ngoc:** Data curation, Formal analysis, Writing – review and editing.

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Appendix A – Full list of questions

Table A1

List of 15 questions and exercises

No.	Question	Category
1	What is the hex equivalent of 0b1101 1101 1101?	1
2	Give an example of a system that is classified as an embedded system.	1
3	What are two features from the thermostat example above that made them to be an embedded system?	1
4	Is a washing machine considered an embedded system or a general-purpose computer?	1
5	Describe three major components of a microprocessor unit.	1
6	What is the solution for the following multiple-choice question? "How many analog pins are used in Arduino Uno board? a) 12 b) 16 c) 8 d) 14?"	1
7	Write one line of code to configure PORTB pin 5 of Atmega328p, so that the data output register, to be 1.	2
8	What is the value of Compare Match Register of Timer1 of ATMEGA328p so that we can have 1 Hz clock out if the input clock frequency is 16Mhz?	2
9	Using the OCR1A from above, write a C program for ATMEGA328p MCU, that uses Timer1 Clear on Compare Match Interrupt to generate a 1Hz clock on PortB pin 5.	2
10	For the above program, if I want to measure the output waveform using a Virtual Bench, how can I connect? Which wires do I need to connect to which pin?	3
11	Describe two methods of debouncing buttons – one hardware-based and one software –based for buttons in embedded system.	3
12	Write a short code to debounce a button connects to PORTD0 of Atmega328p, only by adding a delay time after button is pressed using delay_ms function and the delay time is around 200ms.	3
13	We are sending letter "A" from Arduino Uno using UART TX pin – PD1 with a baud rate of 9600 bps. What is the sequence of bits we will receive from the other end on an UART receiver? Also provide an approximation in microseconds (up to 2 fractional points) for how long it takes to transmit one bit of data in this configuration.	3
14	Write a register-based program for Arduino Uno using the Atmega328p Microcontroller. The program interfaces with two LEDs connected to PORTB0 and PORTB1 with source configuration.	4
	The microcontroller controls two LEDs as like in a simple traffic light controller with only GREEN (when green light is active, it will indicate by turning on PORTB0) for 2 seconds and then turn to RED for 3 seconds (when red light is active, it will indicate by turning on the PORTB1).	

You must design this using finite state machine (FSM) design technique with two states: green_state and red_state.

To accurately manage the time delays for the mentioned intervals, the program utilises the Timer 1 interrupt with a suitable scaling range

- 15 Write a register-based program for Arduino Uno using the Atmega328p Microcontroller. The program interfaces with a single button connected to PORTD2, which is configured as an external interrupt pin (INT0) with a pull-up resistor configuration. Additionally, there is an LED connected to PORTB0 with source configuration. 4

The program's functionality is as follows: When the button is pressed, an external interrupt request is triggered and sent to the microcontroller. The program responds to this interrupt by controlling the LED to generate a specific pattern only one time then stop. The pattern consists of three intervals where the LED remains on for 1 second and then turns off for 1 second. This is followed by two intervals where the LED is on for 0.5 seconds and then off for 0.5 seconds. Finally, the LED is turned off completely.

To accurately manage the time delays for the mentioned intervals, the program utilizes the Timer 1 interrupt with a suitable scaling range. Additionally, it employs the external interrupt with falling edge detection to handle the button press effectively.

Appendix B - Demonstration of using ChatGPT

In this demonstration session, we prompted ChatGPT with questions and exercises of the topic of Timers/Counters of the Introduction to Embedded System course. The session was conducted on 14 June 2023. A video recording of the demonstration session is available at the following link:

<https://www.youtube.com/watch?v=vDLJDdODRkQ>

The chat prompts and results can be accessed via the following link:

<https://chat.openai.com/share/b7660cf3-f0eb-4b22-acab-c6e55ce7a065>