Computers and Education: Artificial Intelligence 7 (2024) 100290

Contents lists available at ScienceDirect

Computers and Education: Artificial Intelligence

journal homepage: www.sciencedirect.com/journal/computers-and-education-artificial-intelligence

AI chatbots in programming education: Students' use in a scientific computing course and consequences for learning

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ARTICLE INFO

Keywords:
AI chatbots
ChatGPT
Programming education
Pair programming
Student learning
Engineering education

ABSTRACT

Teaching and learning in higher education require adaptation following students' inevitable use of AI chatbots. This study contributes to the empirical literature on students' use of AI chatbots and how they influence learning. The aim of this study is to identify how to adapt programming education in higher engineering education. A mixed-methods case study was conducted of a scientific computing course in a Mechanical Engineering Master's program at a Eindhoven University of Technology in the Netherlands. Data consisted of 29 student questionnaires, a semi-structured group interview with three students, a semi-structured interview with the teacher, and 29 students' grades. Results show that students used ChatGPT for error checking and debugging of code, increasing conceptual understanding, generating, and optimizing solution code, explaining code, and solving mathematical problems. While students reported advantages of using ChatGPT, the teacher expressed concerns over declining code quality and student learning. Furthermore, both students and teacher perceived a negative influence from ChatGPT usage on pair programming, and consequently on student collaboration. The findings suggest that learning objectives should be formulated in more detail, to highlight essential programming skills, and be expanded to include the use of AI tools. Complex programming assignments remain appropriate in programming education, but pair programming as a didactic approach should be reconsidered in light of the growing use of AI Chatbots.

1. Introduction

Artificial Intelligence (AI) chatbots promise to enhance educational experiences and support learning processes (e.g., Caldarini et al., 2022; Essel et al., 2024; Lin et al., 2023; Okonkwo & Ade-Ibijola, 2021; Wang et al., 2021). One rapidly emerging type of AI chatbot, such as the 'Chat Generative Pre-trained Transformer' (ChatGPT), is based on generative AI technology. Generative AI can be defined as "a technology that leverages deep learning models to generate human-like content (e.g., images, words) in response to complex and varied prompts (e.g., languages, instructions, questions)" (Lim et al., 2023, p. 2). With the inevitable pervasiveness of generative AI chatbots in everyday life, including their use by students for learning (e.g., Albayati, 2024), higher education has to identify opportunities and risks of this technology, and adapt teaching and learning accordingly (Chiu, 2024; Gašević et al., 2023; Lim et al., 2023; Rudolph et al., 2023). In the domain of Science, Technology, Engineering and Mathematics (STEM) education, programming is an essential skill. AI chatbots seem a promising resource for programming education. This study therefore focuses on students' use of AI chatbots in programming education.

Opportunities for the use of AI chatbots include their potential to enhance learning experiences, supply feedback, create more personalized and interactive learning, and support students' engagement and problem-solving skills (Baidoo-Anu & Owusu Ansah, 2023; Chinoso et al., 2023; Kasneci et al., 2023; Sandu & Gide, 2019). Furthermore, chatbots are easily and 24/7 accessible, and offer immediate responses to students' inquiries (Lin et al., 2023; Okonkwo & Ade-Ibijola, 2021). Risks include a decline in higher order thinking skills and the acquisition of in-depth discipline knowledge as a result of students' (over)reliance on conversations with AI chatbots (Chinoso et al., 2023; Sánchez-Ruiz et al., 2023). Furthermore, concerns exist about the correctness of information, biases, privacy issues and declines in human interaction (Chinoso et al., 2023; Sandu & Gide, 2019; Baidoo-Anu and Owusu Ansah, 2023).

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https://doi.org/10.1016/j.caeai.2024.100290
Received 8 September 2023; Received in revised form 27 August 2024; Accepted 31 August 2024
Available online 2 September 2024

Existing empirical research on students' use of limited language model-based chatbots built for specific educational purposes, show opportunities for AI chatbots to take on various roles and tasks. For example, AI chatbots can assume roles in students' learning processes as a learning companion, teaching assistant, educator, or trainer in a specific area (Lin et al., 2023; Pérez et al., 2020), and they can take on tasks such as delivering course content, answering student questions, and providing individualized support (Okonkwo & Ade-Ibijola, 2021). Case studies covering limited language model AI chatbots used specifically for programming education illustrate how students mainly use functional questions as prompts (Verleger & Pembridge, 2018) and that chatbots could facilitate the students' learning processes and enhance their programming proficiency (Okonkwo & Ade-Ibijola, 2020).

Literature on students' use of large language model-based AI chatbots, predominantly ChatGPT, hitherto mostly consists of explorations, and projections of use, challenges, risks, and opportunities for education (e.g., Baidoo-Anu et al., 2023; Chinoso et al., 2023; Chiu, 2024; Lin et al., 2023; Sok & Heng, 2023; Steel, 2023). In an exemplary first case study, it was found that use of ChatGPT can contribute to students' development of critical thinking skills (Essel et al., 2024). In another case study, students reported a wide adoption and positive evaluation of ChatGPT to support students' learning processes (Rahman & Watanobe, 2023; Sánchez-Ruiz et al., 2023; Shoufan, 2023). However, they also reported concerns about inaccurate responses, need for sufficient prior knowledge for effective use, and concerns about negative impact on education, for example on students' development of transversal skills for future professionals.

This brief overview of current empirical research on limited and large language model-based AI chatbots shows that these chatbots can support students' learning of programming skills. The studies on limited language model-based AI chatbots suggest mainly functional use by students. Studies on large language model-based AI chatbots mainly show expected rather than measured types of use. Given the functional differences between limited language model chatbots developed for specific educational purposes (i.e., chatbots that can only answer question on a limited set of predetermined topics) and large language model chatbots (i.e., chatbots that can answer questions on any topic), such as ChatGPT, the question arises how students actually use large language model-based AI chatbots for programming education. In particular, it remains unclear if students use ChatGPT to support their learning or to create code, how they use (inaccurate) answers from the AI chatbot, or how students' use of ChatGPT affects the common practice of pair programming in programming education.

Considering the nascent state of large language model-based generative AI chatbots, and their application in educational contexts, evidence is needed on (a) how this technology is used by students, (b) how this use affects student learning, and (c) how education can be optimized as a consequence of students' use of AI chatbots. This empirical study investigates these three issues in an explorative case study in the context of a scientific computing course for mechanical engineering students at a University of Technology in [blinded for review]. The resulting knowledge is vital for designing effective learning objectives, activities, and assessments, taking into account that students can and will use AI chatbots as a resource. The aim of this study is to identify how to adapt programming education in higher engineering education following students' use of AI chatbots. The research questions for the case study are:

1. How do engineering students use AI chatbots for a scientific programming assignment?
2. How does students' use of AI chatbots influence their learning?

The results provide suggestions on whether and how to adapt learning objectives, activities, including pair programming, and assessment in programming education. The case serves as an example for a wider debate on the use of AI chatbots for teaching and learning, and on implications of AI chatbots for educational design.

2. Literature review

This literature review introduces the theoretical concepts that underpin the empirical study. The selection of theoretical concepts was based on their alignment with the technological and dialogical nature of AI chatbots. The first research question on students' use of AI chatbots for programming assignments is approached from the perspectives of attitude towards technology, digital literacy, and types of use. The second research question regarding influence on students' learning is considered through the lens of dialogue.

2.1. Students' use of AI chatbots for programming assignments

2.1.1. Attitude towards technology

Research has demonstrated a relation between attitudes towards technology and the use of technological tools for learning and teaching (Afshari et al., 2009; Potvina & Hasni, 2014). Students' attitudes towards technology in general and ICT in particular, are significantly influenced by perceived usefulness and ease of use (Edmunds et al., 2012). This connection extends to attitudes and use regarding AI in higher education (Chatterjee & Bhattacharjee, 2020), also specifically concerning AI chatbots (Malik, Sharma, Trivedi, & Mishra, 2023). It has been found that students' attitudes, perceived usefulness, and ease of use positively affect their intentions to use chatbots for educational purposes (Malik et al., 2023).

Especially in STEM related disciplines, one would expect students to have a positive or constructive critical attitude towards technology and technological innovation (Barak, 2014). The question arises how students' attitudes towards technology influence their use of AI chatbots for programming education.

2.1.2. Digital literacy

The pervasiveness of AI requires students to develop their digital literacy to use AI tools effectively and responsibly (Reddy et al., 2020; Zhai, 2022). In their current form, using AI chatbots predominantly involves formulating effective prompts to get useful answers (Zamfirescu-Pereira et al., 2023). Formulating prompts and evaluating the AI chatbot's responses require content expertise, similar to when using other online information resources (cf. Brand-Gruwel et al., 2017). While examining prompt design, Zamfirescu-Pereira et al. (2023) showed how non-experts wrote implicit, overconfident prompts directly related to their personal need. Experts in prompt design wrote explicit and cautious prompts, focusing on an achievable task. This implies that (some) content expertise is useful for students to effectively use AI chatbots for programming assignments. This raises the question whether use of AI chatbots, as an example of digital literacy, would be affected by computational thinking or existing programming skills (Yadav et al., 2017).

2.1.3. Types of use

Furthermore, current literature does not provide clear evidence yet on *how* (engineering) students use AI chatbots for programming assignments. Building on existing non-AI related literature, Rahman and Watanobe (2023) anticipate four types of use of ChatGPT for programming assignments: *error checking and debugging* by identifying errors in code and providing potential suggestions and code snippets; supporting *conceptual understanding* by providing explanations and examples of various programming concepts (e.g., data structures, algorithms, languages, and programming language syntax) in a concise, simple, and understandable manner; *solution code generation* based on a problem description; and *solution code optimization* by suggesting ways to reduce the memory usage and time complexity. The question remains how students actually use AI chatbots for programming assignments.

2.2. Use of AI chatbots and influence on student learning

AI chatbots engage in a dialogue with their user. Dialogue consists of a series of interactions between humans, or between human and machine (Moore, 1993). These (social) interactions are perceived as the essential mechanisms for knowledge acquisition and skill development (Baloian et al., 2006; Carley, 1986; Vygotsky, 1978). A series of interactions results in a shared definition of a situation or topic (Carley, 1986; Pontecorvo, 1993), which can be seen as a cognitive agreement about the situation or topic at hand (Kjaergaard & Jenson, 2014; Treku & Sun, 2019). However, reaching a shared definition can be complicated, for example when individuals talk past each other because of differences in their respective knowledge bases (Carley, 1986). Dialogue with an AI chatbot is even more complex. Whereas the interaction between humans is a two-way process with questions and answers going both ways and constant checks of each other's understanding (Moore, 1993), the interaction with an AI chatbot like ChatGPT is an unbalanced two-way process of the human asking questions and the AI chatbot supplying answers in one blob without checking understanding. For example, AI chatbots do not ask clarifying questions about unclear prompts but infer meaning and give an answer accordingly (Chinoso et al., 2023).

In the context of programming education, learning by dialogue is emphasised by pair programming in which dyads of students collaborate to develop software in the complementary roles of driver and navigator (Hanks et al., 2011). The driver is responsible for writing the code, the navigator provides assistance and reflects on the coding. Pair programming serves two didactical purposes: to learn coding best practices from peers, and to develop transversal skills. Transversal skills include strategic, creative and critical thinking, communicating and collaborating with others (Gero, 2014; Van den Beemt et al., 2020). During pair programming, students learn in dialogue, leading to a shared definition of the situation. The pervading use of dialogue- and NLP-based AI chatbots by students adds a new entity to the equation. This leads to the question how students' use of AI chatbots in pair programming affects student learning of programming and development of transversal skills. For example, concerns have been raised over declines in human interaction (Baidoo-Anu et al., 2023) and consequent declines of development of transversal skills (Kasneci et al., 2023; Sok & Heng, 2023) as a result of (over)reliance on AI chatbots.

3. Case description

The research was conducted in a Master course Scientific Computing for Mechanical Engineering. The students in this course mainly pursue a Master's degree in Mechanical Engineering, and some in Applied Physics. All students are proficient in the programming language MATLAB, which is used extensively in the bachelor's program. Most students have some experience with Python as well. A few students have experience with other programming languages, such as C, C++, and Java.

The main learning objective of the course is to train students in software development for various applications using both compiled and interpreted languages. The course covers various aspects of programming, including abstraction of data and functions, construction of datatypes, the use of tools such as Git version management, the use of libraries, code design, and testing. The programming languages used in the course are C and Python.

During the course, students organize themselves in teams of five to work on a programming assignment in C. The teams are provided with a basic version of a ray tracer program, which they must enhance with five functionalities: 1) an algorithm to smoothen tessellated surfaces, 2) new material models for shiny, opaque, transparent, and reflecting materials, 3) a new realistic camara model with a distinct focal point, 4) new light and shadow models, and 5) code optimization through parallelization and efficient algorithms to improve the calculation time. Following the pair programming principle, each student is the driver for one of the components and the navigator for another. Careful distribution of roles, preventing that a pair of students acts as each other's driver and navigator in two components, ensures distribution of knowledge on all components across the team members. The distribution of roles is organized among the team members under supervision of the teacher. The ray tracer assignment requires little specific prior knowledge. Most of the underlying models are relatively simple vector calculations. The emphasis is on the implementation of the model in the provided code. However, the fifth component, code optimization, requires some knowledge of advanced data structures. This part of the assignment is typically chosen by the more experienced programmer in a group.

The assessment of the course consists of two parts. The first deliverable is the *individual ray tracer assignment* consisting of the code for which a student was the driver, and a brief individual report. A rubric is used to evaluate the code and the report based on the following criteria: code quality and performance, description of the employed model or numerical technique, explanation of the individual code's integration into the main code, demonstration of the code through a user manual and example, assessment of code performance, and the overall quality of the report. The second deliverable consists of the *group ray tracer assignment* which includes the merged code of all group members, and group report. A separate rubric is employed to assess the quality of the provided user manual, the structure of the code, integration of various components, code execution, and the organization of the source code within a Git repository.

The course setup outlined above has been employed since 2019. After the introduction of ChatGPT to a wide audience in November 2022, the teacher encouraged the students in the 2023 iteration of the scientific computing course to use ChatGPT. The teacher's encouragement followed an open approach based on trusting relationships in a student-centred pedagogy, as suggested by Rudolph et al. (2023). This means that there were no explicit instructions for students to use ChatGPT, leaving it to the students to decide if and how to utilize ChatGPT in the course. The 10-week course ran from February to April 2023. During that period, ChatGPT-3 and -3.5 (as of March 2023) were the current versions. Following the diverse international backgrounds of students and staff, the primary language at the university is English. The course Scientific Computing for Mechanical Engineering is therefore taught in English. No information is available on which language students used in their interactions with ChatGPT.

4. Method

4.1. Participants

Participants were 29 of the 57 students and the teacher of the course Scientific Computing for Mechanical Engineering in the Spring of 2023. The course is part of the Master's program Mechanical Engineering at [blinded for review]. The students were divided into groups of five for the programming assignment, resulting in a total of 12 groups. Based on 8 years of experience by the third author as the teacher of the course, it was expected that students had different levels of programming skills at the start of the course. Participation in the study was voluntary, and the 29 students and the teacher provided informed consent by opting-in.

4.2. Data collection

Data for this mixed-method case study were collected using four methods. First, a questionnaire was administered at the end of the course to all students. The questionnaire included two parts. The first part consisted of the Technology Readiness Index Scale (TRI2; Parasuraman & Colby, 2015), an instrument consisting of the scales optimism, innovativeness, discomfort, and insecurity ($N = 29$). The TRI2 was used to assess students' attitudes towards technology. The second part consisted of questions on experience and application of AI chatbots. This second part of the questionnaire was designed specifically for this study. Closed and open questions asked students about their programming experience (i.e., new to programming, some programming experience, extensive programming experience), for which component of the programming assignment they were the driver, if and how they used AI chatbots, and how AI chatbots were helpful for the programming assignment ($N = 29$).

Second, a semi-structured group interview was conducted with three randomly selected students at the end of the course by the second author. The three students volunteered for the interview upon a request to all students in the course by the second author. The interview aimed to elicit the students' reflections on their experiences in the course in general and the use of ChatGPT in particular, and to gather their perceptions regarding engagement and development of programming skills. The full interview protocol is included in Appendix A. The interview was recorded, but the file was corrupted, leaving only the interviewer's notes from the interview.

Third, a semi-structured interview was conducted with the responsible teacher at the end of the course by the first and second author. The teacher was asked about course organisation his experiences in the course, considerations for using AI chatbots, his perceptions of students' use of ChatGPT, engagement and development of programming skills and expected changes to the course objectives, activities and assessment in response to students' use of AI chatbots. The full interview protocol is included in Appendix B. The interview was recorded, summarized by the first author, and checked by the second author.

The fourth data collection method included students' performance data consisting of grades for the two deliverables of the course: the individual and the group ray tracer assignments. The teacher graded both assignments based on two separated rubrics, as described in the case description. The performance data provided insights into students' academic achievements. These achievement data were linked to questionnaire responses of students who provided their names in the questionnaire ($n = 20$). This allowed a more comprehensive analysis of correspondence between students' academic achievements and their perceptions of technology, programming experience, and usage of AI chatbots.

Collecting data from three sources (i.e., students, teacher, performance data) using multiple methods (i.e., questionnaire, interviews) adds to source and method triangulation. The variety of methods also allowed for the collection of data from the majority of students in the course via the questionnaire and performance data, and for the collection of more in-depth information via the semi-structured interviews. Furthermore, reliability of the data collection was ensured by using the validated TRI2 questionnaire (Parasuraman & Colby, 2015), and through extensive discussion of the other qualitative instruments in the research team.

4.3. Data analysis

For the TRI2 part of the questionnaire, mean scores for each of the four scales were computed in SPSS. Each scale included four items. Cronbach's alpha for the scale Optimism was 0.784, for Innovativeness was 0.657, for Discomfort was 0.674, and for Insecurity was 0.726. Because of the small sample, TRI2 scores were only used for general observations of attitude towards technology among students.

A qualitative analysis of the answers to the open questionnaire questions on students' use and perceived helpfulness of AI chatbots, and the interviewer's notes of the student group interview was conducted following an informed grounded theory approach (Thornberg, 2012). Rahman and Watanobe, 2023 four types of anticipated use of ChatGPT for programming assignments (i.e., error checking and debugging, supporting conceptual understanding, solution code generation, and solution code optimization) served as sensitizing concepts for coding the respondents' answers. Concurrent deductive and inductive coding by the first author led to extension of the meaning of one of the sensitizing concepts, and the addition of three new concepts. The resulting codebook was used by the first and fourth author to code the data. This resulted in an intercoder agreement of 80%. The remaining encodings were discussed, and agreement was reached. The qualitative data analysis was done using Microsoft Word.

A similar qualitative analysis was conducted of the summary of the teacher interview. The developed code book was used to code students' use of ChatGPT from the teacher perspective, including an annotation whether it concerned expected or perceived use. The teachers' comments concerning student engagement and learning and expected changes to the course were condensed into comprehensive summaries in response to the research questions.

This study followed the research guidelines for social scientific studies from Eindhoven University of Technology, and the Universities of the Netherlands. The study was approved by the Ethical Review Board of Eindhoven University of Technology.

5. Results

5.1. Descriptive results

Of the 57 students in the course, 29 responded to the questionnaire. In response to a survey question on students' pre-existing programming skills, two students indicated to be new to programming, 24 to have some programming experience, and three reported to have extensive programming experience. Of the two students that were new to programming one failed the course; the other could not be linked to performance data because no name was provided in the questionnaire. The three students who reported extensive programming experience passed the course with high grades for the individual ray tracer assignment, i.e., 7.2, 7.9 and 9.6 on a scale of 10. Of the 24 students reporting some programming experience, achievements of 16 students could be combined with survey results. Of those 16 students with some programming experience, 2 students did not complete the course. Grades for the individual ray tracer assignment ranged between 3.1 and 8.6. An overview of these descriptive results of the student population is provided in Fig. 1.

The TRI2 scores in Table 1 show that the positive dimensions Optimism and Innovativeness scored highest, while Dissatisfaction scored low. The dimension Insecurity scores relatively. These results suggest that the students, as may be expected from students at a university of technology, are technology proficient and have a critically constructive attitude towards technology.

AI chatbots were used by 26 of the 29 respondents. All 26 students used ChatGPT. One of them used Bing Chat as an additional resource when ChatGPT did not provide the desired output but found that Bing Chat would not provide it either. The remaining three students reported to not have used any AI chatbot.

5.2. Research question 1: how do students use AI chatbots for a programming assignment?

Students used ChatGPT in six different ways. Four ways align with the predicted uses by Rahman et al. (2023), i.e., *error checking and debugging of code, conceptual understanding, solution code optimization,* and *solution code generation*. Concerning code generation, students use ChatGPT not necessarily to generate code for them based on a problem description, but also to translate pseudocode to code and to gain an outline, ideas, inspiration, examples or advice to generate their own code. Two added ways of use are *code explanation,* i.e., explaining the functionality of code in plain language, and *mathematical problem solving.* An overview of how students used ChatGPT for the programming assignment, including exemplary quotations from students, is shown in Table 2

Students used ChatGPT mostly to *explain code* to them in plain language. This helped students to understand the functionality or operation of a piece of code. ChatGPT was also used by students to *generate code* for

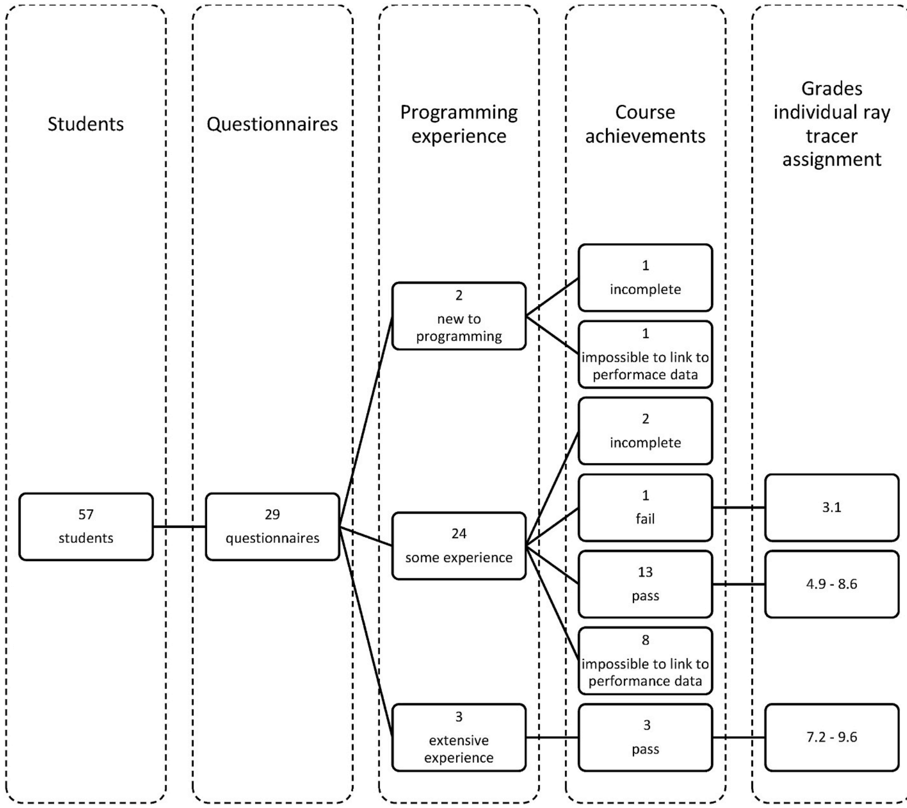

Fig. 1. Overview of descriptive results of the student population.

Table 1
Overview TRI2 scores.

Dimension	M	SD
Optimism	3.29	0.80
Innovativeness	3.90	0.62
Dissatisfaction	2.55	0.63
Insecurity	3.28	0.86

the assignment. However, students did not simply copy-paste code generated by ChatGPT. Students mentioned that ChatGPT could not solve the assignment, but that it could provide a general setup or basic pieces of code. They used those as a starting point or inspiration to write their own code. Furthermore, students utilized ChatGPT for *error checking and debugging* of their code. Students did that in two ways: by asking for how they could debug their own code themselves, and by letting ChatGPT identify errors or bugs. In case of the latter, students found that ChatGPT could mostly not resolve errors or bugs for them; students still had to fix their own code. Another way of use was to support students' *conceptual understanding* of programming. Students asked ChatGPT to explain coding concepts or techniques, or to explore advantages and disadvantages of different possibilities to write their code. In addition, ChatGPT was used by students to *optimize code*, for example by letting it rewrite (parts of) their code to simplify it or increase efficiency. Lastly, ChatGPT was used for *mathematical problem solving*. In the group interview, the students indicated that they sometimes used other internet resources (e.g., Stack Overflow, Slack) to crosscheck ChatGPT's responses.

Besides these six ways of use, students also explicitly reported how they could *not* use ChatGPT: to solve the programming assignment for them. According to the students, ChatGPT did not understand the assignment as it supplied non-useful responses.

Students' use of ChatGPT for the ray tracer programming assignment did not fully align with the expected use as reported by the teacher. He expected students to mainly use it to generate code and implement more complex models in their code. Instead, they used it mostly for questions they would also ask a tutor: to explain code, and how to clean up or debug code. The teacher's assumption is that students did not dare to outsource the code writing, or that they did not understand ChatGPT's output. According to the teacher, he himself, as an experienced programmer, can easily translate material models from ChatGPT to a piece of code, because he sees the structures and understands what they are. Students, mostly with limited programming experience, likely could not. The teacher attributes students' limited modes of use of ChatGPT also to the way it provides answers to students' queries. ChatGPT instantly provides an answer in one blob whereas other resources (e.g., Stack Overflow) require multiple tries and more extensive searches to find an answer. The teacher thinks that the latter, slower process better supports students' thinking and understanding, similar to a teacher who thinks along with a student at their pace and searches for an answer together with the student, instead of just providing the right answer straight away.

For a next run of the course, the teacher intends to support students in their use of ChatGPT as a resource for the programming assignment. He wants to encourage productive types of use, most notably error checking and debugging, code explanation and code optimization, as these types of use still require students to do their own programming. In addition, he will urge students to remain critical of ChatGPT's responses, similar to the way students are critical of other online resources, like Wikipedia. Overall, the teacher and students agree that AI Chatbots like ChatGPT are an inevitable resource that students will use for programming similar to students' use of Matlab for computations, and that student should learn to use it in effective and responsible ways instead of prohibiting its use.

5.2.1. Use and pre-existing programming skills

Students' self-reported level of pre-existing programming skills and use of ChatGPT were compared to identify connections between

Table 2
Overview of students' use of ChatGPT for a programming assignment.

Way of use of ChatGPT	# mentions of a way of use[a]	Exemplary quotations on students' use
Code explanation	18	"If I cannot understand what a piece of code does, I ask the chatbot." (Student 6) "I asked it to explain, in plain language, what a part of standard code does." (Student 9) "I also used it to explain the functionality of existing code." (Student 22)
Solution code generation	15	"I ask it 'I want to do this, how can I do that?" Then it gives a starting point for a code and explains what it does. I can use that to write my own code." (Student 6) "I used ChatGPT mainly for inspiration on how to write certain parts of the desired code" (Student 7) "Writing code, but only if I can be really, really specific on what to write: 'I have this piece of FEM code for 2D, extend it to 3D' or 'I have these functions that use some overlapping functionalities, re-write this piece of code with the use of a parent element'. Things as 'Write a piece of code that uses a hierarchical data structure in this ray tracer code' don't really seem to work, or I couldn't get it to work at least." (Student 27)
Error checking and debugging in code	14	"I asked it to help me figure out how to debug my code." (Student 9) "Gave parts of my code with an error message or bug and asked what could cause this. (…) In most cases it was not able to fix it for me on the spot, but it got me to look in the right spots to fix it." (Student 11)
Conceptual understanding	11	"ChatGPT helped me understand the course materials more efficiently." (Student 25) "Teach the basics and the idea behind code and techniques." (Student 5) "I asked it to summarize advantages and disadvantages of different algorithms I could implement. That helped me make a choice." (Student 9)
Solution code optimization	3	"I used it to find bugs and optimize my code. The starting point/general principle I did myself." (Student 22) "Asking to simplify the code." (Student 3)
Mathematical problem solving	2	"Asking to solve mathematical problems." (Student 3) "I used it to calculate the angles for me, as I was too lazy to figure it out myself, I adjusted the code to rotate the camera around the object." (Student 2)

[a] Note: One student could mention multiple ways of use.

students' digital literacy and use of AI chatbots. The group of students with some programming experience reported all six ways of use. The two students that were new to programming mainly used ChatGPT to increase their conceptual understanding, but also for error checking and debugging, and code generation. The three students with extensive programming experience additionally used it for code explanation. However, given the small sample size, we do not consider it appropriate to make any inferences regarding the connections between students' pre-existing programming skills as a form of digital literacy, and their use of AI chatbots.

5.2.2. *Use and attitude towards technology*

Furthermore, students' TRI2 scores were compared to their use of ChatGPT to identify connections between their attitudes towards technology and use of AI chatbots. There appear to be no clear connections. This could also be a result of the small sample size.

5.3. *Research question 2: how is students' use of AI chatbots related to their learning?*

Students' grades for the individual ray tracer assignment were compared to the ways they used ChatGPT to identify connections between use of AI chatbots and student performance. There are no evident distinctions in use between students who failed the assignment (i.e., grades below 5.5, $n = 3$), and student with average grades (i.e., grades between 5.5 and 8.0, $n = 11$). Two of the three highest scoring (i.e., grades above 8.1) students did not use ChatGPT. However, we consider the sample size unsuitable to draw conclusions about connections between students' performance and use of AI chatbots.

In the focus group discussion, when asked about the added value of using ChatGPT for developing programming skills, students reported that it added to their learning. They indicated that ChatGPT helped them to write more concise code, understand why parts of their code are erroneous, and comprehend what specific pieces of code do. The students found ChatGPT also particularly helpful to identify detailed errors in their code that would have been time consuming to find themselves.

Students reported to believe that they would have come less far with the assignment, learned less, and that it would have cost them more time if they had not used ChatGPT. However, they also indicated that they did not work according to the pair programming principle. All students acted as the driver for a specific part of the ray tracer programming assignment, but no-one served as the navigator for any other part. Students reported to have utilized ChatGPT as the navigator as they found that to be more time-efficient than asking a peer. They also indicated that there was no real collaboration in their teams as they only met a few times to discuss any occurring problems with the assignment. Students worked on their individual branches in Git and merged them at the end of the course.

The teacher reported to be generally satisfied with students' output on the programming assignment. However, while the programming assignment remained unchanged from previous years and the teacher anticipated an improvement in the students' output quality due to their access to ChatGPT, the overall quality was not as high as in previous years. The teacher also found there to be more outliers in students' grades, both among the high- and low-scoring students. Moreover, the teacher perceived a general decrease in students' learning. He found that, of the three levels in programming, i.e., syntax, semantics, and pragmatics, students had learned syntax and semantics to a sufficient extent, but that their learning of pragmatics was insufficient. The teacher thinks this can be related to students' use of ChatGPT as it can readily help students with syntax and semantics, and not with pragmatics. He links the decreased output quality of the programming assignment to students' high expectations of what ChatGPT could do. For example, even though ChatGPT can efficiently and effectively explain code, students still need to acquire the skill of coding, encompassing syntax, semantics and pragmatics, to produce code. The too high expectation of ChatGPT's contribution to the coding process likely limited students' time investment in the programming assignment, decreasing output quality. However, investment of time, and the consequent gaining of programming experience, remains necessary to develop programming skills and produce high-quality code.

Furthermore, the teacher noticed a decrease in other skills among students that could not be outsourced to ChatGPT. Most striking was the decline in collaboration between students in the teams for the ray tracer assignment compared to previous years. This decline in collaboration was noticeable in the quality of the submitted code and the extent to which the code of the individual team members was merged. The teacher suspects that students tried to offload too much to ChatGPT, but that it did not yield the expected results. For example, learning how to merge branches in Git is a skill that students can only learn by doing, and ChatGPT cannot support that. The teachers' perceived decline in collaboration resonates with the students' comments that there was no real collaboration in their teams, and that they used ChatGPT as the navigator instead of being each other's navigator according to the pair programming principle.

From the teacher's perspective, the current learning objectives of the course can remain as students still need to learn how to program. However, the teacher thinks it worthwhile to explore more deeply what ChatGPT can and cannot do (yet) in support of students' development of programming skills. This can be used to create more fine-grained learning objectives, explicating what students need to learn in more detail. For example, one of the current learning objectives is for students to be able to translate a mathematical algorithm into computer code. The teacher thinks that, by breaking this general learning objective down into its underlying components, it can be become more clear what students need to learn and what they can outsource to AI chatbots like ChatGPT. Consequently, the teacher suggests adding learning objectives on the effective and responsible use of AI chatbots for programming and developing programming skills, including reflection on the chatbots' outputs.

6. Conclusion and discussion

6.1. Conclusion

In response to the first research question on how students use AI chatbots for a programming assignment, it was found that students used ChatGPT in six different ways. Students used ChatGPT for error checking and debugging of code, increasing conceptual understanding, generating and optimizing solution code, explaining code, and solving mathematical problems. This finding expands and finetunes the four types of use of ChatGPT as anticipated by Rahman and Watanobe (2023). Links between students' use of ChatGPT, and their attitude towards technology and pre-existing programming skills could not be established. However, this could be a result of the small sample size.

Regarding the second research question on how students' use of AI chatbots is related to their learning, the students and the teacher have partially opposed perceptions. They disagree about how the use of ChatGPT affected students' learning and coding. The students assert that they have learned more programming skills, and that they created a better solution to the assignment in less time as a result of using ChatGPT. Yet, the teacher contends that the students gained less programming skills, and that the quality of their produced code was less compared to previous years. The teacher attributes this decline in learning and code quality to students' overreliance on ChatGPT and a consequent incorrect assumption that less time investment is required to achieve good results. Students and teacher do agree that the use of ChatGPT negatively affected the pair programming practice in the course, and consequently the collaboration between students. Students only acted as the driver and deployed ChatGPT as the navigator. According to the teacher, this negatively affected students' development of collaboration skills.

6.2. Discussion

The overall aim of this study was to identify how to adapt programming education in higher engineering education following students' use of AI chatbots. Although this empirical study was small-scale, it does provide suggestions for adapting programming education. We propose changes in learning objectives, activities and consequently in assessment.

6.2.1. Learning objectives

The emerging use of AI chatbots does currently not eliminate the need for students in higher engineering education to develop programming skills as AI chatbots can't solve complex programming assignments yet. However, students' use of AI chatbots in support of their learning process and programming does raise the question what specific elements of programming remain essential to learn and what elements can be outsourced to AI tools. The results of this study suggest increasing the level of detail in the learning objectives to clarify this. For example, learning objectives could include learning the syntax, semantics and pragmatics of programming in more detail instead of a general objective of learning to program. Furthermore, the results put forward the need to explicitly include information literacy skills in the learning objectives, most notably concerning effective and responsible use of AI chatbots for developing programming skills and writing code. The latter aligns with assertions by Zhai (2022) and Chiu (2024) that students should learn to use AI tools in support of domain-specific tasks. Additionally, they state that education should increasingly focus on developing students' creativity and critical thinking (Zhai, 2022) and on the inclusion of hands-on learning activities (Chiu, 2024), suggesting that these should be more prominently included in learning objectives as well.

6.2.2. Learning activities

The results of the case study show that AI chatbots cannot solve complex programming assignments (yet). Students still need to generate code themselves and develop programming skills to be able to do so. Conducting a complex programming assignment therefore remains an appropriate learning activity, also if students use AI chatbots.

Furthermore, pair programming was a central part of the learning activities in the presented case study. Pair programming generally serves two distinct purposes. First, it provides students with opportunities to learn coding best practices from one another. Second, it supports students' development of transversal skills, most notably concerning communicating and collaborating with others. The findings of this study show that communicating and collaborating with others also serves the quality of the merging of the code of individual students. The results of this study show that the pair programming principles was compromised by students' use of ChatGPT as the navigator, thereby limiting communication and collaboration between peers and consequent skill development. The questions of if and how to maintain the pair programming principle in programming education requires further consideration as this case study only highlights the problem and literature does not provide clear solutions yet. On the one hand a study by Kim et al. (2022) seems to suggest that AI chatbots can replace a human navigator in pair programming. They found that students' use of AI follows three consecutive stages: learn about AI, learn from AI, and learn together with AI, and that appropriate instructional strategies can support students to move to the third stage. In addition, Rudolph et al. (2023) state that ChatGPT can facilitate collaboration and teamwork between students when appropriate instructional strategies are applied. This suggests that with fitting and sufficient scaffolding, AI chatbots could both serve as a navigator in pair programming while also facilitating collaboration between peers. On the other hand, Hill et al. (2015) found that dialogue between humans and AI chatbots is more limited than human-to-human dialogue. Even though conversations with chatbots lasted longer, messages were shorter and lacked the rich vocabulary used in human-to-human communication thereby affecting the quality of such dialogue. Moreover, Hill et al. (2015) assert that AI chatbots cannot have goal-directed discussions based on common understanding or shared experiences. This highlights the importance of peer collaboration to support students' development of programming skills and code generation and suggests maintaining the pair programming principle with a human navigator.

6.2.3. Assessment

The results of this study do not directly present required changes in assessment. However, the principle of constructive alignment asserts that changes in learning objectives and activities should be reflected in assessment. Zhai (2022) suggest that new formats of assessment should focus on issues that AI cannot substitute, like creativity and critical thinking.

Overall, we want to emphasize that students' use of AI chatbots is still in its early stages. Following the instrumental approach to students' use of tools for learning (Rabardel & Bourmaud, 2003; Trouche, 2004) a shift is to be expected from the current instrumentation use to instrumentalization. According to Kock et al. (2023), the affordances and constraints of ChatGPT currently influence students' practices and knowledge development (i.e., instrumentation) whereas this is likely to shift to students' adaption of these tools to their own needs (i.e., instrumentalization). In this process, students will develop dynamic ways of using ChatGPT, fitting with situations, aims and regulations (Kock et al., 2023).

6.3. Implications

Students' use of ChatGPT for programming assignments requires adaption of learning objectives. Learning objectives should become formulated in more detail to highlight what programming skills are essential to learn, and what can be outsourced to AI tools. Learning objectives should also be expanded to include digital literacy skills concerning the use of AI tools. Complex programming assignments remain an appropriate learning activity as students still need to generate code themselves in order to solve these assignments. Pair programming as a central learning activity in programming education is affected by students' use of AI chatbots. It requires further consideration if and how to maintain the pair-programming principle. Changes in assessment should follow from changes in learning objectives and activities to maintain constructive alignment in programming education.

6.4. Limitations and future research

The current study shows how students use ChatGPT for programming assignments and that this use affects student learning. As a result of the small sample size, it remains unclear if and how pre-existing programming skills and attitudes toward technology affect students' use of ChatGPT and how this influences learning. It is also uncertain whether data saturation was achieved in the qualitative data on students' use of ChatGPT and its perceived influence on their learning. We therefore recommend caution with extrapolating the findings of this study. Further research with a larger sample size could address these issues.

Furthermore, this study shows that pair programming as a didactic approach is compromised by students' use of an AI chatbot as the navigator instead of a peer. More research is needed to gain in-dept understanding how students use an AI chatbot as the navigator and how this use affects pair programming. Additionally, future research could identify what aspects of the navigator and driver roles can and cannot be outsourced to an AI chatbot, and how the pair programming principle can be adjusted or expanded to include an AI chatbot in an effective and responsible way.

The general Technology Readiness Index Scale (TRI2; Parasuraman and Colby, 2015) was used to assess students' attitudes towards technology. Since the general attitude towards technology and innovation affects the educational use of ICT (Van den Beemt & Diepstraten, 2016), we consider this appropriate. However, in the course of this study we found that more specific scales exist regarding attitudes and use of AI in general (Suh & Ahn, 2022), AI in higher education (Chatterjee & Bhattacharjee, 2020), and AI chatbots (Malik et al., 2023). We propose the use of the most fitting scales in future studies to gain valuable insights.

This study was limited to students' use of ChatGPT. However, teachers also can and do use AI chatbots for their education, for example as a teaching assistant (Pérez et al., 2020). Future research could identify how teachers can effectively and responsibly use AI chatbots to support them in their educational tasks. It could focus on integrating chatbots with human educators and advancing chatbot capabilities to create optimal learning environments in engineering education. Furthermore, with a rapidly increasing number of generative AI chatbots becoming available, it could be worthwhile to explore differences in their affordances for educational purposes.

Besides code generation, AI can also be applied to check the quality of developed code (Saranti et al., 2020). It would be worthwhile to explore how this could be included in programming education as well, both for students to check the quality of their own code and for teachers to use in the assessment of code quality.

Ethics and data availability statement

The study was approved by the Ethical Review Board of Eindhoven University of Technology with ID: ERB2023ESOE2. Informed consent was obtained from all participants, and their privacy rights were strictly observed. The data can be obtained by sending a request e-mail to the corresponding author.

CRediT authorship contribution statement

Suzanne Groothuijsen: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Antoine van den Beemt:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Joris C. Remmers:** Writing – review & editing, Conceptualization. **Ludo W. van Meeuwen:** Writing – review & editing, Validation, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT in order to improve readability and language of the manuscript. After using this tool/service, the author(s) reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was funded by the BOOST! Education Innovation Program of Eindhoven University of Technology. The authors thank Shane O'Seasnáin for proof reading the manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.caeai.2024.100290.

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