Exploring the role of generative AI in science teacher education programs
A qualitative study

de Putter-Smits, L. G.A.; Pols, C. F.J.; Dekkers, P. J.J.M.; Runhaar, P. R.; Timmer, M.; Van der Veen, J. T.

DOI
10.1016/j.ijedro.2025.100492

Publication date
2025

Document Version
Final published version

Published in
International Journal of Educational Research Open

International Journal of Educational Research Open 9 (2025) 100492

Contents lists available at ScienceDirect

International Journal of Educational Research Open

journal homepage: www.elsevier.com/locate/ijedro

Exploring the role of generative AI in science teacher education programs: a qualitative study

L.G.A. de Putter-Smits [a,*], C.F.J. Pols [b], P.J.J.M. Dekkers [b], P.R. Runhaar [c], M. Timmer [d], J.T. Van der Veen [a]

[a] Eindhoven University of Technology, Applied Physics and Science Education, Eindhoven, the Netherlands
[b] Delft University of Technology, Department of Science & Engineering Education, Delft, the Netherlands
[c] Wageningen University & Research, Education and Learning Sciences, Wageningen, the Netherlands
[d] University of Twente, Faculty of Behavioural and Social Sciences, Enschede, the Netherlands

ARTICLE INFO

Keywords:
Science education
Teacher education
Generative AI

ABSTRACT

The introduction of transformative generative open AI (GenAI) has impacted science education, presenting opportunities for students and teachers to enhance teaching and learning efficiency. Equally GenAI poses challenges, including risks such as plagiarism and superficial engagement with content. Science teacher education programs play a key role in the way these opportunities are realized and how challenges are dealt with through educating the future generation of science teachers. Science teacher educators face the challenge to remodel their teaching program to showcase how GenAI is used appropriately. Their student teachers face the challenge of working with GenAI in their own learning, but also in their classroom teaching where their students in secondary education might be using GenAI. This interview study explored how science teacher educators and student-science teachers in the teacher training programs of the four technical universities in The Netherlands envisage the potential impact of GenAI on university science teacher education. Few of the teacher educators had actually used GenAI, compared to the number of student teachers that had used GenAI. Potential uses for GenAI in science teacher education and for science teaching in general were identified, as well as desired new learning goals. A strong need for a policy on the use of GenAI was expressed, including a need for clear guidelines and rules. The conclusion presents possible design characteristics for science teacher education to benefit from the advent of GenAI and circumvent associated risks.

1. Introduction

The rapid introduction and adoption of the generative artificial intelligence (GenAI) engine ChatGPT in 2022, with an estimated 100 million monthly visitors within just two months (Hu, 2023), has caused changes to science education at the secondary school level (e.g. Avila et al., 2024; Yeadon & Hardy, 2024). ChatGPT is a so-called Large Language Model (LLM) that specializes in processing and generating human language. The accessibility and ease of use of this LLM have led to widespread adoption (Bick, Blandin & Deming, 2024) including in education in all school levels (Tiwari et al., 2024). As a result teacher training programs should also change.

A major goal of science education at secondary school level is to raise scientific literacy (e.g., Roberts & Bybee, 2014; NGSS, 2013), where science teachers in particular can be a primary source for students' learning to critically assess the quality and reliability of information (Holbrook & Rannikmae, 2007). Although initial versions of GenAI provided unreliable, incorrect, and inconsistent answers to questions in for instance physics, newer and more advanced GenAs demonstrate significant improvement in providing correct answers and explanations in the science domain (Gregorcic & Polverini, 2024; Santos, 2023). How GenAI can be used reliably should be included in scientific literacy skills, since the reliability of information it provides can be taken at face value by inexperienced users.

Teacher education therefore needs to incorporate learning goals surrounding knowledge on the uses of GenAI in student teachers' future careers (Whalen & Mouza, 2023) as well as adapt the own education to the advent of GenAI. Research is needed in this area to determine how AI can be used to support pre-service teacher learning. Studying the views of science teacher educators and future science teachers can be a starting

* Corresponding author at: CC 3.14 PO Box 513 5600 MB, Eindhoven; The Netherlands.
E-mail address: l.g.a.d.putter@tue.nl (L.G.A. de Putter-Smits).

https://doi.org/10.1016/j.ijedro.2025.100492
Received 13 March 2025; Received in revised form 2 June 2025; Accepted 4 June 2025
Available online 7 June 2025

point of redesigning education by the teacher's teacher, the future science teacher's work, working through in the teaching in the science classrooms of tomorrow. With the current exploratory study we aim to gain insights into how science teacher education can innovate by incorporating GenAI, from the perspective of science teacher educators and future science teachers.

2. Background

A major goal of science education at secondary school level is to raise scientific literacy (Roberts & Bybee, 2014), which involves the development of general scientific awareness and understanding of science required to participate meaningfully in society and make substantiated decisions regarding contemporary socio-scientific issues (Laugksch, 2000). The competence to judge the reliability of information is an important skill for secondary school students to master in order to make these decisions (Castenade Valle, 2024). Developing the ability to determine whether information provided by GenAI is correct is important, since GenAI is purporting to be scientific, whilst an increase of misinformation has been found to be produced (Ng et al., 2021). Science teachers can be a primary source for students' learning to critically assess the quality and reliability of scientific information (Holmes, Wiemann & Bonn, 2015). Science teachers acquire their knowledge on how to teach in teacher education, from teacher educators. Therefore, the incorporation of learning goals surrounding GenAI starts there.

Teacher education needs to incorporate learning goals surrounding knowledge on the uses of GenAI in student teachers' future careers, including an expansion on digital literacy (Whalen & Mouza, 2023). Student science teachers will also have found their way to using GenAI for their own education, which means that teacher education also needs to rethink their approaches and strategies of teaching, learning, and assessment. Teacher educators thus have a double task when it comes to GenAI: They are expected to introduce student teachers to possible beneficial and unwanted uses of GenAI in their course work as well as to advise them about its uses in their future profession as teachers. Moreover, the teacher educator is expected to be a role model in showcasing how GenAI can enhance one's teaching and might aid in developing teaching materials, in lesson planning, designing activities, creating ideas for mentoring and individual tutoring and support in assessment tasks (Mollick & Mollick, 2023; Mondridou, Matzakos & Doukakis, 2024). This dual role automatically leads to a situation where double-standards can arise: what can a teacher educator use GenAI for that a student teacher cannot? And: What can a teacher use GenAI for that a student cannot? A demand for a policy including the ethical considerations quickly emerges, since the cases of student teachers openly or covertly using GenAI for their training are mounting (Kim, Lee & Cho, 2022; Lee & Zhai, 2024; Shamsuddin & Shariff, 2024).

Policy in university education includes statements on academic integrity including plagiarism and proper citing of sources and owners of academic products (e.g. Macfarlane, Zhang & Pun, 2014). Referencing to a GenAI is new, although more recently the GenAI engines now include a statement on how to refer to their input on their homepages. Each course should now decide to what extent a GenAI can be used and rephrase learning goals accordingly. Another consideration are the privacy and ownership of data shared with a GenAI since the engines use information provided in prompts for answering a next query (Huallpa, 2023). Then there is the severe environmental impact of the servers on which these LLMs are run that should be considered when using GenAI as a tool (Berthelot, Caron, Jay & Lefevre, 2025).

3. Research questions and backdrop

The research we report on here explored what teacher educators and student teachers think about the use of GenAI in and for education. The science teacher education departments of four technical universities in The Netherlands regularly confer on their education, since they have more similarities to one another than to the engineering master programs that are most prominent in technical universities. A case on a student using GenAI for their reflective report on teaching triggered us to start a study into the current and desired use of GenAI in and for science teacher education. This led us to collaboratively formulate the following research question:

What are the views of science teacher educators and student science teachers on current practices and future developments regarding the use of generative AI in science teacher education?

This question is explored through the following sub-questions:

1. How do science teacher educators and student science teachers currently use GenAI in their teacher education?
2. What current and desirable future uses for GenAI do science teachers educators and student science teachers identify?
3. What changes in teacher education due to GenAI do science teacher educators and student science teachers identify and foresee?

Answering these questions will provide insight into the way GenAI can be incorporated in science teacher-education and inform future science teachers about the opportunities, limitations and ethical use of GenAI in their classrooms.

3.1. Backdrop

This research was carried out in the teacher education departments of the four Dutch technical universities that are formally referred to as the 4TU collaboration. The 4TU institutes offer science teacher education programs in the high school subjects physics, chemistry, computer science, geography, mathematics, and research & design. These institutes collaborate in aligning their curricula and courses on a regular basis, and for quality assurance purposes (Van Puffelen & Vonk, 2020). The 4TU collaboration offers it's teachers small grants to innovate and perform evaluative research with the aim of redesigning their courses. The authors applied for such a grant to afford themselves the time and means to gain information as a starting point to redesign science teacher education. The grant requires teachers to publish findings on the 4TU public website and to disseminate results to peers. The grant givers judge grant application by the standards of educational research. Grant number: IF2023- Putter.

4. Method

4.1. Research design

A qualitative case study design was chosen to explore the experiences and perspectives of student teachers and teacher educators on the use of GenAI. Taking the four programs as a single case was justified by the significant similarities in the structure and content of the teacher education programs across the different science disciplines. In terms of the introduction of GenAI, we assumed and verified that the four teacher education programs are sufficiently similar to be regarded as one single case.

The research method comprised of semi-structured interviews, with sub-questions to further the conversation on the topic. The full interview protocol can be found in Appendix A. For example, participants were asked: "Do you use GenAI in science teacher education; if so, please elaborate?" (sub-question 1), "What opportunities do you see for the use of GenAI in science teacher education?" (sub-question 2), and "Do you foresee any changes in teacher education due to the advent of GenAI, such as in learning goals or assignments?" (sub-question 3). The interviews were conducted in Dutch, recorded using MS Teams, transcribed verbatim, and subsequently anonymized. Once transcription was complete, all recordings were deleted to safeguard anonymity.

4.2. Participants

Potential participants were approached by email to volunteer for a semi-structured interview. In total, 17 student teachers (7 female; 10 male) and 25 teacher educators (9 female; 16 male) from all four science teacher education institutes took part in this study. The interviews were conducted online or in person between November 2023 and February 2024 by individuals who held no authority over the participants, ensuring that participants felt comfortable to speak freely.

The student teachers were enrolled for a teaching degree as presented in Table 1. The teacher educators represented the courses in the program, such as general pedagogical courses, pedagogical content knowledge (PCK) courses in the different disciplines, internship coaches and so on. Each teacher educator had a unique profile, varying from expert secondary school science teachers in a discipline who are part-time involved in university teacher education, via former science teachers who changed their careers to become educational researchers, to full professors who are research experts in the field of science education.

4.3. Data-analysis

ATLAS.ti 24 software was used for the coding. The coding system for the interviews was developed in two stages. In the first stage, a coding frame was constructed based on expected answers directed towards answering the research sub-questions. We expected the participants to name examples of the use of GenAI from actual, or near actual personal experiences and to describe future plans involving GenAI. We foresaw a need for codes based on the participants' actual use of GenAI (sub-question 1) and possible use of GenAI (sub-question 2) and specified five kinds of responses: (1) negative examples in higher education, for instance students using GenAI for writing their final report without personal input; (2) negative examples in secondary education, for instance student teachers using GenAI for generating content knowledge they do not have themselves and using it to teach in secondary education without checking facts; (3) positive examples in higher education, for instance using GenAI as writing buddy to overcome spelling errors due to dyslexia; (4) positive examples in secondary education, for instance using GenAI to brainstorm on lesson activities that would then be adapted to actual use in a specific class; and (5) general use, such as generating pictures that convey a message better, without specific reference to the context.

Regarding possible changes in teacher education (sub-question 3), we expected participants to provide answers involving learning goals for higher and secondary education and issues regarding policy and ethics in higher and secondary education. Codes were constructed accordingly.

Two researchers coded half of the interviews separately first, then each coded the other's interviews (blind). The resulting codes were discussed to reveal around 80 % coder agreement. The comparative discussion yielded that often a single quote, was given three or more codes. An interview where the participant had indicated how GenAI could be harmful to learning goals in higher education with a dreamed-up example of possible mis-use and possible use could be given three codes as explained above, whilst not providing actual information, since the participant had no real experience with GenAI. The participant data we obtained provided us with an overview of the participants' understandings of and views on the use of Gen AI in teacher education, but views and understandings based on remote sources rather than personal experience. The data in that sense were too different from expectations to warrant continued use of this initial coding frame.

We decided that a realistic picture of actual future developments required that we focused on respondents with sufficient personal experience with GenAI. We argued that a realistic view on what is and is not possible with GenAI requires at a minimum that the respondent has had some personal experience with composing prompts and utilizing the resulting GenAI products. We therefore reduced the dataset to isolate views and perceptions derived from actual personal experience of the participants and developed a second coding framework. The reduced dataset included 22 participants: eight teacher educators and 14 student teachers.

We then started a thematic analysis and open coding of the data-subset (Cohen, Manion & Morrison, 2002) with the sub-questions as a guide or general category for a code. Two researchers each recoded five interviews to identify and validate the new codes. The resulting second coding frame has codes for 'actual examples' (cf. sub-question 1) and 'worked potential examples' (cf. sub-question 2). For sub-question 3 we arrived at one code for 'policy in teacher education' and one for 'learning goals in teacher education'.

The meaning of each new code was discussed and agreed upon. Next, a second round of coding was carried out on two interviews by the two researchers simultaneously (blind). The coding results were agreed upon (fully). One of the researchers then coded all interviews in the reduced dataset with the new coding system. The second researcher audited the coding and full agreement was reached. The codes used are depicted with an exemplary quote in Table 2.

Table 1
student teachers per subject in teaching degree.

Teacher education in:	No. of student teachers
Chemistry	2
Computer Science	2
Geography	2
Mathematics	1
Physics	9
Research & Design	1
Total	17

Table 2
Second coding system & exemplary quotes.

Sub-question	Short description	Code	Example quote
1.	Current use	Lesson preparation & planning	"Well, you have to make a lesson series, so I asked him to plan the lessons out for me"
		PCK	"I wanted to change the lab experiment for my physics class, so I asked (GenAI) how I could change it for the equipment we have at this school."
		Writing reports	"I use it to get rid of the duplications in my reflection report"
		General educational use	"I asked for advice on what to do with a difficult student"
		Other	"I put in my lectures notes and scribbles and asked to write it up nicely in full sentences."
2.	Possibilities	-same set as above	
		Writing reports	"it (GenAI) would have been so useful when I had to formulate my vision on education. When you have to use all these theories. That would save me so much time."
3.	Changes	Learning goals	"They should teach us how to use GenAI to design our lessons, that would save us so much time later."
		Policy & ethics	"I think the (teacher) education institute should tell me when I can use GenAI and how to refer to it".

4.4. Ethical statement

Ethical consent for the research was applied for and granted by the Ethical Board (ERB2023ESoE7). All student teachers and teacher educators gave their consent to be interviewed and for the anonymized transcription to be used for this research. One participant requested not to be quoted. All selected quotes were translated into English by the authors.

5. Results

In the results section we first discuss the personal experience with GenAI of all respondents, followed by a global overview of their main views and understandings of GenAI and its current and potential future impact, based on the complete dataset. Then, realistic views on current uses of GenAI in teacher education are presented, based on the *reduced* dataset of respondents with personal GenAI experience in science teacher education, followed by these participants' views on possibilities for applications of GenAI in that area. Lastly, the views on new goals of learning that science teacher education should incorporate are presented.

Comparison of data from the four different institutions showed that considering all as examples from a single case was justified: opinions, concerns and needs were very comparable. With the exception of 'learning goals', this was the case as well in a comparison of teacher educator and student teacher data. With that exception, we therefore aggregate these data in reporting the results.

5.1. Experience with GenAI

Respondents in this section are the participants with and those without experience with GenAI.

Participants in the reduced dataset with experience in using GenAI in teacher education ($n = 22$), had used the free version of ChatGPT (a subscription version was available at the time of research). Other GenAI's mentioned (but not necessarily used) included: Dall-E ($n = 7$), Bard ($n = 4$), CoPilot ($n = 2$), Fotor ($n = 2$), Firefly (1), Whisper (1), Midjourney (1) and Grammarly (1). The Microsoft search engine Bing was also mentioned, but according to our definition is not a GenAI, although it can offer users the GenAI CoPilot to further their search. Eighteen participants used ChatGPT (free or paid version) regularly; one exclusively used Bard; three participants had used it once or twice (one had used it to prepare for the interview).

Participants who had no experience in using GenAI in teacher education or otherwise ($n = 20$), also named ChatGPT most often ($n = 12$ and 5, respectively). Wolfram Alpha was mentioned twice and Bing (not a GenAI) three times. Other GenAI's mentioned directly were Symbolab, Dall-E, Bard and Deep AI. Some participants tried to remember GenAI's they heard of, which we identified to be: "something with Dream in it" (Dreamweaver), "a tool in Lesson-Up", "NVIDIA has one". One participant, in an effort trying to help the interviewer, googled the ones they half-remembered during the interview: Canva and Hotpot.AI.

5.2. GenAI issues in science teacher education

5.2.1. Understanding of GenAI

At the time of the study many participants had only limited awareness of what GenAI actually is, what GenAI's are available and what they can accomplish (in science teacher education). Some participants indicated that they were simply waiting for this new technology to pan out and planned to get involved when necessary. Some had naïve ideas on the possibilities with GenAI such as: "apparently you can just have it make your PowerPoint presentations for you in the blink of an eye" or on how widespread use of GenAI is or is expected to become: "I think it [GenAI] won't be a big thing".

Only a minority (8 of 25) of the interviewed teacher educators had personal experience with the use of GenAI in the teacher training program. These respondents described actual and expected future applications extrapolated from their own attempts to use it in relevant practice. The knowledge of the others was not necessarily incorrect, but based on third hand information only, derived from popular media and hearsay.

5.2.2. Responsiveness of science teacher education

The majority of respondents agreed that an adequate response of the teacher education programs to the advent of GenAI is important and urgent. There where however few concrete ideas as to what that response should look like. Most respondents agreed that teaching education programs have a responsibility to prepare teachers for an educational system in which learners learn how to make appropriate, adequate and responsible use of GenAI. There were few experience-based ideas on how that might be accomplished.

"For computer science there is kinda a double meaning here. The tools [i.e. GenAI] are developed from computer science. So it is also course content, so we wanted to see it as such. Working with such a tool requires writing proper prompts. What are the characteristics of prompts? Develop prompts you can provide to your high school students to use, so they can use ChatGPT and others effectively."

Some teacher educators held the view that in their particular school subject area, mathematics or physics education, GenAI was less relevant than for instance the humanities, and a response less urgent. In their experience, GenAI could not do 'the math' or 'required calculations' and they foresaw more concerns for the languages, where GenAI's would be good at producing required homework or assessment answers:

"I think that for Dutch or [other] languages the consequences are much larger than for us [science subjects]".

5.2.3. Policy issues

All participants mentioned concerns about referencing and ethical use and the strong need for an institutional policy on the use of GenAI, seen as necessary to avoid full texts being generated by GenAI alone and not fed by the actual experiences and knowledge of the student teacher. All teacher educators expressed concerns about referencing and plagiarism, for example:

"Yes, there should be a good protocol on how to indicate it [GenAI]. How you use it. How you should cite it. That kind of thing."

Respondents identified further possible threats, including subject-specific and educational threats as well as the legal aspects of copyright: who owns the product generated by a GenAI?

None of the teacher educators was of the view that GenAI should be banned from schools or programs, though virtually all saw a need to review aims of learning and design appropriate methods of assessment. The number of practically applicable ideas was scarce.

While some respondents saw no reason to limit the use of GenAI at all for anyone, most participants indicated that the use of GenAI should be limited or banned in areas where students have not yet attained certain aims of learning (e.g. in reflecting on and learning from teaching experience) but ought to be permitted or encouraged once they were attained (for example, in generating inspiration for introducing a topic or planning lesson activities). However, while most student teachers expressed this view with regard to their secondary school students, they did not advocate putting any restrictions on their own work as students (or teachers). Student teachers were on average more enthusiastic about applying GenAI whenever possible in both teaching and teacher education than teacher educators. Indeed, most student teachers had used ChatGPT or another GenAI before the interview, although use in the teacher training program was still limited (with the exception of computer science). Whether they refrained from using GenAI because they regarded the use of GenAI as inappropriate, a form of deceit, inadmissible or merely not useful remained unclear – all of these may have played a role.

No concrete policy was proposed by any of the participants. However they felt a clear need for institutional policy on ethically appropriate use

of GenAI in the programs, and clarity on e.g. what is permitted and how the use of GenAI should be reported. Building on all the elements mentioned by the participants the result on policy can be given as: The policy that should be developed to counter the threats posed by GenAI should indicate that each examiner for the course or subject at hand writes a protocol that specifies for what purposes GenAI can and cannot be used and explains why. The adaptable protocol could include demands for the student teacher to describe the procedure used when applying GenAI in their work, the name of the GenAI - properly cited - and the prompts used to obtain answers. The protocol to be used should be formulated together with the student teachers, on a yearly basis, and be publicly available, in particular to alumni. As one of the respondents put it:

> "… together with students, you know, formulate a vision, an implementation for education. Every year again. And share it with alumni, that we simply share our vision on AI"

5.3. Current GenAI use in science teacher education

The actual and potential or envisioned use of GenAI in teacher education, as found in the reduced dataset, can be summarized in four categories, discussed consecutively below: 'Lesson preparation and planning', 'Pedagogical content knowledge', 'Writing reports', and 'General and other educational use'. First actual uses are presented, followed by potential use or opportunities for application of GenAI.

5.3.1. Lesson preparation and planning

Actual use of ChatGPT in lesson planning was described by five participants. They specified the available time and desired learning goals in their prompts. They obtained mixed results where some were satisfied and adapted the plan a little to put it to use, while others indicated that the time line they received from the GenAI was not feasible in practice.

"I noticed, when I was preparing a lesson with ChatGPT, that I had clearly indicated what learning goals I wanted to reach. And that there should be time for instruction and for students to work on assignments and that there should be 5 min for starting and finishing the lesson. But then I had asked Chat to make a lesson plan with the timeline but if you added it all up it was much longer than the lesson time."

The participants were conscious of the possibility that their prompts to the GenAI may not have been good enough to obtain the desired result. One participant indicated that the proposed lesson was very useful, and even included a helpful suggestion for differentiating between students based on academic performance. Twelve participants indicated that they use GenAI for inspiration, but that they created the actual activities and lessons themselves.

Potential use of GenAI in education was mentioned by 13 participants with GenAI experience. Options included the use of GenAI for obtaining creative ideas and inspiration for lesson activities, for having GenAI produce illustrations, PowerPoints and lesson plans, and obtaining content information quickly to refresh a physics topic. Two exemplary quotes what the respondents would ask GenAI are:

"This is my learning goal. Can you generate a series of lessons that will enthuse secondary school students? Then he gets you some activating lesson ideas that I could use and elaborate on."

"How do you formulate learning goals for secondary school students, that you want to help them learn and that you have to assess them on?"

Respondents indicated that the reliability of GenAI answers is often questionable and that they know it is very hard to obtain a product from GenAI that is completely satisfactory. They indicated they expected GenAI to be a source of inspiration, but that they would subsequently create the actual lessons themselves.

5.3.2. Pedagogical content knowledge

Examples and experiences of using GenAI related to pedagogical content knowledge (PCK) were described by 11 student teacher participants. The most concrete examples were: generating questions and model answers for a quiz, task or assessment; producing worksheets for students; creating a game. Participants indicated that the generated output almost always needed tweaking or correcting. One example involved creating a fictitious story to use as input for discussions on fake news, as follows: "I was making a test [for students in secondary education] on digital literacy. And I thought it would be fun to have a question on fake news. So I asked ChatGPT to generate a fake news text. I adapted it a little to my liking and then I used it: What are giveaways in the text to identify it as fake news?"

Other uses for both student teachers and their secondary school students included summaries for educational content knowledge, such as a history of education, a summary on a certain science topic or an explanation for a phenomenon.

One participant had GenAI produce a mathematical proof for their secondary school students to give feedback on and analyze the quality of the chatbot's work. In computer science, using databases for copying programming code is more common, so the focus reported here was on how to write the correct prompt for GenAI to obtain the best answer.

Fifteen respondents offered comments about potential contributions of GenAI related to PCK, for instance to illustrate the proof of a mathematical theorem.

Ten participants suggested GenAI could generate ideas for subject-specific lesson preparation, such as providing ideas for the start of a lesson, activating learning activities, tasks and exercises, calculations with moles, practical work, lesson structure and for generating extra practice materials.

Generating (inspiration for) questions, problems, quizzes or tests was suggested by five participants, who saw themselves as novices with few existing teaching materials. Reusing old tests or revamping old tests to modern contexts, adapting exercises to each secondary school student's level and enhancing (student-) teacher's own personal creativity were also mentioned:

> ".. to generate individual or more inspiring problems, because when you want to do something on acceleration or something, but then they are always difficult and boring problems. And then you could say [to a GenAI]: I want to use Asterix and Obelix [cartoon characters] and then a story, and that works fine."

The development of a rubric or assessment tool was mentioned, with the respondents' caution that not every aspect generated may be correct or adequate.

Student teachers suggested to develop activities that involve having their students in school use ChatGPT, such as finding the errors in discipline-oriented texts generated by ChatGPT:

"So that you have your students give feedback on a text generated by ChatGPT, that could maybe be an example?"

5.3.3. Writing reports

Five student teachers had used GenAI for help with their reports in teacher education. One participant had GenAI write the complete assignment on a certain topic:

"I even had a complete report for [course name] written by ChatGPT by putting in the assignment and some questions, then I edited one or two things and I had a pass mark. So, that was the moment that I thought, this kind of education has to change."

Two participants used GenAI to help with their personal reflection on teaching during their internship. The other two used GenAI to help formulate goals and to remove duplications from their report.

Suggestions for using GenAI for writing reports included six suggestions involving GenAI improving your own text in terms of legibility and clarity, both from teacher and student perspective. Five student teachers suggested to use GenAI as an idea generator, for instance to overcome writer's block or to get the writing started. As one teacher educator put it:

"I am under the impression that student teachers are actually unable to write well because they have not done so for a long time during their [technology or science] classes. And I prefer that someone puts his writing through ChatGPT so that I don't have to see and read all those spelling errors and typo's."

A student teacher's view:

"To overcome writer's block, you know, that can happen when you write your internship report. Or you say: "I don't know how to start, I am stuck". […] Normally you would ask a colleague, but now you can ask AI."

Four participants indicated that a whole report or essay could be written by GenAI. Other suggestions included creating fitting illustrations to a report and finding the matching references for their literature section.

5.3.4. General and other educational use

Participants indicated they asked GenAI for advice on how to deal with difficult students or classroom situations. For example:

"I had a case [i.e. a problem with a student] that I wanted to discuss with other students [student teachers], but I also asked ChatGPT to see what advice he would give."

GenAI is used for delving into theory and pedagogy from different stances: finding sources on a certain topic, providing a summary of a certain account, helping express a student teacher's opinion on a particular issue or elaborating on a student teacher's vision on a certain theme.

Seventeen17 further possible uses for GenAI in education examples were collected in this category. These included using GenAI in producing text, ranging from (general) grammar and spelling to generating full texts and from bulleted lists of notes or ideas to reformulating clumsily constructed emails. Other uses included: creating a classroom observation form, building a website, collecting information, general inspiration and a peer review engine for secondary school students. This quote illustrates one of the variety of items in this category:

"What I did is build a website with ChatGPT's help. I can program, but it is much, much quicker and it just looks better if I let him do it."

Participants suggested a broad range of ideas, from creating illustrations and PowerPoint presentations to assistance in learning processes. For the teacher's role they envisioned a GenAI to provide individual student feedback by creating prompts to make an adaptive learning system and to grade tests. For teacher education they envisioned a GenAI to be able to:

- provide an efficient summary and content of what they need to learn;
- reformulate incomprehensible assignments;
- generate a personal work-schedule;
- give suggestions for answers to questions;
- to aid student teachers to create better products;
- write reports (in general).

"It could be used to provide more effective learning materials to student teachers, instead of having us student teachers look everywhere for information […] a summary of what you need to know that is easy to understand and not too lengthy."

Ideas for learning how to work with a GenAI were: write a report on a certain issue using GenAI and then fact check the product and give feedback; provide secondary school students with different prompts to explore an issue with GenAI and have them compare results.

5.4. New learning goals in science teacher education

All respondents felt that the learning goals for teacher education should change to include the use of GenAI. Given proper guidance, newly graduated teachers were seen to be able to promote change by bringing examples and expertise of the use of GenAI to the schools, and stimulate and assist teachers there in developing GenAI opportunities. This development was seen as similar to the past advent of search engines such as Google or the advanced pocket calculator.

Teacher educators indicated that they might need to reformulate their assignments either to specify where and when student teachers can use GenAI or to ensure that the desired product represents work by their student teachers, rather than by GenAI. One teacher educator would include GenAI in assignments to show student teachers what working with it can entail. Two teacher educators raised the concern that the student teachers need to learn what to expect in the classroom when secondary school students use GenAI.

Student teachers gave a rich variety in answers as to what they would like to learn:

- how to use GenAI in general, including adequate prompts;
- how to use GenAI for your future job as science teacher, including subject specific options, use in the classroom, use by secondary school students, lesson preparations, creating assessments, activities and so on;
- how to check GenAI answers for reliability, validity and quality;
- in which circumstances using GenAI is beneficial (time, goals) and in which cases it is not;
- how to refer properly to having used GenAI;
- learning to reflect on the ethics of using GenAI;
- which GenAI's exist, how they differ and what they are used for;
- what happens with data you enter into GenAI, especially when dealing with privacy;
- changing teacher education from learning facts and writing reports to learning to think critically;
- what are the limits for using GenAI in general and within teacher education assignments;
- how to handle conflicts with students and possibly their parents when you as a teacher suspect that GenAI was covertly used.

The following quotes exemplify the use of GenAI in general and the need for verification:

"You know, some kind of work flow or flowchart saying: ok, what kind of prompts do I put in, what is the output? What do I then do with the output? What are typical questions you should ask yourself before using the output?"

"That basic knowledge is what you need, because the output of ChatGPT is not always reliable. It is based on everything that is on the internet and not everything that is on the internet is true. So some kind of basic knowledge remains a necessity to reflect on whether the quality is sufficient."

Some student teachers even described how current assignments could be adapted to include learning to work with GenAI.

When asked whether the learning goals for their teaching in secondary education should change as well, answers were strongly divided about the restrictions that should be enforced, varying from total freedom to complete banning. Generally, the respondents agreed that students in secondary school should first develop content knowledge and skills before they ask a GenAI to do the work. They all agreed that students in secondary school should learn how to use GenAI effectively and responsibly.

6. Discussion

We initiated an interview-based case study to explore the views of teacher educators and student teachers regarding the use of GenAI in science teacher education, since there were limited insights available from existing literature on current practices and future developments. A minority (8 out of 25) of the interviewed teacher educators had personal

experience with the use of GenAI in their teacher training program, although all interviewees could name at least one GenAI. The majority (14 out of 17) of student teachers, however, had experience using GenAI, even though the experiences were modest and showed varying degrees of success as far as teacher education was concerned.

We realized that while all of our respondents would have interesting and worthwhile opinions, we could not rely on those without firsthand experience for a realistic view of current and future applications. We therefore analyzed the entire dataset first, so as to describe those views. We then isolated respondents with experience in using GenAI to obtain a realistic description of current and envisaged usage of GenAI chatbots, and of the associated new learning goals for science teacher education.

6.1. Summary of findings

Teacher educators had modest information on what GenAI actually is and what it can be used for. Still, they were of the view that teacher education should respond to this novel technological development, both in terms of student teachers' work in the programs and by preparing them for developments in secondary education. All expressed a clear need for policy development to specify what applications of GenAI are permitted in what circumstances, and how to report the use of GenAI. The consensus view is that policy ought to be flexible and adaptable to the educational setting at hand, and a matter of negotiation between the educator and the learner. Policy development was felt to be needed where GenAI would prevent rather than support the attainment of learning objectives, as it could provide student teachers and secondary school students with means to commit undetectable fraud, letting GenAI do the work that ought to demonstrate the learner's attainment of aims.

Some teacher educators thought that GenAI posed (as yet) less of a threat in their subject (e.g., mathematics) as compared to more language-based subjects. Recent developments in the areas of applied science and mathematics (e.g. Polverini & Gregorcici, 2024) suggest however that this may not be the case much longer.

It would seem that teacher educators are interested in this new technological development and are aware of the need to adapt teacher training to it in various ways, but they are not well informed about the implications, potential benefits and threats. Most have limited relevant experience (at the time of the interviews) and insufficient practically useful ideas on how to go about that adaptation. It would seem that teacher educators have not yet used their students as sparring partners in changing education even though early research indicates that teacher that use GenAI enjoy their work more (Noy & Zhang, 2023).

In virtually all areas that involve the production and use of written text, student teachers and teacher educators who do use GenAI in teacher education have used it for myriad purposes, and see potential applications in many more. Whether in the area of subject matter content, pedagogy or PCK, whether in planning, execution, assessment or reflection – whenever written text is to be utilized or produced, our respondents either have used GenAI or see a potential use. Conform other recent studies (e.g. Lee & Zhai, 2024; Shamsuddin & Shariff, 2024), they all add the warning that the quality and trustworthiness of GenAI output is limited, cannot be automatically trusted and requires verification. GenAI can provide inspiration and structure, but (at the time of study) could not produce a complete and satisfactory piece of work in this context.

All participants who have used GenAI are of the opinion that teacher education should strive for developing new learning outcomes in all of the areas just listed, where it may make the work of teachers easier, improve its quality and free up time for e.g. personal contact between teachers and learners, which indirectly can enhance educational quality.

6.2. Implications

We derived the following summary of what teacher educators think is the desired response to the rise of GenAI.

a. Gaining hands-on experience and developing familiarity with GenAI is essential to address teacher educators' lack of experience with the use of GenAI. Once they have developed an understanding of the opportunities and threats it offers, they could explore how GenAI can support the development of teacher education, and how its detrimental effects can be avoided. Next they could explore how their student teachers can use it in supportive and desirable ways. For example, could GenAI assist students in evaluating their educational practice during teaching practice, where the teacher educator is absent and the availability of tutoring potentially limited? In what way could GenAI provide a sounding board for the student teacher?
b. Accommodating learning how to use GenAI appropriately should be added to the learning aims of the teacher education programs, taking into account GenAI's many potentially supportive contributions. Since GenAI may be helpful in developing lesson plans and constructing various kinds of assessment, but cannot be trusted to be fully reliable, what skills do students need to develop in learning how to use GenAI effectively and reliably?
c. Determining in which activities or assessments the application of GenAI may prevent the student from engaging in or accounting for their learning, and explore ways to avoid this. Reliable assessment becomes impossible if GenAI can replace the student without being detected. Observing the student during the activity or assessment may be an effective countermeasure, but is likely time and energy consuming. Although work is needed in developing GenAI-proof assessment methods, educational development should also be directed at enhancing students' intrinsic motivation to engage in learning, rather than reinforcing measures that rely on extrinsic motivation. Moreover, student teachers will be confronted with this same problem in their own teaching, therefore teacher education needs to address this issue at that level as well.
d. Both student teachers and their educators need to develop awareness regarding how secondary school students use and abuse the application of GenAI in their learning, and engage e.g. in classroom research to explore how to incorporate GenAI in beneficial ways in the teaching and learning of their subject. As an example, the student teachers in our teacher education programs have since this interview study developed activities where GenAI was asked to solve exam questions and students explored its strengths and limitations as well as potentially supportive and detrimental contributions to their learning.

   Other examples included activities designed by participants that involved secondary school students using GenAI, verifying the quality of the product and evaluating their own work in obtaining it. For example, in designing a lesson about the solar system for their peers. Working iteratively towards an entirely satisfactory result, school students assessed process and product. Secondary school students prompted GenAI do the work they would normally do themselves, and then determined whether that had helped and if so, how.

a. Engage with teachers in secondary school, in particular with the tutors of their student teachers, to explore the implications of several of the issues discussed above. Teacher educators arguably have a responsibility that goes beyond educating their own students, who, in turn, tend to have a greater adaptability to newly developed technology than school teachers. The latter however, usually have a greater awareness of what is and is not feasible in secondary education. Collaboration between teacher educators, students and teachers in research and development of education that properly takes GenAI into account is desirable if not essential.
b. Engaging with their student teachers and their tutors at teaching practice schools, and collaborating in optimizing the developments listed above. For example, the activities developed by our students would benefit from being tried out and improved by more

experienced school teachers to ensure an optimal fit with pupils' prior knowledge and coherent integration into the teaching program as a whole.

We have tried to illustrate that many new and potentially powerful activities can be developed at all levels: supporting the teaching of teacher educators, teachers and student teachers, as well as the learning of school students and student teachers. We have shown that this is no trivial matter, as many concerns surround the use of GenAI that need careful consideration. Furthermore, many aspects of PCK in this area still need to be developed, implemented and shared, since PCK development can be strengthened by student teacher interaction (Park & Oliver, 2008). The appropriate integration of GenAI in the teaching practice of teachers in schools, student teachers and teacher educators in teacher education programs crucially requires that all stakeholders start to collaborate in learning to develop these activities, eventually resulting in secondary school students learning how to use GenAI expertly, appropriately and responsibly.

6.3. Limitations

This study in science teacher education is an attempt to monitor, describe and tentatively suggest directions for its response to GenAI as it becomes widely available, applicable, and gradually performs ever better. The most important limitation of this study is the speed of the technological development in GenAI that it is trying to capture the response to. Applications that may seem impossible at this time may be common a year from now, while paywalls or legislation may soon curb productions that are easily obtainable at the moment.

In terms of the professional development of teacher educators, the study describes merely a moment in time: it is not known how they will respond to the needs and challenges identified in this paper. Further limitations involve the setting of the study: our findings provide a reliable picture of the situation in Dutch teacher education programs at its Universities of Technology, but cannot be generalized to teaching programs at other universities or in other (non-STEM) subjects. We see no limitations in terms of the sample size for teacher educators, since for at least one program virtually all were interviewed, and views at other institutions did not deviate substantially. The relative number of student teachers was more modest but sufficiently diverse as well.

7. Conclusions

There are many opportunities for teacher educators to innovate teacher education programs in response to the rise of GenAI. In virtually all areas that involve processing and producing text, this technology has the potential to alleviate their work and that of their student teachers. However, this requires that they work with their student teachers in engaging with that technology, exploring the options, identifying the weaknesses and limitations, and acquiring appropriate know-how. Education has the responsibility to enable today's children in using this technology skillfully and responsibly and develop digital literacy. Teacher education is responsible for preparing teachers for delivering such education. Teacher educators, their students and teachers in school have a unique opportunity to design, explore and develop such education, and to develop the pedagogy to effectively guide these processes. We have described some interesting entries that could benefit that endeavor.

The data that support the findings of this article cannot be made publicly available because they contain personal information that could inadvertently identify participants. The data are available from the authors upon reasonable request.

CRediT authorship contribution statement

L.G.A. de Putter-Smits: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **C.F.J. Pols:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Conceptualization. **P.J.J.M. Dekkers:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis. **P.R. Runhaar:** Writing – review & editing, Resources, Methodology, Conceptualization. **M. Timmer:** Writing – review & editing, Investigation. **J.T. Van der Veen:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: The research was sponsored by our institutions (standard procedure) with the intention to supply its staff with time and means to innovate their courses based on research. Granting the funds is based on submitting a decent research plan. Some might find that a conflict of interest, but we feel that we are free to innovate our courses as we see fit, using the research as input. Our institute requires only to publicly present and publish our results in return for the funding.

Acknowledgments

The team is grateful to graduate student Stan van Etten MSc, for his willingness to incorporate our interview questions into his GenAI chemistry gamification study, saving us and the participants valuable time. We express our gratitude to our colleagues and our students who were willing to participate voluntarily and confided all their thoughts and actions with GenAI to the interviewers.

The 4TU collaboration offers it's teachers small grants to innovate and perform evaluative research with the aim of redesigning their courses. The authors applied for such a grant to afford themselves the time and means to gain information as a starting point to redesign science teacher education. The grant requires teachers to publish findings on the 4TU public website and to disseminate results to peers. The grant givers judge grant application by the standards of educational research. Grant number: IF2023- Putter.

Appendix. Interview protocol

A.1. Instruction for the interviewer

It is wise to write along with the interview, even if the recording is ongoing. This often speeds up the transcription process. First read the section Consent and GDPR to the participant and hand over the form. Take the signed form and see if permission has been granted. When granted, you can continue with the interview. The form can also be completed online via: [link]. Check if the participant is okay to start the recording and if so, start the recording.

Read the background to the research to the participant and then go to the questions.

Ask the main question, wait for an answer, and then try to get the interviewee to go deeper into the answer using the topics/examples below the main question. Ways to elicit an additions can be:

"What do you mean exactly?"

"Do you see […] as an influence?"

"For example, […]?"

"Are there any other things that have to do with this?"

Try not just to get an answer, but also to check whether the answer is complete and understandable. Keep the conversation relaxed and ask open, continuing questions.

After the interview, transfer the recording to the research drive and give the codes agreed upon. Check if the copy you made there is functional and then delete the recording from your own recording device. Scan the consent form; give the form the agreed name and put it on the

research drive as well.

Consent and GDPR

First, I would like to ask you for permission to use your answers to this interview for research purposes. We record the interview to be able to transcribe it verbatim. The transcription and its use in analysis and perhaps a publication will be anonymous. We use Participant1, 2 etc.

Would you please read and fill out this form about the research and data use? - Or Have you read and completed the digital form?

Background to the research

With the teacher training programs at 4TU, we want to see what the influence of language-based generative AI such as ChatGPT is on education and the training of future teachers. There are no right or wrong answers in this interview, we would like to collect all thoughts, experiences and concerns.

The teacher educator questions:

1. How long have you been working as a teacher educator?
2. What tasks, functions, jobs do you have besides teacher educator?
3. Can I have your age please?
4. [write down whether it is a man or woman; if you don't think it's clear, write down 'other']

   The questions are about you in your role as a teacher educator. Could you please answer the questions from that perspective?
5. Have you ever used an AI chatbot like ChatGPT yourself?
   a. Which one was that? Which version (number, paid etc.)
   b. Have you also used ChatGPT for your own work within teacher education?
   c. For what purpose?
   d. What (product(s)) did that yield?
6. What other examples do you know of the use of an AI chatbot in teacher education?

   For each of the examples:

   What do you think of using this application? Do you think this application can be used positively? Under what conditions? Do you think this application can have negative consequences? Can they be prevented? Please ask for as many examples as possible.
7. What applications of an AI chatbot do you expect to be developed for teacher education?

   Have the interviewee give as many examples as possible.

   For each of the examples:

   What do you think of using this application? Do you think this application can be used positively? Under what conditions? Do you think this application can have negative consequences? Can they be prevented?
8. Who do you think is responsible for the learning goal, learning to use chatbots ethically?
   a. How do you see the role of teacher education in this?
   b. How do you see your own role in this?
9. Who do you think is responsible for the learning objective of "being able to value the quality of the information provided by chatbots"?
   a. How do you see the role of teacher education in this?
   b. How do you see your own role in this?
10. Who is responsible in secondary school for the mentioned learning objectives: ethical use and quality of information in the use of Chatbots?
    a. How do you see the role of teacher education in this?
    b. How do you see your own role in this?
11. What other consequences does the arrival of an AI chatbot have for your profession as a teacher educator?

    Ask about the following things if they are not mentioned spontaneously:
    a. Consequences for the method of assessment? Which one?
    b. Consequences for the training policy? Which one?
    c. Consequences for the OER? Which one?
    d. Consequences for the Learning Objectives? Which one?
    e. Consequences for guidelines within the institute for the use of and fraud with AI chatbots? Which one? Or are they already there? Can you describe them?
12. Can you think of an example of a chatbot application that you find permissible for yourself, but not for your students?
    a. Can you elaborate on this?
13. Can you think of an example of an application that is permitted for your student teacher, but not for a student in secondary education?
    a. Can you elaborate on this?
14. Are there any other generative AIs that you know of that are being used for education?
    a. If so, for what?
15. All things considered, given the learning process of the student teacher, do you expect advantages from using a chatbot, or disadvantages?
    a. What are the benefits? What disadvantages?
16. Would you like to say something else about an AI chatbot or about anything else related to this interview?

The student teacher questions:

1. Which teacher education program are you in? (ask details)
2. Are you only a student teacher, or do you study for another program as well or are you employed?
   a. If so, ask details
3. Could I ask your age please?
4. [write down whether it is a man or woman; if you don't think it's clear, write down 'other']

   The questions are about you in your role as a student teacher. Could you please answer the questions from that perspective? We first ask questions about your use of an AI chatbot and then about the use of such a chatbot in teacher education and in secondary education.
5. Have you ever used an AI chatbot like ChatGPT yourself?
   a. Which one was that? Which version (number, paid etc.)
   b. Have you also used a chatbot for your studies in teacher education?
   c. For what purpose?
   d. What (product(s)) did that yield?
6. What other examples do you know of the use of an AI chatbot in teacher education?

   For each of the examples:
   a. What do you think of using this application? Do you think this application can be used positively? Under what conditions? Do you think this application can have negative consequences? Can they be prevented? Please ask for as many examples as possible.
7. What applications of an AI chatbot do you expect to be developed for teacher education?
   a. Have the interviewee give as many examples as possible.

      For each of the examples:
   b. What do you think of using this application? Do you think this application can be used positively? Under what conditions? Do you think this application can have negative consequences? Can they be prevented?
8. Who do you think is responsible for the learning goal, learning to use chatbots ethically?
   a. How do you see the role of teacher education in this?
   b. How do you see your own role in this?
9. Who do you think is responsible for the learning objective of "being able to value the quality of the information provided by chatbots"?
   a. How do you see the role of teacher education in this?
   b. How do you see your own role in this?

10. Who is responsible in secondary school for the mentioned learning objectives: ethical use and quality of information in the use of Chatbots?
    a. How do you see the role of teacher education in this?
    b. How do you see your own role in this?
11. What other consequences does the arrival of an AI chatbot have for your profession as a student- teacher?
    Ask about the following things if they are not mentioned spontaneously:
    a. Consequences for the method of assessment? Which one?
    b. Consequences for the training policy? Which one?
    c. Consequences for the OER? Which one?
    d. Consequences for the Learning Objectives? Which one?
    e. Consequences for guidelines within the institute for the use of and fraud with AI chatbots? Which one? Or are they already there? Can you describe them?
12. Can you think of an example of a chatbot application that you find permissible for yourself, but not for your students in secondary school education?
    a. Can you elaborate on this?
13. Are there any other generative AIs that you know of that are being used for education?
    a. If so, for what?
14. All things considered, given the process of becoming a teacher, do you expect advantages from using a chatbot, or disadvantages?
15. What are the benefits? What disadvantages?
16. Would you like to say something else about an AI chatbot or about anything else related to this interview?

Thank you for your time.

References

Avila, K. E., Steinert, S., Ruzika, S., Kuhn, J., & Küchemann, S. (2024). Using ChatGPT for teaching physics. *The Physics Teacher, 62*(6), 536–537. https://doi.org/10.1119/5.0227132

Berthelot, A., Caron, E., Jay, M., & Lefevre, L. (2025). Understanding the environmental impact of generative AI services. *Communications of the ACM*.

Bick, A., Blandin, A., & Deming, D. J. (2024). *The rapid adoption of generative AI (No. w32966)*. rev. 2025. National Bureau of Economic Research. https://doi.org/10.3386/w32966.

Castaneda Valle, R. (2024). *The triangle of lifelong learning: Strategies, motivation, and self-belief, pisa in focus, 128*. Paris: OECD Publishing. https://doi.org/10.1787/45ec682f-en

Cohen, L., Manion, L., & Morrison, K. (2002). *Research methods in education* (5th edition). London: Routledge.

Gregorcic, B., & Polverini, G. (2024). ChatGPT-4 and the satisfied Socrates. arXiv preprint *arXiv:2401.11987*.

Holbrook, J., & Rannikmae, M. (2007). The nature of science education for enhancing scientific literacy. *International Journal of science education, 29*(11), 1347–1362.

Holmes, N. G., Wieman, C. E., & Bonn, D. A. (2015). Teaching critical thinking. *Proceedings of the National Academy of Sciences, 112*(36), 11199–11204.

Hu, K. (2023). ChatGPT sets record for fastest-growing user base. *Analyst Note*. Last checked Dec 3 2024. Available from Https://www.reuters.com/technology/chatgpt-sets-record-fastest-growing-user-base-analyst-note-2023-02-01/.

Huallpa, J. J. (2023). Exploring the ethical considerations of using Chat GPT in university education. *Periodicals of Engineering and Natural Sciences (PEN), 11*(4), 105–115.

Kim, J., Lee, H., & Cho, Y. H. (2022). Learning design to support student-AI collaboration: Perspectives of leading teachers for AI in education. *Education and Information Technologies, 27*(5), 6069–6104.

Laugksch, R. C. (2000). Scientific literacy: A conceptual overview. *Science education: Issues & trends., 84*(1), 71–94. https://doi.org/10.1002/(SICI)1098-237X(200001)84:1%3C71::AID-SCE6%3E3.0.CO;2-C

Lee, G. G., & Zhai, X. (2024). Using ChatGPT for science learning: A study on pre-service teachers' Lesson planning. *IEEE Transactions on Learning Technologies*.

Macfarlane, B., Zhang, J., & Pun, A. (2014). Academic integrity: A review of the literature. *Studies in Higher Education, 39*(2), 339–358.

Mollick, E., & Mollick, L. (2023). Assigning AI: seven approaches for students, with prompts. arXiv preprint *arXiv:2306.10052*.

Moundridou, M., Matzakos, N., & Doukakis, S. (2024). Generative AI tools as educators' assistants: Designing and implementing inquiry-based lesson plans. *Computers and Education: Artificial Intelligence, 7*, Article 100277.

Next Generation Science Standards (NGSS). (2013). Appendix D: all standards, all students: Making the next generation science standards accessible to all students. *Next generation science standards*. Last checked: 17 Feb 2025 https://www.nextgenscience.org/sites/default/files/Appendix%20D%20Diversity%20and%20Equity%206-14-13.pdf.

Ng, D. T. K., Leung, J. K. L., Chu, S. K. W., & Qiao, M. S. (2021). Conceptualizing AI literacy: An exploratory review. *Computers and Education: Artificial Intelligence, 2*, Article 100041. https://doi.org/10.1016/j.caeai.2021

Noy, S., & Zhang, W. (2023). Experimental evidence on the productivity effects of generative artificial intelligence. *Science, 381*(6654), 187–192. https://doi.org/10.1126/science.adh2586

Park, S., & Oliver, J. S. (2008). Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education, 38*, 261–284.

Polverini, G., & Gregorcic, B. (2024). Performance of ChatGPT on the test of understanding graphs in kinematics. *Physical Review Physics Education Research, 20*(1), Article 010109.

Roberts, D. A., & Bybee, R. W. (2014). Scientific literacy, science literacy, and science education. In *Handbook of research on science education, II* pp. 559–572). Routledge.

Santos, R.P.D. (2023). Enhancing physics learning with ChatGPT, bing chat, and bard as agents-to-think-with: A comparative case study. arXiv preprint *arXiv:2306.00724*.

Shamsuddin, W. N. F. W., & Shariff, N. A. M. (2024). Can AI create better lesson plans than humans? This is what Malaysian English instructors think. *Advance – e-Research Magazine, 62*(5).

Tiwari, C. K., Bhat, M. A., Khan, S. T., Subramaniam, R., & Khan, M. A. I. (2024). What drives students toward ChatGPT? An investigation of the factors influencing adoption and usage of ChatGPT. *Interactive Technology and Smart Education, 21*(3), 333–355. https://doi.org/10.1108/ITSE-04-2023-0061

Van Puffelen, E. A. M., & Vonk, C. (2020). Learning from education innovation using the 4TU. CEE innovation map. In *The 16th International CDIO Conference Proceedings-Full Papers* (pp. 264–272).

Whalen, J., & Mouza, C. (2023). ChatGPT: challenges, opportunities, and implications for teacher education. *Contemporary Issues in Technology and Teacher Education, 23*(1), 1–23.

Yeadon, W., & Hardy, T. (2024). The impact of AI in physics education: A comprehensive review from GCSE to university levels. *Physics Education, 59*(2), Article 025010. https://doi.org/10.1088/1361-6552/ad1fa2