Artificial intelligence in K-12 instruction: the role of teacher professional development

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Abstract

This study examines 532 school teachers' perspectives on instructional quality, new teaching and learning opportunities, and the necessity for professional development (PD) activities related to artificial intelligence (AI) for K-12 education. Quantitative analyses revealed that AI-related PD opportunities are utilized to a limited extent thus far. However, the frequency of participation and satisfaction with the training are significantly and positively associated with key aspects of instructional quality (cognitive activation, classroom management, individualization, supportive climate). Furthermore, qualitative analyses indicate that the teaching profession is in its early stages of AI integration. The findings suggest that the transformative potential of AI for instruction remains either unclear to practitioners or beyond their current capacity for implementation. These results emphasize the importance of PD in AI for teaching in K-12 schools in the age of AI.

Keywords: Artificial intelligence, Teachers, Germany, Denmark, Instructional quality, Professional development

Introduction

Artificial intelligence (AI) is as a promising technology, with the potential to enhance teaching and learning in K-12 education (Bauer et al., 2025). Specifically, generative artificial intelligence (GenAI)—such as large language models (e.g., ChatGPT, Copilot) and text-to-image generators (e.g., Midjourney, DALL-E)—has gained widespread prominence due to its accessibility and user-friendly interface. Research has demonstrated that educators and students are increasingly utilizing GenAI tools for teaching and learning tasks (Stanford University, 2024; Vodafone Foundation, 2025). Findings revealed that students across seven European countries utilize AI-based tools for various purposes, including gaining information, generating explanations (e.g., terms, concepts), or providing complete solutions to tasks (Vodafone Foundation, 2025). However, these uses must be evaluated and supported with critical reflection, given the hallucination and data bias that are inherent to GenAI tools, among other challenges (Hicks et al., 2024). Yet, despite the need for support among students in using GenAI tools, teachers are the least involved in providing such support as compared to parents, friends, or classmates, with only 50% of students reporting receipt of assistance from them (Vodafone Foundation,

2025). Furthermore, only 44% of the students perceive their teachers as adequately prepared to utilize AI applications. A recent large-scale study (Jude et al., 2025) highlights that also teachers feel ill-prepared. The majority of teachers (62%) reported feelings of insecurity regarding the use of AI-based tools for school purposes, with only a small percentage (6%) expressing a sense of profound competence.

This indicates the urgent need of professional development (PD) courses for educators to develop the necessary competencies to utilize AI effectively, to be able to serve as role models for students, and to provide learners with high quality instruction in the age of AI (Organization for Economic Cooperation and Development [OECD], 2025). Research shows that PD is crucial to enhance instructional quality in general (e.g., Darling-Hammond et al., 2017; Desimone et al., 2005) and GenAI-focused PD specifically to enable teachers to develop the necessary AI literacy to incorporate GenAI tools into their teaching successfully (Tan et al., 2025). However, there is a limited knowledge of teachers' participation in PD and the effect of PD on instructional quality. Furthermore, there is a lack of knowledge on how teachers try to enhance instructional quality with AI and their needs for future PD.

To fill this research gap, this study adopted a mixed-methods approach by collecting both quantitative and qualitative data from Danish and German teachers. By focusing on education systems that differ in their pace of educational technology adoption—Denmark has long been a frontrunner in technology adoption, while Germany lagged behind until recently (Kerres, 2020; Mah et al., 2025; Regeringen [Danish Government], 2003)—this study provides comprehensive insight into GenAI-focused PD and teachers' implementation of AI-enhanced teaching and learning in the K-12 educational sector. This study sheds light on teachers' participation and satisfaction with GenAI-focussed PD and quality of instructional design when utilizing GenAI for school purposes. It provides teachers' insights into the new possibilities for teaching and learning that GenAI presents and actionable knowledge on what future PD should focus on.

Theoretical background
AI in the teaching profession
AI in education shows promise in transforming teaching and learning for both teachers and students. Focusing on teachers, AI-enhanced tools may, for example, support teachers in lesson planning and help create tailored learning and assessment materials (Crompton et al., 2022; Kasneci et al., 2023). This reduces the time spent on organizational tasks and gives them more time for personal interactions (Bozkurt et al., 2024; Crompton & Burke, 2024). Moreover, AI-based tools also provide teachers with advanced insights into learning patterns and student progress (Luckin & Cukurova, 2019; Yusuf et al., 2024). Similar advantages are also highlighted by Celik et al. (2022) in a systematic review on the implications of AI for educators. Their analysis demonstrated that AI offers teachers several opportunities for enhanced planning, implementation, and assessment of their teaching. These opportunities include, for example, defining and becoming familiar with students' needs, providing immediate feedback and tailored teacher intervention, and utilizing automated scoring for assessment. In contrast, the utilization of AI-enhanced tools by educators for academic purposes comes with challenges. For example, concerns have been raised regarding access, licensing, data privacy

and protection, ethical considerations, and hallucinations (Bianchi et al., 2023; Hicks et al., 2024; Holmes et al., 2022). Consequently, the evolving landscape of AI in education indicates a transformative shift, with calls to embrace AI in the classroom (Walter, 2024). Conversely, the present discussion leans toward a more critical and reflective viewpoint, thus emphasizing a more nuanced perspective on AI-enhanced teaching and learning—beyond the hype (Bauer et al., 2025).

Furthermore, Celik et al. (2022) also emphasize that teachers play an important role in AI education. They should promote and support students in developing a holistic AI literacy. Therefore, it is crucial to understand teachers' perceptions regarding AI literacy education and provide pedagogical strategies, resource development, and needs-based professional training for both pre-service and in-service teachers (Yim & Su, 2025).

Yet, a recent representative study (Jude et al., 2025) conducted among 1540 teachers in Germany revealed that the majority of the participants do not feel sufficiently prepared. However, the study indicates that over half of the teachers utilize AI tools for creating assignments and lesson planning. This suggests that AI is not only influencing how students learn but also the how teachers work. It is noteworthy, that over 50% of respondents expressed a desire for additional training in leveraging AI for lesson design, with almost half seeking instruction on methodologies to promote critical thinking (e.g., source evaluation), employing AI in lesson planning and assessing student performance. In addition, teachers expressed a desire to develop didactic qualifications for the integration of AI into the classroom (Jude et al., 2025).

Research in instructional design and the instructional quality of teaching with AI has recently emerged (Mah & Egloffstein, 2025) with the aim to modify and extend established models, such as the technology pedagogical content knowledge (TPACK) (Mishra & Koehler, 2008; Petko et al., 2025), in the age of AI. For example, Lorenz and Romeike (2023) introduced the framework AI-TPACK, with reference to AI domains for the AI era. Celik (2023) proposed an extended TPACK framework, integrating knowledge with teachers' ethical assessments. Moreover, a recent model by Prilop et al. (2025) highlights the triadic nature of AI literacy (AI as a teaching tool, AI as learning content, AI as a learning tool) in the teaching profession that requires teachers to be AI literate even if they do not plan to use AI-tools themselves.

Professional development and instructional quality

In this light, AI-focused professional development (PD) can play a key role in developing teachers' AI literacy and supporting the successful integration of AI in schools (Tan et al., 2025). Teacher PD courses have long been considered "essential to efforts to improve … schools" (Borko, 2004, p. 3). A substantial body of research reveals that PD can effectively enhance instructional quality and improve student learning outcomes (e.g., Borko & Putnam, 1995; Darling-Hammond et al., 2017; Desimone et al., 2005). Researchers suggest that these high-quality instructional settings can be further enhanced by using AI (Kasneci et al., 2023). In general, research indicates that certain teaching processes are consistently positively related to students' cognitive and affective outcomes (e.g., Allen et al., 2013; Praetorius et al., 2018). While various frameworks describe these teaching processes, two prominent examples are the three basic dimensions framework (e.g., Klieme et al., 2001; Praetorius et al., 2018) and the CLASS framework (Pianta & Hamre,

2009). These frameworks characterize high-quality instructional settings as marked by well-organized classrooms (classroom management), emotionally and instructionally supportive environments (supportive climate, individualization), and cognitively engaging activities (cognitive activation).

Classroom management has long been regarded as a crucial component of effective teaching (e.g., Kounin, 1970). Successful classroom management is reflected in the efficient use of instructional time, which is achieved through effective time management and minimizing classroom disruptions. A supportive classroom climate focuses on fostering respectful and appreciative social interactions between teachers and students as well as among students (Praetorius et al., 2018). For teachers, this entails showing interest in students' individual interests and discussing their learning progress in a personalized manner. Teachers can cognitively support students through individualization (Lipowski, 2015). This involves adapting tasks to match students' current knowledge levels and providing constructive feedback. Cognitive activation is achieved by implementing instructional strategies that present students with challenging tasks and stimulate higher-level thinking processes (Baumert et al., 2010; Klieme et al., 2009). Thus, teachers need to design tasks that demand mental effort and foster problem-solving skills.

Recently, researchers have suggested that advanced AI tools, such as ChatGPT or Claude, could support teachers in implementing these high-quality teaching processes (Kasneci et al., 2023). While studies specifically focusing on advanced AI tools remain scarce, insights can also be drawn from studies on earlier digital tools. For example, digital tools have been shown to assist teachers in effective lesson planning, thereby increasing time-on-task and enhancing classroom management (Sabanci et al., 2014). Moreover, AI chatbots can help provide support tailored to students' individual learning needs (Lee & Maeng, 2023), and AI tools can aid teachers in automating feedback during learning tasks (Meyer et al., 2024), thereby enabling a higher degree of student individualization. Additionally, digital tools have been found to increase cognitive activation (Fütterer et al., 2022). AI tools—such as chatbots—can facilitate interactive, conversational learning environments, which can further enhance student engagement (Guo et al., 2024).

Given the significant impact of classroom management, individualization, supportive climate, and cognitive activation on student outcomes (e.g., Allen et al., 2013; Dorfner et al., 2018; Kunter et al., 2013), it is important to analyze the extent to which teachers use AI tools and their associated capabilities to support these crucial teaching processes.

Research gap and study objectives

As outlined, recent studies highlight that teachers are ill-prepared for successfully incorporating AI into their classrooms (Jude et al., 2025) and fail to offer students the necessary support in navigating this emerging technology (Vodafone Foundation, 2025). With students increasingly using GenAI tools in the classroom (Stanford University, 2024; Vodafone Foundation, 2025), this shows a pressing need for PD courses that enable teachers to develop AI literacy for successful adoption in the classroom.

Yet, there is limited evidence regarding the effect of PD on instructional quality, which quality dimensions of instruction (cognitive activation, classroom management, individualization, supportive climate) teachers choose to support with AI tools, and

which changes to teaching need to be considered for future professional development initiatives.

Accordingly, this study addresses the following research questions:

1. **RQ 1:** To what extent do teachers in Germany and Denmark participate in AI-related PD, and what are their satisfaction levels regarding such training opportunities?
2. **RQ 2:** Are teachers' participation in and satisfaction with AI-related PD associated with their self-reported instructional quality when using AI tools, and do these associations differ between Germany and Denmark?
3. **RQ 3:** How do teachers describe AI-enabled teaching practices, and to what extent do these practices reflect established dimensions of instructional quality (cognitive activation, classroom management, individualization, and supportive climate)?
4. **RQ 4:** What changes do teachers envision for classroom teaching and assessment in the age of AI?

Methods

Data collection and sample

An online questionnaire was designed to collect data from teachers in Germany and Denmark. From January 2025 to February 2025, a market research institute (Norstat) collected data by organizing and conducting participant acquisition and providing questionnaires. The questionnaires were provided in German for teachers in Germany and in Danish for teachers in Denmark. This therefore constitutes a random sample. The total sample size was $N = 532$ teachers ($N_{Germany} = 256$, $N_{Denmark} = 276$). Of the participants, 293 (57.8%) were female, 213 (42.0%) were male, and 1 (0.2%) identified as diverse. Most of the teachers ($n = 244$) were in the age group of between 30 and 49 years (48.1%), 131 were in the age group of between 50 and 59 (25.8%), 97 were 60 years old and above (19.1%), and 35 (6.9%) were aged 29 years and younger. Twenty-five participants preferred not to reveal their gender or age. Of the participating teachers in Germany, 22.4% are employed at ISCED level 1 (primary schools), 63.7% at a different ISCED level (secondary schools), and 13.9% at another school type (UNESCO Institute for Statistics, 2012). Of the participants in Denmark, 60.3% are teachers at Fokeskole (primary schools), 14.1% Privatskole/Friskole (either primary or secondary schools), 4.2% Efterskole, 8.4% Gymnasium (secondary school), and other school types (13.0%). The three subjects that were taught most frequently were native language (German/Danish) (40.8%), mathematics (28.8%), and second language (28.8%) (multiple answers possible).

The authors state that all relevant ethical guidelines and principles were carefully considered in the preparation of this scientific article. The conduct of the research, as well as data collection, analysis, and interpretation, was performed in strict adherence to ethical standards. The present study consisted of an anonymous, voluntary online survey of adult participants on non-sensitive educational topics and did not involve patients or interventions. Thus, in line with the guidelines of the German Research Foundation (DFG), the present study does not require formal ethics committee approval (https://www.dfg.de/en/research-funding/proposal-funding-process/faq/humanities-social-sciences). The authors further state that prior to the quantitative survey, all participants

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were comprehensively informed about the objectives and purpose of the study. They were also provided with detailed information regarding the secure and compliant handling of their data in accordance with data protection regulations. Participation was entirely voluntary, and participants had the right to withdraw at any time without any consequences.

Instruments

The majority of the items for the online questionnaire were adapted from existing literature (e.g., Fraillon & Rožman, 2024; Meyer et al., 2023; Quast et al., 2021; Runge et al., 2023) (i.e., the original item wording was changed from "digital tools/technologies" or "ICT" to "AI-based tools"), while two were newly developed (e.g., open-ended questions) (Table 1). Furthermore, the survey inquired about the respondents' gender, age, main subjects, and their school type. Only minor linguistic and contextual adjustments were made when adopting the items to accommodate their translation into the respective national languages.

Data analysis

The study employed a mixed-methods approach to generate both robust quantitative insights and nuanced qualitative findings. For the quantitative analyses (RQ1 and RQ2), descriptive statistics and regression analyses were conducted using IBM SPSS 29 (New York) software (IBM Corporation, 2022). No cases were excluded from the dataset. When individual variables contained missing values, no imputation

Table 1 Instrument sections for RQ with sample items, answer formate/scale, and reliabilities

Sample item	Answer format/scale
Professional development	
How often did you participate in professional learning activities dealing with AI in the context of teaching in the past two years? [adapted from Fraillon and Rožman (2024)]	Single choice: Not at all—>Only once—>More than once (1–3)
How satisfied were you with the PD on AI overall? [adapted from Meyer et al. (2023)]	6-point Likert scale: Not at all satisfied—> Fully satisfied (1–6)
Self-reported instructional quality [adapted from Quast et al. (2021); Runge et al. (2023)], 9 items, $\alpha = 0.96$	
1. Cognitive activation (3 items), e.g. In class, I ask students to demonstrate different ways to solve a problem using AI-based tools	5-point Likert scale: Never—> Every lesson (1–5)
2. Classroom management (3 items), e.g. In class, I use AI-based tools to summarize the most important things	5-point Likert scale: Never—> Every lesson (1–5)
3. Individualization (2 items), e.g., In class, I use AI-based tools to meet the needs of students with different levels of competence	5-point Likert scale: Never—> Every lesson (1–5)
4. Supportive climate (3 items), e.g. In class, I use AI-based tools to inform students about their individual progress	5-point Likert scale: Never—> Every lesson (1–5)
Teaching with AI (self-developed)	
What has AI enabled you to do in your teaching that wasn't possible before? What innovations have you introduced in your teaching?	Open-ended question, String
In the age of AI, how do you think school teaching and exams should change?	Open-ended question, String

procedures were applied. Composite scores for the four instructional quality dimensions were created by averaging the corresponding items, all of which were coded in the same direction. No control variables were included as the focus was on the associations between professional development, satisfaction with training and instructional quality. All regression analyses were conducted using standard linear models. To answer RQ1 and RQ2, a descriptive analysis and multiple linear regression analyses were conducted. First, the descriptive analysis was run to determine how often the surveyed teachers had participated in additional training or PD opportunities related to AI within the last two years. Then, the relationship between satisfaction with the training and instructional quality was analyzed. Mean values were created for the four dimensions of instructional quality (cognitive activation, classroom management, individualization, and supportive climate) as dependent variables. A series of multiple linear regression analyses was conducted to examine the relationship between participation in teacher training and the quality of instructional practices. The dependent variables were the four dimensions of instructional quality. The key predictor was participation in PD. This variable was originally categorized into three levels: (1) no participation, (2) participation in one training session; and (3) participation in multiple training sessions. Dummy coding was conducted to include this variable in the regression models. Then, a regression was performed using satisfaction with continuing education as an independent variable and one dimension of instructional quality.

For the qualitative analyses of open-ended responses (RQ3 and RQ4), qualitative content analysis was performed following Mayring's (2021) systematic approach. RQ3 utilized deductive category application, where responses were first classified as instructional optimization (improving existing practices) or instructional innovation (enabling new possibilities) based on linguistic indicators, then further categorized according to the four quality dimensions framework (cognitive activation, classroom management, individualization, supportive climate). RQ4 employed inductive category development, where categories systematically emerged from the data through iterative coding rounds. Following Mayring's (2021) procedure, initial categorization, systematic revision, and category refinement was performed until saturation was achieved. Both analyses utilized systematic keyword-based classification combined with manual boundary case resolution. Data processing for the qualitative analyses involved several steps: For RQ3, 3 invalid responses (off-topic or incomprehensible) were excluded from the initial 488 responses, leaving 485 responses for analysis. For RQ4, 16 non-informative responses were excluded from the initial 488 responses, leaving 472 valid responses for analysis. English translations of all responses ensured consistent cross-linguistic analysis. After excluding invalid responses, all remaining responses were successfully categorized (n = 485 for RQ3; n = 472 for RQ4). A small proportion of responses were assigned to miscellaneous categories due to unclear content (RQ3: 2.3%, n = 11; RQ4: 2.5%, n = 12). For RQ3, 82% of responses were automatically classified through keyword-based coding, while 18% required manual boundary case resolution. For RQ4, systematic recoding across multiple iterations reduced unclear/miscellaneous responses from 106 to 12, systematic recoding reduced unclear responses from 106 to 12 (88.7% reduction). Coding reliability was ensured through transparent coding rules and systematic recoding procedures

following Mayring's (2021) quality criteria. The detailed coding schemas with category definitions and example responses are provided in the Appendix.

Results

RQ1: Teachers' participation and satisfaction regarding AI-related PD

Table 2 presents the results for teachers' participation and satisfaction in AI-related PD over the last two years—59.3% of respondents did not participate in any AI-related PD, 25.2% participated once, and only 15.5% participated more than once. Teachers in Germany have participated more in PD activities than teachers in Denmark, particularly repeated participation.

The overall satisfaction levels varied among the 210 teachers who had participated in at least one AI-related PD opportunity (Table 2). While most teachers expressed at least moderate satisfaction with AI-related PD, German teachers reported being generally more satisfied than their Danish counterparts.

RQ 2: Impact of teachers' participation in and satisfaction with AI-related PD on their self-reported instructional quality when utilizing AI

The multiple regression model that predicted cognitive activation was statistically significant, $F(2, 510) = 37.75$, $p < 0.001$, explaining 12.9% of the variance. Compared to teachers with no training, those who attended the training once reported significantly higher levels of cognitive activation ($B = 0.436$, $SE = 0.094$, $\beta = 0.197$, $p < 0.001$), with even stronger effects for repeated participation ($B = 0.937$, $SE = 0.113$, $\beta = 0.353$, $p < 0.001$). The cognitive activation model was statistically significant, $F(1, 206) = 19.35$, $p < 0.001$, thereby explaining approximately 8.6% of the variance. Further, satisfaction with the PD significantly predicted the implementation of cognitively activating strategies ($B = 0.30$, $SE = 0.067$, $t = 4.40$, $p < 0.001$, $\beta = 0.29$), thereby indicating a moderate positive effect.

The multiple regression model was statistically significant, $F(2, 510) = 24.33$, $p < 0.001$, explaining 8.7% of the variance in classroom management. Compared to teachers without training, those who attended once scored significantly higher in classroom

Table 2 Descriptive statistics on participation and satisfaction with AI-focused PD

	Total		Germany		Denmark	
	n	%	*n*	%	*n*	%
Participation						
Participants	507		245		262	
Not at all	306	59.3	130	51.6	176	66.7
Only once	130	25.2	68	27.0	62	23.5
More than once	80	15.5	54	21.4	26	9.8
Satisfaction						
Participants	210		122		88	
Not at all satisfied	13	6.2	4	3.3	9	10.2
Rather not satisfied	29	13.8	16	13.1	13	14.8
Partially satisfied	68	32.4	37	30.3	31	35.2
Rather satisfied	72	34.3	47	38.5	25	28.4
Fully satisfied	28	13.3	18	14.8	10	11.4

management ($B=0.340$, $SE=0.096$, $\beta=0.154$, $p<0.001$), with even higher scores among those with multiple training sessions ($B=0.773$, $SE=0.115$, $\beta=0.293$, $p<0.001$). The regression model for classroom management was statistically significant, $F(1, 206)=28.90$, $p<0.001$, explaining 12.3% of the variance. Further, satisfaction with the PD significantly predicted the implementation of classroom management strategies ($B=0.35$, $SE=0.065$, $t=5.38$, $p<0.001$, $\beta=0.35$), thus indicating a moderate positive effect.

The multiple regression model was statistically significant, $F(2, 510)=26.77$, $p<0.001$, explaining 9.5% of the variance in individualization. Compared to teachers without training, those who attended training once ($B=0.361$, $SE=0.095$, $\beta=0.166$, $p<0.001$) and those with multiple sessions ($B=0.795$, $SE=0.114$, $\beta=0.304$, $p<0.001$) reported significantly higher levels of individualization. The regression model for individualization was statistically significant, $F(1, 206)=33.97$, $p<0.001$, explaining 14.2% of the variance. Moreover, satisfaction with the PD significantly predicted the implementation of individualized teaching strategies ($B=0.37$, $SE=0.063$, $t=5.83$, $p<0.001$, $\beta=0.38$), thus indicating a moderate positive effect.

The multiple regression model was also statistically significant, $F(2, 510)=32.47$, $p<0.001$, explaining 11.3% of the variance in constructivist support. Teachers who attended the training once ($B=0.380$, $SE=0.090$, $\beta=0.181$, $p<0.001$) and those who attended multiple training sessions ($B=0.836$, $SE=0.109$, $\beta=0.331$, $p<0.001$) reported significantly higher levels of constructivist support than those without training. The regression model for supportive climate was statistically significant, $F(1, 206)=24.17$, $p<0.001$, explaining 10.5% of the variance ($R^2=0.105$, adjusted $R^2=0.101$). Further, satisfaction with the PD training significantly predicted the implementation of supportive classroom practices ($B=0.32$, $SE=0.065$, $t=4.92$, $p<0.001$, $\beta=0.32$), thus indicating a moderate positive effect.

RQ 3: AI-enabled teaching practices and AI teaching practices by instructional quality dimensions

A total of 485 teachers provided valid responses regarding AI-enabled teaching practices. The analysis revealed that 175 teachers (36.1%) indicated no current AI adoption, while 32 (6.6%) provided generic statements (13 positive, 7 negative, 12 ambivalent) without specific applications. Among the 267 teachers (55.1%) who reported substantive AI use, instructional optimization dominated over innovation, with 231 teachers (86.5%) describing efficiency improvements to existing practices compared to only 36 (13.5%) reporting fundamentally new teaching possibilities. Eleven responses (2.3%) were classified as miscellaneous due to unclear content. As presented in Table 3, cognitive activation emerged as the dominant application area, representing 70% of all AI use cases. Teachers primarily described content creation activities, such as generating worksheets, creating visual materials, and preparing lesson resources. Individualization represented 17.6% of applications, focusing on differentiated task design and adaptive learning approaches. Applications of AI to create a supportive classroom climate (12%) emphasized student autonomy and collaborative learning enhancement. Applications of AI for classroom management were minimal (0.4%).

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Table 3 AI teaching practices by quality dimensions

Quality dimension	Example quote	Optimization *n* (%)	Innovation *n* (%)	Total *n* (%)
Cognitive Activation	"I can quickly find explanations, generate worksheets, and design tasks."	165 (71.4)	22 (61.1)	187 (70.0)
Individualization	"Every student can learn according to their performance."	38 (16.5)	9 (25.0)	47 (17.6)
Supportive Climate	"More intensive group work"	27 (11.7)	5 (13.9)	32 (12.0)
Classroom Management	"Silent assignments"	1 (0.4)	0 (0.0)	1 (0.4)

N = 267 AI users. Percentages in the Optimization and Innovation columns are based on column totals (*n* = 231 and *n* = 36, respectively). Total column percentages are based on all AI users (*N* = 267)

Table 4 Teacher visions for AI-era educational changes

Category	Example quote	*n* (%)
AI Relationship Strategies	"We need to use AI, but not at any price"	142 (30.1)
Uncertainty & Resistance	"I lack knowledge in this area"	141 (29.9)
Assessment Transformation	"More oral examinations needed"	97 (20.5)
Pedagogical Changes	"Focus on critical thinking skills"	45 (9.5)
Institutional Requirements	"Teachers need AI training"	35 (7.4)
Miscellaneous	"I am glad that I'll be retiring in just over a year"	12 (2.5)

N = 472 valid responses

RQ 4: Teachers' visions for classroom teaching and assessment in the age of AI

A total of 472 teachers provided valid responses regarding future changes in AI-era education. Our analysis revealed six main categories of suggested changes, with AI Relationship Strategies (30.1%) and Uncertainty & Resistance (29.9%) representing almost 60% of all responses. Twelve responses (2.5%) were classified as miscellaneous due to unclear content.

As presented in Table 4, AI Relationship Strategies dominated teacher responses, with teachers primarily favoring integration approaches over avoidance strategies. Within this category, 80 teachers (56.3%) emphasized integration ("We should make more use of it"), 35 teachers (24.6%) focused on education ("Students must be taught how to use it correctly"), and 27 teachers (19.0%) advocated avoidance ("Ban AI"). Assessment Transformation represented the third-largest category, with 65 teachers (67.0%) suggesting format changes, such as shifts toward oral examinations and handwritten tests, 30 teachers (30.9%) addressing evaluation focus changes ("Evaluate less content and focus more on approaches, processes, and understanding"), and 2 teachers (2.1%) proposing AI integration in assessment processes.

The high proportion of responses in the Uncertainty & Resistance category revealed significant knowledge gaps among teachers, with 130 teachers (92.2%) explicitly stating knowledge gaps ("I don't know", "I lack knowledge in this area") and 11 teachers (7.8%) expressing resistance to change ("Why always do everything differently? The old method has proven itself""). Further, Pedagogical Changes included 15 teachers (33.3%) who focused on skills development, 20 teachers (44.4%) who suggested teaching methods modifications, and 10 teachers (22.2%) proposed content changes. Institutional Requirements included 15 teachers (42.9%) who identified teacher development needs,

12 teachers (34.3%) who cited infrastructure requirements, and 8 teachers (22.9%) who emphasized governance frameworks.

Discussion, conclusion, and future research

In this study, we examined the perspectives of school teachers in Germany and Denmark on AI-related PD, instructional teaching quality, and new possibilities when teaching and learning with AI. Our quantitative findings (RQ1) reveal that AI-related PD opportunities in the school sector have been utilized only to a limited extent thus far, although AI is an emerging topic in education, and research reveals that many teachers feel unsure regarding the utilization of AI-based tools for school purposes and would like to participate in such activities (Jude et al., 2025). In keeping with this, research indicates that AI-related PD activities for teachers remain rather limited (Ng et al., 2025; Sperling et al., 2024; Tan et al., 2025). Over half of the teachers in Germany and two-thirds in Denmark reported not participating in any such training in the past two years. This is in notable contrast to the growing societal and educational relevance of AI.

Notably, a small proportion of teachers engaged in repeated training, thus suggesting a lack of continuous learning opportunities or incentives. Despite the low participation rates, the results reveal that the frequency of participation and satisfaction with the training are significantly and positively associated with key aspects of instructional quality—such as cognitive activation, classroom management, individualization, and a supportive classroom climate (RQ2). These results emphasize the importance of PD in integrating AI into teaching and demonstrate that PD can measurably impact teachers' classroom practice. This finding is line with research that indicates the positive effects of a PD program on AI literacy (Younis, 2024). A country-specific analysis revealed that German teachers were more likely to have participated in AI-related training and reported higher satisfaction levels than their Danish counterparts. This may reflect differences in PD landscapes, institutional frameworks, or training program content and design (Mah et al., 2025c).

Our qualitative analysis reveals that the teaching profession is at an early stage of AI integration. With regard to AI-enabled teaching practices (RQ3), 36.1% of teachers reported no current adoption. This substantial nonadoption rate suggests significant barriers to implementation, which potentially include insufficient training, technical limitations, or pedagogical skepticism. Among AI adopters, the 6.4:1 ratio of optimization to innovation indicates that teachers primarily conceptualize AI as an efficiency tool rather than a transformative educational technology (Bauer et al., 2025). This finding suggests that the transformative potential of AI for instruction remains either unclear to practitioners or is beyond their current implementation capacity. The dominance of cognitive activation applications (70%) aligns with AI's strength in content creation and task design (Kasneci et al., 2023), yet reveals its underutilized potential in other quality dimensions. Individualization (17.6%) and supportive climate (12.0%) applications were notably underrepresented, despite AI's documented capabilities for adaptive learning and personalized feedback (Bozkurt et al., 2024; Crompton et al., 2022). The virtual absence of classroom management applications (0.4%) was particularly unexpected, thus suggesting that teachers view AI primarily as a preparation tool rather than an active instructional resource during lessons. With regard to future visions for educational

change (RQ4), teacher responses revealed contrasting approaches between pedagogical and assessment considerations. While pedagogical changes (9.5%) suggest developmental adaptation to AI capabilities, assessment transformation responses (20.5%) were predominantly conservative, thereby emphasizing format restrictions and analog alternatives rather than innovative integration. This pattern may indicate that teachers perceive AI as challenging the validity of traditional assessment while recognizing its potential for instructional enhancement (Bower et al., 2024). The substantial uncertainty rate (29.9%) combined with explicit mentions of training needs in institutional requirements (7.4%) highlights significant PD gaps (Sperling et al., 2024; Tan et al., 2025). Teachers' pragmatic recognition that "students will use it whether we like it or not" reflects an awareness of the inevitability of AI use (Prilop et al., 2025), but the emphasis on format restrictions suggests institutional challenges in developing frameworks for meaningful AI integration in educational assessment.

The results should be interpreted with consideration of the study's limitations. First, the data are based on self-reports from teachers and may be subject to the social desirability bias or other subjective distortions. Additionally, the content, format, and quality of the training sessions were not evaluated, which limits the interpretability of the satisfaction ratings. Second, due to the cross-sectional design of the study, no causal inferences can be drawn. Although significant associations were found among participation, satisfaction, and reported instructional practices, it is possible that particularly motivated or tech-savvy teachers are more likely to attend AI-related PD and implement innovative teaching strategies, regardless of the training itself. Third, country-specific comparisons should also be interpreted with caution because national policy contexts and curriculum frameworks were not included in the analysis, thus making it difficult to generalize the results.

Furthermore, a few methodological considerations should be noted regarding our qualitative analyses. The single-coder approach limits intercoder reliability assessment, although systematic keyword-based classification and high categorization success rates (>97%) suggest robust category validity. Moreover, translation effects may influence the cross-cultural interpretation of responses, particularly regarding pedagogical terminology and cultural nuances in AI perceptions. The exploratory nature of future-oriented questions (RQ4) inherently involves uncertainty, which are reflected in the high "don't know" response rates across both countries. Additionally, self-reported data may be subject to social desirability bias, and the cross-sectional design prevents the assessment of how teacher perspectives evolve over time as AI tools become more prevalent in educational settings.

To obtain an even more comprehensive understanding of teachers' perspectives on AI integration in teaching practices, future research should address several important directions that have emerged from our qualitative findings. Longitudinal studies that track teachers' AI adoption and application patterns over time could provide insights into the effectiveness of PD and the natural evolution of AI integration. A cross-cultural comparative analysis of AI application patterns warrants systematic investigation, as preliminary observations suggest potential differences between teachers in Germany (efficiency/tool-focused) and teachers in Denmark (pedagogical/student-focused approaches). Additionally, intervention studies that examine the impact of targeted PD

on teachers' ability to leverage AI for individualization and supportive climate applications could address the underutilization identified in our findings.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40561-026-00442-4.

> Additional file1 (DOCX 24 kb)

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