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Research paper

A case study of teachers' generative artificial intelligence integration processes and factors influencing them

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A R T I C L E I N F O

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A B S T R A C T

How schoolteachers integrate generative artificial intelligence (GenAI) into their teaching remains underexplored. This case study of 22 teachers from Guangdong delineates four GenAI user types, i.e., cautious adapters, efficiency enhancers, technology enthusiasts, and pedagogical innovators; groups teachers' GenAI integration into five levels, from low to high; and examines how transformation of GenAI integration is influenced by individual, technological, and environmental factors. These findings extend the Substitution, Augmentation, Modification, and Redefinition (SAMR) model into PSAMR – the "P" stands for "Prohibition" – emphasizing GenAI's dynamic, controversial nature. They also indicate that, during integration, educators should focus more on human factors than on tools' functionalities.

The rapid development of generative artificial intelligence (GenAI) has further facilitated the integration of technology into education (Jin et al., 2025). GenAI allows its users to generate new text, images, audio, video, and 3D models by inputting requests (Chen et al., 2025; Dwivedi et al., 2023). Able to engage in natural-language processing and reasoning (Meskó & Topol, 2023), it is expected to transform teaching processes, methodologies, and assessment (e.g., Wang et al., 2025). Integrating GenAI into teaching can not only enhance learning outcomes (e.g., Kim et al., 2025) but also improve learners' problem-solving abilities (Mokmin & Rassy, 2024), communication skills (Liu et al., 2024), autonomy (Szabó & Szoke, 2024), creativity (Vartiainen & Tedre, 2023), and learning emotions (Luo, 2024).

However, four important gaps remain in research on teachers' GenAI integration. First, despite a consensus that the quality of teachers' technology integration is more important than the mere frequency of their tool use (Backfisch et al., 2021), the existing literature tends to maintain a deterministic, technocentric focus on the GenAI tools teachers use and their functionalities, rather than looking pedagogically at the extent to which such tools are meaningfully exploited to support them and their students. Paying due attention to the varying quality levels and evolutionary processes of GenAI integration can be expected to help educators better understand their own roles in such integration (Szabó & Szoke, 2024).

Second, teachers face numerous obstacles to GenAI integration, including their own and their students' digital-literacy gaps (Lan & Chen, 2024); ethical concerns, notably around academic dishonesty and information security (Chan & Hu, 2023); and cultural barriers (Yusuf et al., 2024). Identifying the factors that facilitate and hinder diverse teachers' GenAI integration could therefore help streamline and support the integration process. Detailed vignettes illustrating how those factors influence that process would enable researchers and other stakeholders to establish guidelines for GenAI use and create a secure, reliable environment for its application, but such vignettes are rarely presented (Dwivedi et al., 2023).

Third, previous research on technology integration suggests that teachers' GenAI integration levels shift over time (Consoli et al., 2023; Hamilton et al., 2016). Investigating this shift will allow us to view GenAI integration not merely through a technological lens, but also from the teacher's perspective, addressing a limitation of earlier models.

Finally, previous technology-integration frameworks have drawbacks. The Technological Pedagogical Content Knowledge framework (TPACK; Koehler & Mishra, 2009) helps explain the knowledge teachers need if they are to integrate technology into their teaching, but overlooks environmental and technological factors that could facilitate or hinder such integration. Antonietti et al. (2023) extended the Interactive, Constructive, Active, Passive framework (ICAP; Chi & Wylie, 2014) to technology integration, but their scale focuses on predicting instructional outcomes rather than providing qualitative analysis of the integration process. The Substitution, Augmentation, Modification, and Redefinition model (SAMR; Puentedura, 2006), meanwhile, provides a

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more practical framework for categorizing technology-integration levels (Blundell et al., 2022) but broadly ignores that different teachers may have different integration processes with a wide range of influencing factors; and it has not hitherto been empirically tested in GenAI-use contexts.

Therefore, this research uses case-study methods to explore GenAI integration across different teachers, the factors influencing such integration, and how the teachers' levels of integration change. Its research question is: How do teachers integrate GenAI into their teaching practices under various influencing factors, and how does this integration evolve?

1. Literature review

1.1. Definition of technology integration

Early studies of technology integration often counted the number of times digital devices and software were used in the classroom and/or measured teachers' familiarity with and positive attitudes toward technology (European Commission, 2013). Moreover, such studies tended to view technology integration as a relatively simple process. For example, Hsu's (2016) survey found that most technology integration occurred in language-related tasks such as teaching reading, writing, and grammar, and listed the technologies used by teachers (e.g., websites, overhead projectors, SMART Boards). However, it did not further explain *how* teachers used these tools to enhance or transform existing classroom practices.

The quality rather than the quantity of technology use has received increasing attention and is more often defined as how digital technologies are used to stimulate students' cognitive engagement and interest in learning (Consoli et al., 2025; Fütterer et al., 2022; Lachner et al., 2024). Following Backfisch et al. (2021), technology integration can be understood along two dimensions: the extent to which technology is used to transform and redefine learning activities, and the degree to which it enhances instructional quality and learning outcomes. Because teachers' GenAI integration has not yet been clearly conceptualized, the present study primarily focuses on technology exploitation (which corresponds to Backfisch et al.'s first dimension), and defines teachers' GenAI integration as their varying degrees of utilizing GenAI in activities such as instructional design, implementation, and assessment, while transforming learning activities in the process.

1.2. Models of technology integration

There are several classic models of technology integration. Among them, the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT) primarily focus on teachers' willingness to accept and use technology, among other attitudes towards it (Scherer & Teo, 2019; Šumak & Šorgo, 2016). While useful for revealing the role of individual factors in technology integration, they tend to reduce the outcome variable – integration – to the frequency of technology use (e.g., Šumak & Šorgo, 2016), rather than its creativity or other aspects of its quality.

TPACK, built on Shulman's Pedagogical Content Knowledge (PCK) model (Graham, 2011), offers a comprehensive view of the knowledge required for technology integration (Rosenberg & Koehler, 2015). TPACK encompasses content knowledge (CK), i.e., of specific subject matter; pedagogical knowledge (PK), i.e., of teaching methods, strategies, and assessment; and technological knowledge (TK), i.e., of various technologies and how to apply them in teaching (Brantley-Dias & Ertmer, 2013). However, while TPACK is suitable for analyzing the knowledge levels required to reach a certain technology-integration stage, it is product-oriented (Hamilton et al., 2016) and devotes little attention to how either the external environment or the technology itself may facilitate or hinder integration. Feldman-Maggor et al. (2024) argued that TPACK's emphasis on teacher competencies renders it unable to capture AI's unique characteristics such as prompt engineering, or to address issues related to generated content. However, those claims were not grounded in empirical evidence. Mishra et al. (2023) extended each component of TPACK to better fit the context of GenAI, and Lan et al. (2025) added a new component: Generative AI Technological Ethical Assessment Knowledge (GenAI-TEAK). Arguably, however, neither of these augmentations to the TPACK framework provides sufficiently detailed explanations of the various instructional processes that involve or might involve GenAI use.

The ICAP-based self-assessment tool for technology integration developed by Antonietti et al. (2023) is effective at evaluating the quality of technology-supported learning activities. However, according to Backfisch et al. (2021), exploring the quality of technology integration should include not only the level of teaching quality, but also the level of technology exploitation. The present study focuses on a specific form of technology integration, technology exploitation, which describes the extent to which technologies are used to transform and redefine learning activities during and after their implementation. In essence, technology exploitation mirrors teachers' ability to leverage the distinct potentials of educational technologies.

The Will, Skill, Tool, Pedagogy (WSTP) model proposed by Knezek and Christensen (2016) provides a useful framework for exploring the relationship between influencing factors and teachers' technology integration. It includes four dimensions: *will* (e.g., teachers' attitudes and motivation to adopt GenAI), *skill* (e.g., teachers' GenAI knowledge and competencies), *tool* (e.g., access to and availability of GenAI), and *pedagogy* (e.g., strategies and methods for GenAI integration). It links personal and technological factors with pedagogy. For instance, Sawyerr and Agyei (2023) demonstrated the WSTP's ability to predict teachers' ICT integration and highlighted its tool dimension as the strongest predictor. This framework helped us anticipate potential factors influencing teachers' GenAI integration and assisted our subsequent analysis. However, the present study does not seek quantitative predictions; and the WSTP model lacks elaboration on different levels of technology integration, and gives only limited consideration to the impact of environmental factors such as organizational culture and colleagues' behaviors and attitudes.

The SAMR model, in contrast to WSTP, outlines four hierarchical levels of technology selection and use in K-12 education (Blundell et al., 2022; Hamilton et al., 2016) and encourages educators to move toward higher levels (Blundell et al., 2022; Hamilton et al., 2016). Specifically (Fig. 1), at the *substitution* level, digital technology substitutes for analog technology without any functional change (Puentedura, 2006). In

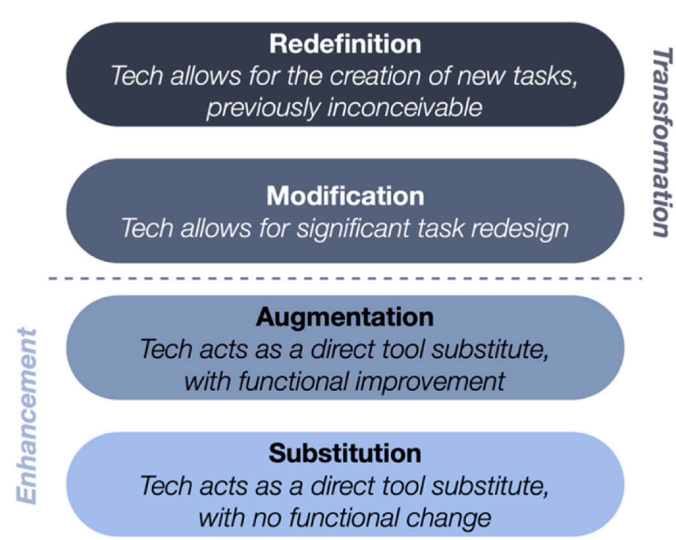

Fig. 1. Puentedura's Substitution, Augmentation, Modification, and Redefinition (SAMR) model (2006).

augmentation, such substitution enhances task outcomes in some way. In *modification*, technology integration involves a significant redesign of the task; and at the *redefinition* level, technology is used to create new tasks that were previously inconceivable.

As compared to the other aforementioned frameworks, SAMR is more widely used to explain teachers' technology integration (Blundell et al., 2022). It also aligns better with our core aim of understanding individual teachers' technology-integration levels as a basis for offering guidance to a range of education stakeholders. In contrast to similar models such as Replacement-Amplification-Transformation (RAT; Hamilton et al., 2016), SAMR provides highly detailed sub-classifications of the higher levels of creative integration. And, in addition to being easy for teachers to understand and apply, SAMR emphasizes the transformative potential of educational technology, aligning it well with the disruptive nature of GenAI. More specifically, each SAMR level explicitly highlights the relationship between technology and human behavior, which helps teachers identify their current level of integration and take steps to maximize its benefits while minimizing its risks. However, traditional SAMR faces at least three drawbacks: it does not directly incorporate influencing factors (Hamilton et al., 2016); it does not differentiate among the stages whereby technology integration evolves for different types of teachers; and it does not explain how various factors affect transformation on each of its levels.

Accordingly, this study will use a modified version of SAMR as its theoretical framework for analyzing teachers' GenAI-integration practices. However, it should be noted that this choice was based solely on SAMR's relevance to our present research aims, and does not imply the rejection of other frameworks. At the same time, we will take account of multiple influencing factors – individual, environmental, and technological; draw on some factors from previous models, especially WSTP; and explore how these factors interact with SAMR's stages.

1.3. Teachers' GenAI integration

Teachers' integration of GenAI is accelerating, primarily due to this technology's lower economic and time costs, as compared to previous types of AI (Bower et al., 2024). However, the extent of such integration still warrants exploration. Here, we categorize previous studies of this topic using the SAMR model's four levels.

At the substitution level, Moorhouse and Kohnke (2024) reported teachers' belief that GenAI functions could replace some traditional reading and teaching materials. Similarly, Muslimin et al. (2024) noted teachers' replacement of printed dictionaries with GenAI-based ones in translation exercises.

At the level of augmentation, a learning activity in which students wrote imaginative diaries inspired by AI-generated images achieved positive outcomes (Lee et al., 2024). However, that study did not reflect on teachers' role in the activity. A review by Celik et al. (2022) noted that teachers had used GenAI to enhance personalized learning, provide faster access to information, and deliver instant feedback.

At the modification level, Lan and Chen (2024) designed a GenAI agent that taught students how to use sequence words correctly when speaking and writing. However, they did not reveal students' outcomes. Various other studies (e.g., Jochim & Lenz-Kesekamp, 2025; Kim et al., 2025; Mokmin & Rassy, 2024) have reported that teachers generally endorse students' use of GenAI to generate content, provided that they then analyze, question, and verify it.

Lastly, at the level of redefinition, Muslimin et al. (2024) reported on students' use of GenAI to create images as the basis of new descriptive texts, and teachers' feedback on those images and texts. Similarly, Kong and Yang (2024) showcased the development of K-12 students' Chinese-writing skills using a self-regulated learning framework incorporating GenAI tools. Personalized learning plans and instant feedback guided the students to enhance their attention, participation, and self-reflection. Teachers were also reimagined as skilled facilitators and humanistic storytellers who craft differentiated instruction. The results suggested that GenAI-literate teachers can improve their teaching strategies in ways that better prepare their students for future challenges.

Some GenAI-integration studies have also highlighted concerns and challenges. First, many (e.g., Chan & Hu, 2023; Gammoh, 2025) highlight ethical concerns, notably that students may submit AI-generated content as their own work, and that existing plagiarism-detection tools struggle to catch them (Gammoh, 2025). Teachers and students alike have also expressed concerns about data privacy and security, as some GenAI tools collect user information to improve their systems and may not properly protect it (Mohamed, 2024). Moreover, GenAI models may perpetuate social prejudices and biases that were present in their training datasets (Dai et al., 2025; Jaboob et al., 2025).

A second challenge is that gaps in teachers' digital literacy hinder their effective educational use of GenAI (Lan & Chen, 2024; Moorhouse & Kohnke, 2024). In some cases, this may take the form of overestimation of GenAI's capabilities, followed by failure to critically evaluate the content it generates (Chan & Hu, 2023).

Third, cultural differences may affect teachers' and students' acceptance of AI-generated content. In cultural contexts where interpersonal interaction and/or critical thinking are highly valued, skepticism about AI outputs is greater (Ji et al., 2024). Cultural variations in perceptions of academic integrity may also influence whether GenAI use is considered cheating (Yusuf et al., 2024).

Collectively, the above findings suggest that teachers' GenAI integration is a complex, multifaceted process influenced by many factors. Focusing on it, rather than solely on student outcomes, can reasonably be expected to provide more actionable insights for teachers looking to harness GenAI's potential. It can also guide the creation of usage policies and training programs that will be better able to ensure fair, responsible, and impactful integration of GenAI into education.

1.4. Factors influencing teachers' GenAI integration

Many teachers are considering whether to incorporate GenAI into their teaching, or the extent to which they should do so (Zhang & Tur, 2024). It is therefore essential to understand the existing empirical evidence about factors that may motivate or demotivate such incorporation. The relevant studies, which have mostly been conducted in higher-education settings, categorize these factors into three levels: GenAI's capabilities (e.g., to create personalized learning activities or engage emotionally), teachers' concerns regarding it (e.g., ethical issues or negative impacts on teacher creativity), and institutional support for its use (Al-Mughairi & Bhaskar, 2024; Bhaskar & Rana, 2024). In contrast to university teachers, who are encouraged to utilize GenAI and have access to advanced technological resources, K-12 teachers are likely to face more barriers. For example, Annamalai (2024) reported that the benefits and risks of GenAI for high-school language teaching and learning included its restricted uses in classrooms and the limitations of traditional teaching as an arena for its use. The same study's participants also saw unethical GenAI usage as connected to passive learning. Collie and Martin (2024), meanwhile, identified contextual factors, occupational experiences, and background factors as valuable predictors both of K-12 teachers' valuations of GenAI and of their integration of this technology into their professional practices. Among other results, they found that teachers' striving for professional growth was linked to higher levels of GenAI integration, and that those teachers who saw GenAI as important were more likely to use it. However, Collie and Martin's research did not cover whether/how technical factors impacted teachers' motivation. Moreover, none of the studies mentioned in this subsection investigated how teachers' GenAI-integration processes or their applications of GenAI in the workplace were shaped by their distinct pedagogical beliefs, philosophies, and practices; their reflection, professional learning, and interactions with colleagues; or their schools' climates. We will therefore augment the existing empirical evidence by investigating those factors. The results can be expected to inform the education-research community and other stakeholders about the current circumstances of teachers' GenAI-use processes, and thereby enable the development of effective strategies for enhancing K-12 teachers' confidence and proficiency with this emerging technology, while mitigating the challenges particular to various teacher types.

1.5. Transformation of teachers' GenAI integration

From the above discussion, it is evident that few scholars have studied changes in teachers' GenAI implementation over time. Nevertheless, some trends can be tentatively identified from existing research. First, integration appears to typically proceed from lower-level to higher-level activities. For example, teachers aiming to reach the SAMR model's redefinition level are likely to progress through lower ones along the way, such as organizing existing materials or generating images and text examples for their lesson plans (Moorhouse & Kohnke, 2024). After a period of experimentation, they may move toward previously inconceivable lesson designs, such as using GenAI to extend textbooks' storylines (Kong & Yang, 2024). Second, as teachers move from lower to higher levels of GenAI integration, their focus may shift from how to use the technology itself to how it affects people: for example, how it could be used to cultivate students' critical thinking, creativity, and problem-solving, as opposed to just memory and comprehension (Jochim & Lenz-Kesekamp, 2025; Lu et al., 2024). And third, teachers' GenAI integration may shift over time from single-subject applications to broader and/or interdisciplinary ones (Lee et al., 2024). However, finding empirical evidence for or against these possible trends will require detailed case studies.

2. Methods

2.1. Context

This study was carried out in 18 regular public elementary, middle, and high schools in Shenzhen City, Guangdong Province, China. This city's rich resources afford its teachers enhanced opportunities for utilizing GenAI in their work. The term "regular" when applied to Chinese public schools means that, unlike "elite" public schools or private schools, they are supported and supervised by local governments and do not differ markedly from one another – or from classroom to classroom – in terms of infrastructure, Internet access, class size, curriculum goals, teachers' educational qualifications, teachers' years of experience, or students' average performance at the time of admission (Education Bureau of Shenzhen, 2022). We sampled only teachers from these schools to help minimize confounding variables.

2.2. Participants

Purposive sampling via social-media posts and chat groups led to our recruitment of 26 language teachers from the target schools between April and June 2024. This sampling approach involves selecting participants based on specific criteria relevant to one's study, as a means of ensuring rich, relevant information (Merriam & Grenier, 2015). We also selected it because, rather than merely rating teachers' GenAI integration, our intent was to thoroughly investigate a range of teachers' integration processes and the factors influencing them. Language teachers were targeted because their work – notably, drafting activity notices and delivering reading, writing, and speaking instruction – align well with GenAI's core functionalities: natural-language processing and text-based content creation (Liu et al., 2024). Additionally, most participants in prior empirical studies of GenAI-assisted teaching have been language teachers (e.g., Lan & Chen, 2024; Moorhouse & Kohnke, 2024), although the applications identified by such studies have included interdisciplinary activities (Lee et al., 2024), suggesting that their findings may be applicable to other subject areas.

Our inclusion criteria for teachers were 1) at least one year of teaching experience in a language subject, 2) an active teaching role in a regular public school within the previous year, and 3) use of GenAI at least once per week during the previous year. Importantly, due to current GenAI tools' effectiveness being highly user-dependent, we did not impose any restrictions on the teachers' selection of such tools. A full listing of those they used during the study can be found in column 2 of the Supplementary Materials.

Of the 26 teachers we initially recruited, two were excluded following a pre-interview chat for having hardly any knowledge of GenAI, and another two for having few formal teaching responsibilities. As Table 1 shows, the remaining 22 participants' teaching experience averaged six years. Eight taught in elementary grades, three in middle school, eight in high school, and three in both middle and high schools. Before data collection, all teachers were informed of and accepted the ethical rules governing this research.

2.3. Instruments

We conducted individual interviews, the data-collection strategy most commonly used by qualitative researchers seeking to access their participants' perceptions, attitudes, opinions, and knowledge (Lambert & Loiselle, 2008). The interview protocol included questions about the interviewees' learning, GenAI usage in education, and the changes that ensued from such usage. Four example interview questions are set forth below.

1. In the past year, have you used GenAI in your daily work or teaching?
2. What factors do you think have influenced your GenAI integration?
3. How do you and your students feel about using GenAI?
4. What has been the transformation process of your GenAI integration?

2.4. Data collection and analysis

To minimize the risk of subjective bias, we transparently documented the participants' teaching levels, genders, teaching experience, and GenAI experience. All participants signed consent forms and were interviewed via Zoom or Tencent at times of their convenience over a four-week period. Each interview was semi-structured and lasted 30–35 min. The interviewees were also asked to provide records of their

Table 1
Participants' demographic information.

ID	Grade taught	Gender	Type of degree	Teaching experience (years)
T1	High school	F	Bachelor's	6
T2	Middle school	F	Master's	13
T3	Middle school and high school	F	Master's	3
T4	High school	F	Bachelor's	8
T5	Middle school	F	Master's	24
T6	Elementary school	F	Master's	2
T7	Elementary school	F	Master's	12
T8	High school	F	Master's	2
T9	Middle school	F	Master's	10
T10	Elementary school	M	Master's	2
T11	High school	F	Master's	1
T12	High school	F	Master's	5
T13	Middle school and high school	F	Master's	5
T14	Middle school and high school	F	Master's	6
T15	High school	F	Master's	5
T16	High school	F	Master's	1
T17	Elementary school	F	Master's	4
T18	Elementary school	F	Master's	7
T19	Elementary school	F	Master's	3
T20	Elementary school	F	Master's	5
T21	High school	F	Master's	4
T22	Elementary school	F	Master's	5

interactions with GenAI and of the output produced by it (e.g., texts, images, videos) to complement and confirm the accuracy of their interview data. All interviews were recorded and transcribed in real time using the meeting software's recording function. To further enhance the trustworthiness of our findings, and to add detail to some of the views expressed in the main round of interviews, follow-up interviews and member checks (Roulston & Choi, 2018) were also employed. To maintain confidentiality, all data were anonymized.

We employed a deductive-inductive analysis technique. That is, before analyzing them, we aligned the interview data with participants' GenAI outputs and interaction histories. We then familiarized ourselves with the transcripts and focused on the distinct experiences of each participant. Next, we delineated key events in each participant's GenAI adoption and integration, and abstracted and categorized them with an emphasis on the exact SAMR stage of GenAI integration they represented, their usage contexts, important influential factors, and the teachers' self-reported feelings. Knezek and Christensen's (2016) extended WSTP model's four dimensions were the basis for our systematic examination of obstacles and facilitators. Emerging environmental themes that were not sufficiently or directly represented by the existing WSTP framework, notably including the influences of the participants' colleagues and students and of social-media marketing, were identified through open coding. Finally, factor-related codes were classified into three major categories: personal (e.g., aspects of will, skill, and pedagogy associated with a particular participant); technical (i.e., attributes of GenAI); and environmental (e.g., teaching setting and institutional support). Descriptions of each category, with illustrative data excerpts, are provided in Table 2. As an example of the entire process, T5's statement "*A teacher told me about [GenAI tool] IFlyspark […]. After learning about it, I used it to turn my students' compositions into videos. It's easy and convenient for me [… and my] students are interested in the videos and actively involved*" was assigned to the integration level "augmentation". Then, it was abstracted and categorized as "converting students' compositions into videos_writing_GenAI use context", "teacher interation_colleague influence_environmental factor", and "the ease of use of GenAI_usability_tool_technological factor".

After completing our individual analyses of each participant, we conducted a cross-case analysis of their similarities and differences. Based on its results, we summarized the characteristics of teachers' adoption of GenAI for teaching and their levels of GenAI integration (as per SAMR) into four types. The teacher who best fit each type was then selected as the subject of a vignette. These four vignettes, in turn, served as the foundation for a matrix that cross-referenced the different levels of GenAI integration and influencing factors for each participant, facilitating systematic comparisons across cases and highlighting shared experiences and variations. Our final theoretical framework of teachers' GenAI integration was then reviewed and confirmed by a panel of experts; and the final themes, vignettes, and framework were translated into English and reviewed by a language expert.

To ensure coding accuracy and the rigor of our qualitative analysis, inter-coder agreement was calculated following Huberman and Miles (2002). That is, two researchers independently coded the same dataset using predetermined codes taken from the SAMR and WSTP frameworks, and their initial agreement about which codes had been applied was 85 %. Then, during weekly meetings, the remaining 15 % of codes on which they had initially disagreed were discussed until full agreement was reached.

3. Results

The detailed codes we assigned to participants' unique GenAI-integration experiences and related influencing factors, which can be found in the Supplementary Materials, indicated that there were four broad teacher types: *cautious adapters*, *efficiency enhancers*, *technology enthusiasts*, and *pedagogical innovators*. Each represents distinct integration levels and transition stages, and is shaped by its own set of

Table 2
Coding framework, factors impacting teachers' integration of generative artificial intelligence (GenAI).

Levels/ Categories	Sub-categories	Description	Interview excerpts exemplifying influential factors
Individual level			
Will	Interest	Teachers' pleasure and satisfaction with GenAI	I'm interested in all types of AI, including GenAI. *(T22)*
	Willingness	Teachers' readiness to acquire knowledge and skills relating to GenAI	I want to learn more about GenAI after seeing some excellent instances of its applications in education. *(T1)*
	Utility	Teachers' beliefs about the usefulness of GenAI for teaching	I think GenAI is beneficial for my work. *(T2)*
	Concern	Teachers' fears about the negative impact of GenAI on teaching	I'm worried that my students might complete their assignments with GenAI. *(T18)*
Skill	GenAI-related knowledge	Teachers' understanding of GenAI	I don't know how GenAI works. *(T1)*
	GenAI-related skills	Teachers' general ability to use GenAI	I know how to use GenAI to generate images. *(T8)*
		Teachers' competency to use GenAI for pedagogical and administrative tasks	I ask GenAI to clarify complex educational concepts for me. *(T5)*
	Adaptability	Teachers' ability to adapt to diverse GenAI tools	I know a lot of Chinese GenAI tools and can utilize them for different purposes. *(T14)*
Technological level			
Tool	Usability	The user-friendliness of GenAI interfaces and operations	To achieve an ideal outcome, I have to repeatedly improve my prompt-engineering skills. *(T22)*
	Accessibility	GenAI's accessibility to teachers	Only Chinese-developed GenAI tools are available to me. *(T1)*
	Cost	The cost of using GenAI	I haven't spent any money on GenAI. *(T15)*
Environmental level			
School	Leadership support	School leaders' attitude and support for GenAI	The school principal advised us to utilize GenAI. *(T6)*
	Technical support	School's provision of technological support for teachers	I learned GenAI all by myself. *(T15)*
	Colleague influence	Colleagues' expectations and attitudes about the integration of GenAI into teaching, and their integration proficiency	My colleague recommended I use iFlytek Spark for different tasks. *(T14)*
	Student influence	Students' expectations and attitudes about the integration of GenAI into teaching, and their integration proficiency	My students used GenAI to create play scripts, and their performance demonstrated the value of GenAI to me. *(T15)*
Society	Public discourse	Public opinion about GenAI use in education	I got information on GenAI via the official WeChat account. *(T6)*

motivating and demotivating factors across personal, environmental, and technological dimensions. Some teachers fit into two different types, which is why our grand total of type members exceeds 22. Table 3 compares the differences in factors influencing GenAI integration across the four types.

The next four subsections, which respectively cover each teacher type, include maps illustrating that type's process of GenAI integration and the positive and negative factors influencing it, along with the representative vignettes mentioned above. Importantly, these four narratives were chosen because they most clearly reflected the integration levels, influencing factors, and transformation processes associated with their respective types, and should *not* be taken to suggest that the four selected teachers exhibited the most effective GenAI integration within their types. Additionally, although demographic information about the four teachers in the vignettes is presented, we did not find a significant correlation between type membership and any demographic variable.

3.1. Case 1: Cautious adapter

Eight teachers were "cautious adapters" whose integration had shifted over time to augmentation from *prohibition*: a level not included in traditional SAMR. We use it to refer to a deliberate initial avoidance or rejection of GenAI for teaching and other day-to-day tasks. Notably, remaining at the prohibition level was often not due to technological or environmental factors such as a lack of access to GenAI or an unsupportive school. Rather, teachers chose not to use GenAI due to personal factors such as concerns about losing professional skills and fears of student abuse. We therefore consider prohibition to be a precursor level that cautious adapters must overcome before moving to substitution or any higher level. Our choice of the label "adapter" (as opposed to "adopter") reflects that teachers with this profile shift from initial resistance to using GenAI to leveraging it for daily work and teaching materials, and ultimately recognize some of its advantages.

Wang, a teacher of grades 1–3, serves as a representative case of a cautious adapter (Fig. 2). At first, Wang resisted learning about GenAI due to skepticism about its true effectiveness: "*When the school began arranging GenAI training for us a year ago, I thought it was just another flashy but impractical technology*." Although the training showed her how to use Wenxin Yiyan and IFlyspark, Wang was predominantly affected by her concerns that her professional ability would be undermined by GenAI and that children would misuse it, and she deliberately avoided using it in any aspect of her work. Her eventual use of GenAI was triggered by chance: "*My leader asked me to give a speech the next day. I quickly used GenAI to draft it and then made my own edits*" (Fig. 3). This experience of GenAI's emergency assistance aligned perfectly with her goal of speeding up tedious tasks when overwhelmed, and marked her shift from prohibition to substitution. Specifically, she used GenAI to "*record reading materials for students*" that were adequate in both "*pronunciation and emotion*".

However, Wang's use of GenAI remained limited to organizing scattered materials from work reports or pre-existing instructional designs. This was not due to laziness or inattention; on the contrary, her colleagues and leader – whom we also interviewed – praised her for her passion, creativity, and responsibility in teaching and teamwork. Wang's caution and skepticism partly stemmed from her experiences with GenAI-enhanced practices: "*Sometimes the content it generates is not accurate, and the sources are doubtful. I am still concerned that relying on it might erode my professional skills*." Worried about privacy leaks, she also disliked the need to "*register with a phone and enter verification codes each time*". Her theoretical concerns about her students developing the habit of abusing GenAI to complete assignments were mitigated in practice by her school's prohibition on student use of electronic devices in the classroom.

By the time of her interview, Wang's GenAI integration had reached the augmentation level. That is, in the above-mentioned recordings of reading materials, she had begun asking IFlyspark for help with "*adjusting speed, pauses, different reading roles, and emotions*", and said that this made the assignments more enjoyable for her students. Asked about more complex teaching designs, she said that they primarily depended on her own skills, but that she was willing to gradually explore further educational possibilities as the technology continues to advance.

3.2. Case 2: Efficiency enhancer

Ten teachers were categorized as efficiency enhancers, i.e., had progressed in their GenAI integration from substitution to augmentation. In terms of individual factors, they – unlike cautious adapters – did not start using GenAI only when feeling overwhelmed; instead, they approached it from the start with the intention of improving their work efficiency or freeing up time for more complex work-related tasks. Meanwhile, rather than via school-provided GenAI training, they often discovered relevant and cost-free tools through colleagues' recommendations; and, having experienced GenAI's speed and what they saw as its high-quality content, they began to use it frequently, particularly for

Table 3
A comparison of the factors influencing generative artificial intelligence (GenAI) integration across the four identified types of teachers.

Type	Individual_positive	Individual_negative	Environmental_positive	Environmental_negative	Tech_ positive	Tech_ negative
Cautious Adapter	Goal of enhancing efficiency when overwhelmed	Worried about dependency, decrease of professional skills, and students' abuse on assignments	GenAI training conducted by the school	Prohibits students from using such electronic devices	Rapidity; Emergency assistance	Incorrect content and questionable sources at times; privacy disclosure risk
Efficiency Enhancer	Goal of promoting efficiency; Goal of saving time for detailed instructional design	Worried about being a conveyor	Promotion by school colleagues	Scarcity of specific training	Rapidity; High-quality content structure	Multiple modifications of prompts
Technology Enthusiast	Enthusiastic interest in new tech; Personal background and knowledge related to GenAI	Worried about changes to assessment driven by unrestricted student usage	A school climate that supports technology use	Needing regulatory standards on students' usage	Rapidity; Adapt-ability; Reasoning skills; Capabilities across tasks	Accuracy or knowledge limitations
Pedagogical Innovator	Goal of creating an interactive and engaging classroom; Goal of redesigning some pedagogy and tasks	Requiring creativity, critical thinking and self-discipline by teachers and students	Recommend-ations from friends working in social-media or IT companies	Needing regulatory standards for students' usage, and understanding or support of parents	Rapidity; Multimodal materials; Idea stimulation	Need to refine GenAI outputs; Technical hiccups in lessons; Preparedness for intervention

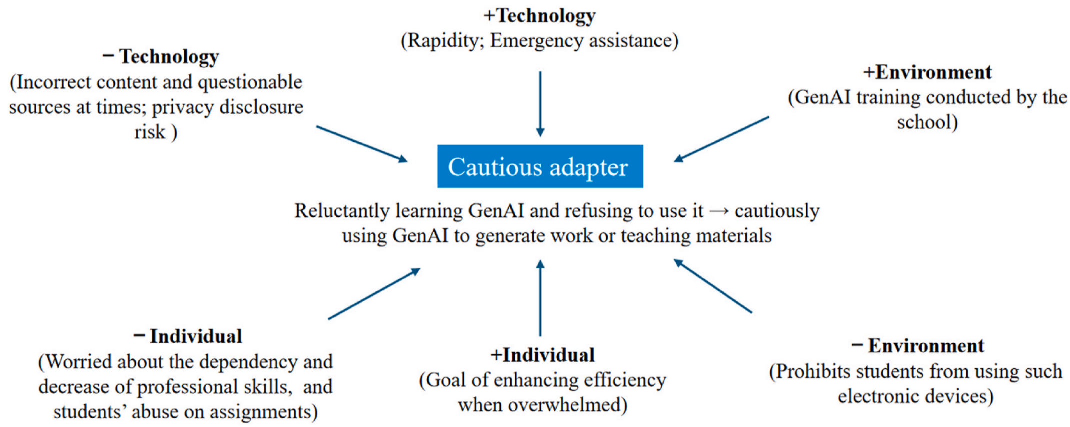

Fig. 2. Factors that influenced Wang's GenAI integration as a Cautious Adapter.

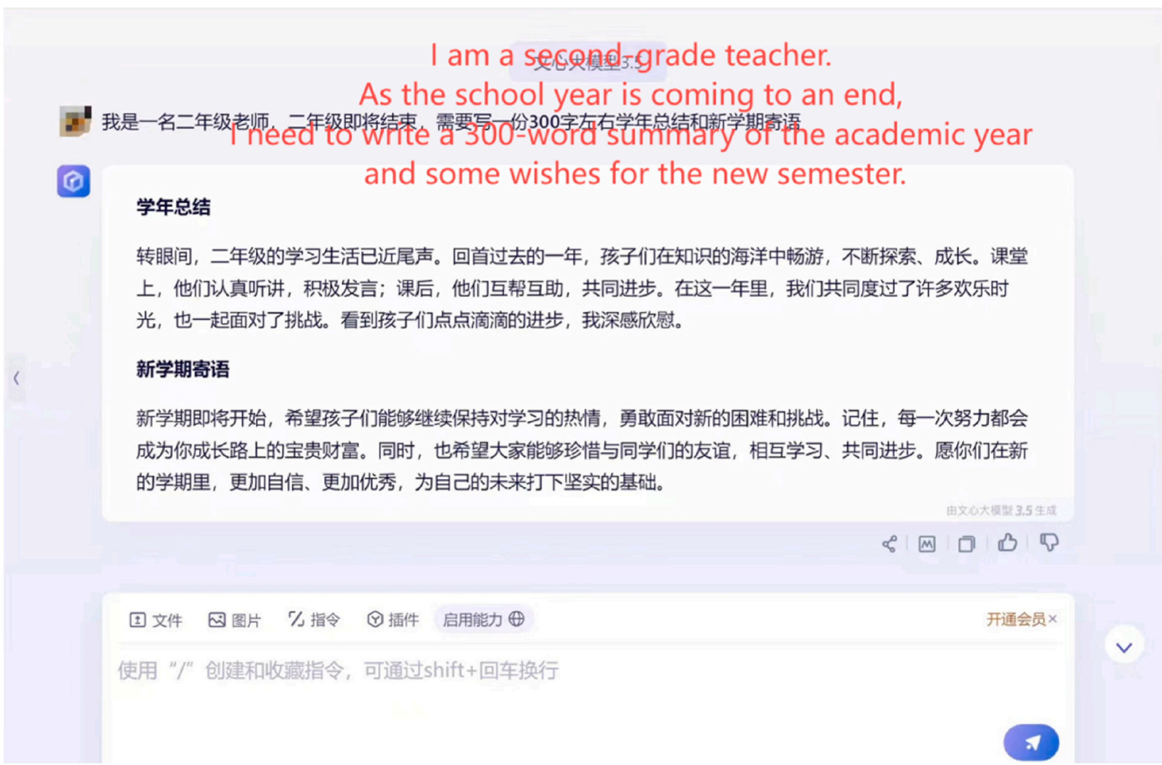

Fig. 3. Example of using GenAI to draft a speech.

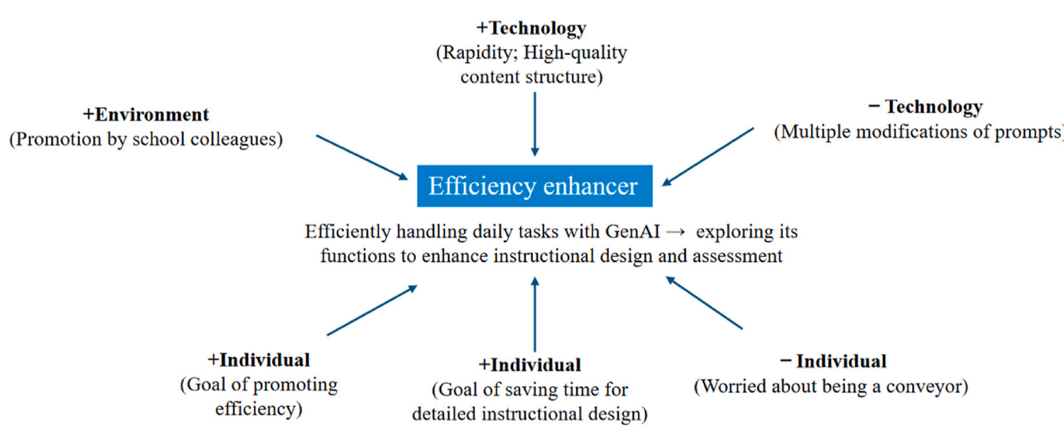

Fig. 4. Factors that influenced Yu's GenAI integration as an Efficiency Enhancer.

generating administrative documents. When more familiar with it, they utilized GenAI to create teaching materials and to assist them with grading. However, its technical limitations, requiring repeated prompt modifications, coupled with their own concerns about becoming mere "conveyors" of AI-generated content, prevented efficiency enhancers from progressing to higher levels of GenAI integration.

We selected Yu, a teacher of Chinese in a middle school who had recently been appointed head of Year 7, as our most representative efficiency enhancer. Unlike the cautious adapters, she had felt since long before encountering GenAI that technology might help improve her daily-task efficiency (Fig. 4). Yu's adoption of GenAI was both sparked and enhanced by colleagues' recommendations. She first encountered it when an IT teacher at her school shared some API accounts for ChatGPT, and the school permitted its use. She asked GenAI to write a model essay for her students – which she would normally have written herself – and was surprised that its "*language and structure were actually quite good*" (Fig. 5). This led her to appreciate GenAI's speed and ease of use, which allowed her "*to focus on the details of instructional design.*"

Still prioritizing efficiency, Yu researched various GenAI tools and leveraged ChatGPT and Wenxin Yiyan for various complex, time-consuming tasks such as generating test questions, summarizing meeting notes and sending notifications to parents. The high quality of the outcomes led her to regard GenAI not only as a substitution tool but also as offering augmentation. Jettisoning her former view that its responses were "*correct but meaningless*", she started using it to check student assignments and to create general frameworks for comments and lesson plans. For instance, when she asked Wenxin Yiyan for a lesson plan on the Chinese text *The Winter of Jinan*, it accurately captured the key sentences highlighting Jinan's winter and even designed activities for student analysis of the passage. "*However, getting more detailed answers often requires refined prompts and several adjustments*," she noted, viewing this as a double-edged sword: that is, she struggled to strike a balance between using the GenAI to save time and exploring its other potential advantages.

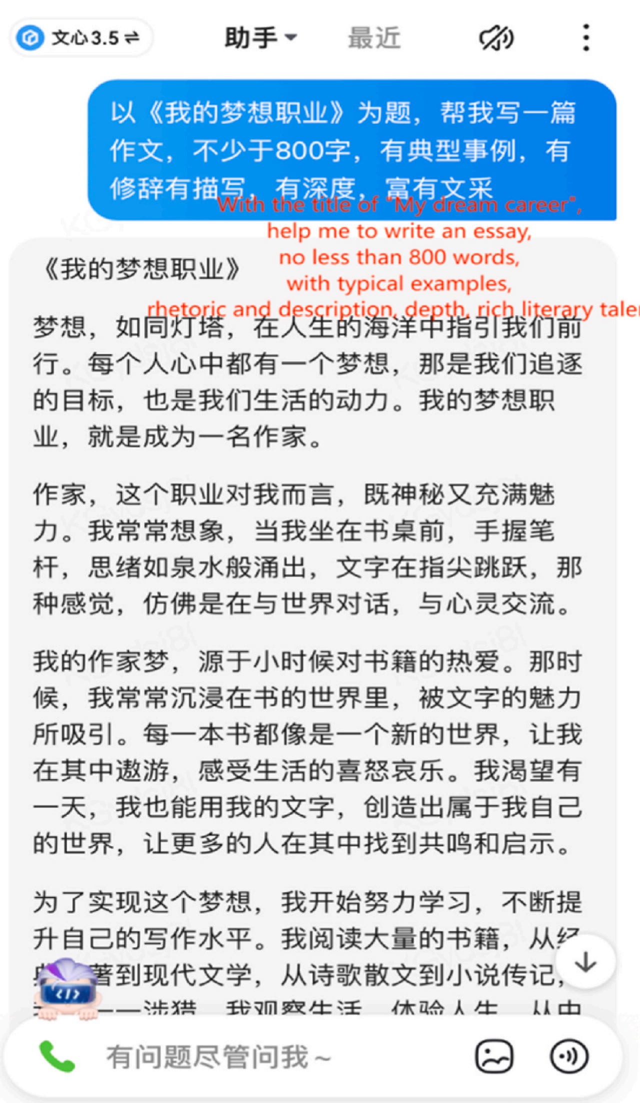

Fig. 5. Example of using GenAI to write an essay.

Yu said that she hoped GenAI would become "*smarter*", i.e., suitable for even more advanced tasks. However, she also expressed concerns about it replacing her. "*[W]hat if one day it truly thinks like a human? Would I then just become a 'conveyor' of information or ideas?*"

3.3. *Case 3: Technology enthusiast*

Three teachers were classed as technology enthusiasts: i.e., their GenAI integration had progressed from augmentation to modification. They displayed a strong interest in and acceptance of technology in general, and high enthusiasm for exploring various GenAI tools and their applications. Unlike the previous two teacher types, whose GenAI use was rooted in convenience, the technology enthusiasts had backgrounds in technology-related fields and/or extensive pre-GenAI experience of integrating technology into their work. This enabled them to quickly leverage GenAI's abilities to assist with the creation of teaching materials and differentiate those materials by student-proficiency levels. Within school environments that allowed student use of GenAI, they allowed their students to utilize it for research and idea generation, and saw this as helping their classrooms become more participatory and reflective. However, their further integration of GenAI was hindered by concerns about the absence of established norms and policies governing its use and misuse by students. Additionally, these teachers were apprehensive that unregulated GenAI use would alter assessment standards and thereby create fairness issues.

Shen, our representative technology enthusiast, taught Chinese in an elementary school and also oversaw students' inquiry-based and IT courses (Fig. 6). Her undergraduate background in computer science had provided her with an above-average ability to learn new technologies, and she often developed a passion for them. "*I've been interested in AI for a long time,*" she told us. "*When ChatGPT first came out, I was already following its development. Just last month, I attended the World Artificial Intelligence Conference.*" Regarding her school's supportive climate, she said: "*My leader is very encouraging when it comes to using technology. She even asked me to help other teachers learn new GenAI tools.*" At the time of her interview, Shen had already used ChatGPT 4.0, MidJourney, Diffit, and various Chinese-developed GenAI applications.

In the beginning, Shen's GenAI integration primarily focused on its core functions for augmentation. But then, she realized that their speed, adaptability, and reasoning capabilities could potentially enrich students' experiences, especially through personalization:

> In my previous teaching, I would often read through the materials with the students during inquiry lessons and guide them to discuss and think critically. Once [….] I gave an article to GenAI and asked it to generate three versions with different levels of vocabulary and grammar for my students [see Fig. 7]. The students first read individually, then discussed and presented in groups. [… W]hen they read materials that matched their level, they thought more deeply, and even the weaker students were able to present their ideas logically. GenAI made my long-imagined goal of having every student genuinely and joyfully participate a reality.

Shen also used GenAI to introduce immediate assessments into her lessons. Previously, she said, "*it was hard to assess whether students had*

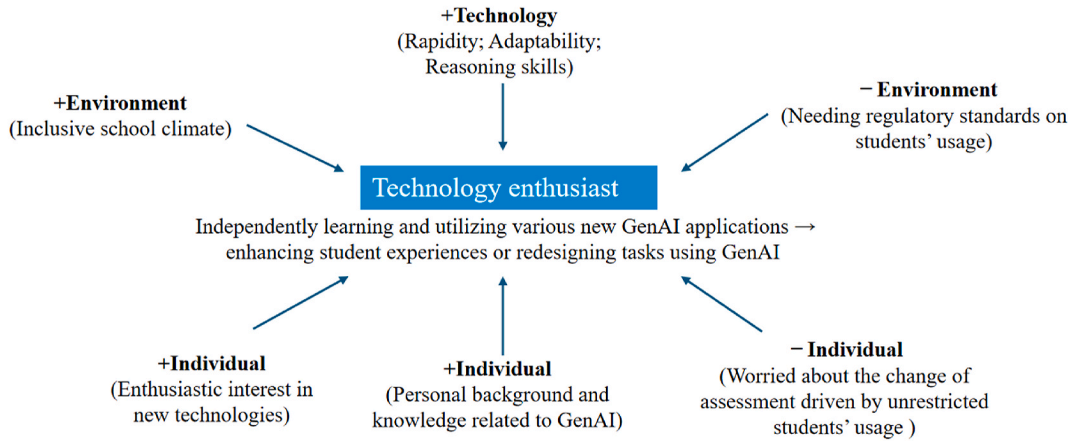

Fig. 6. Factors that influenced Shen's GenAI integration as a Technology Enthusiast.

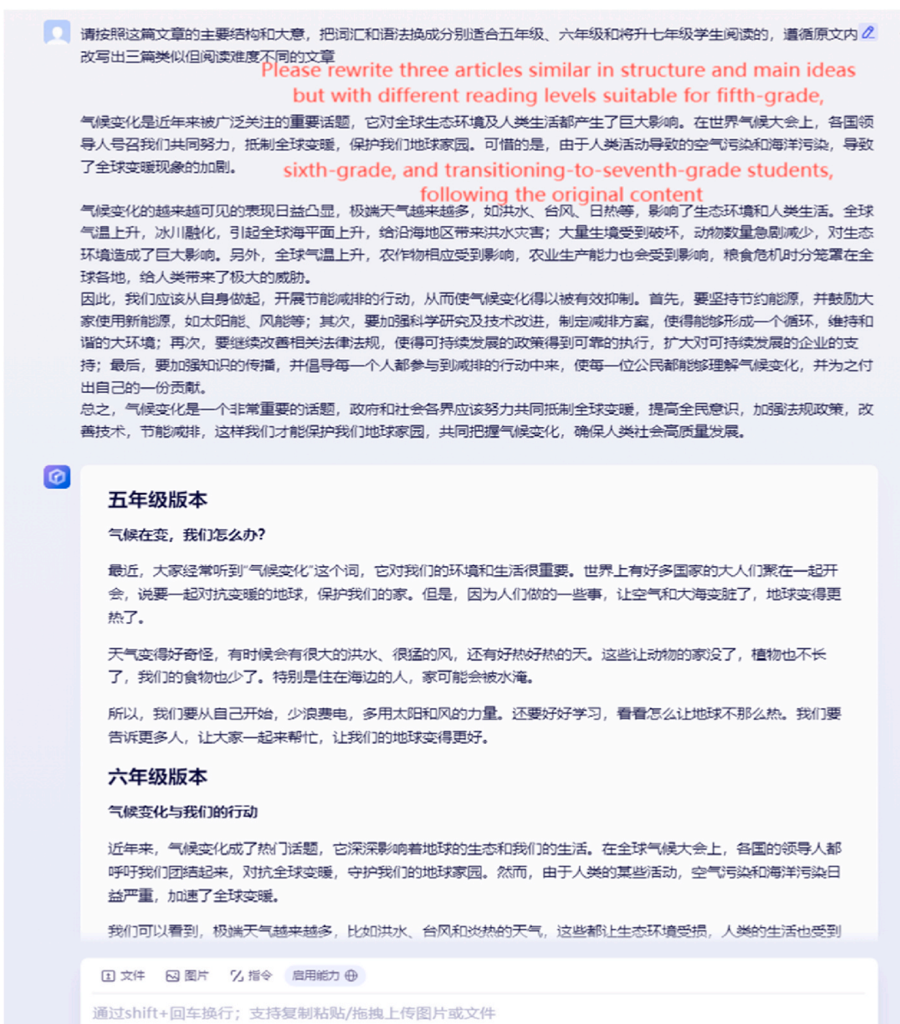

Fig. 7. Example of allowing GenAI to be used to revise articles with different levels of vocabulary and grammar.

grasped a particular concept during class. Now, I just give tools specific requirements and examples, and I can quickly generate exercises in class to check students' understanding."

However, Shen worried that, in the absence of suitable standards for students' use of GenAI, they might abuse it, leading to unfair evaluations: "*If some students learn to use these tools to complete assignments, it could harm those who put in the effort to think and complete the work themselves.*" Nevertheless, she remained optimistic about GenAI's future: "*There is no definitive answer, but you cannot 'stop eating for fear of choking'.*"

3.4. Case 4: Pedagogical innovator

Lastly, seven participants fit the pedagogical-innovator profile, meaning that their GenAI integration had progressed from augmentation to redefinition. Unlike the other three types, their motivations for exploring and applying GenAI stemmed neither from a strong interest in technology itself nor from a desire to work more efficiently, but rather from a desire to innovate as teachers: notably, by redesigning pedagogy and learning tasks to meet personal educational goals. Initially, they utilized GenAI to design simple interactive activities. However, as they became more proficient at using it, and proactively sought advice from colleagues and their social networks about which GenAI tools were best suited to their teaching needs, they began incorporating its content into their teaching processes, thus modifying their traditional approaches to teaching writing, poetry appreciation, and interdisciplinary inquiry. Within limits, they also permitted students to use GenAI to complete assessments.

These teachers' aspirations to revolutionize pedagogy through GenAI encountered several personal and environmental challenges, however. One was their recognition that advanced GenAI integration required them and their students to possess creativity, critical-thinking skills, and self-discipline. Additionally, they highlighted the importance of clear regulation of students' GenAI use and of working with parents to alleviate concerns about GenAI misuse and dependency.

Chen, a high-school Chinese teacher with five years' experience, was our representative case (Fig. 8). Despite beging early in her teaching career, she had long thought about improving her pedagogy with the aim of teaching more engaging classes. When she learned about Wenxin Yiyan from friends, she immediately thought of using it to enhance classroom interaction, student engagement, and creativity. When teaching the works of famous Tang Dynasty poet Du Fu, she said,

> I asked some students to simulate Du Fu's tone in writing a paragraph about his emotions while composing the poem, while others used GenAI to generate the same task using prompts. Then, we compared and discussed the differences between the two creations, evaluating their strengths and weaknesses.

In the long run, GenAI's speed and generative capability enabled Chen's long-desired student-centered teaching model to become a reality:

> They were all quite interested in this approach. If GenAI's writing was better than theirs, they could analyze why it was better without feeling embarrassed about their own writing. If GenAI's writing was worse, they gained confidence by recognizing the key points and what made their writing stronger.

Varying the GenAI applications she used to create multimodal materials also enhanced classroom engagement. For example, she used Kimi to transform classical Qing Dynasty text *A Letter to My Wife* into a song (Fig. 9). She then had her students modify parts they deemed unnecessary or illogical, to justify those changes, and to generate relevant images during or after class. She reported that the students "*seemed very engaged because many had not learned through such multimodal materials*

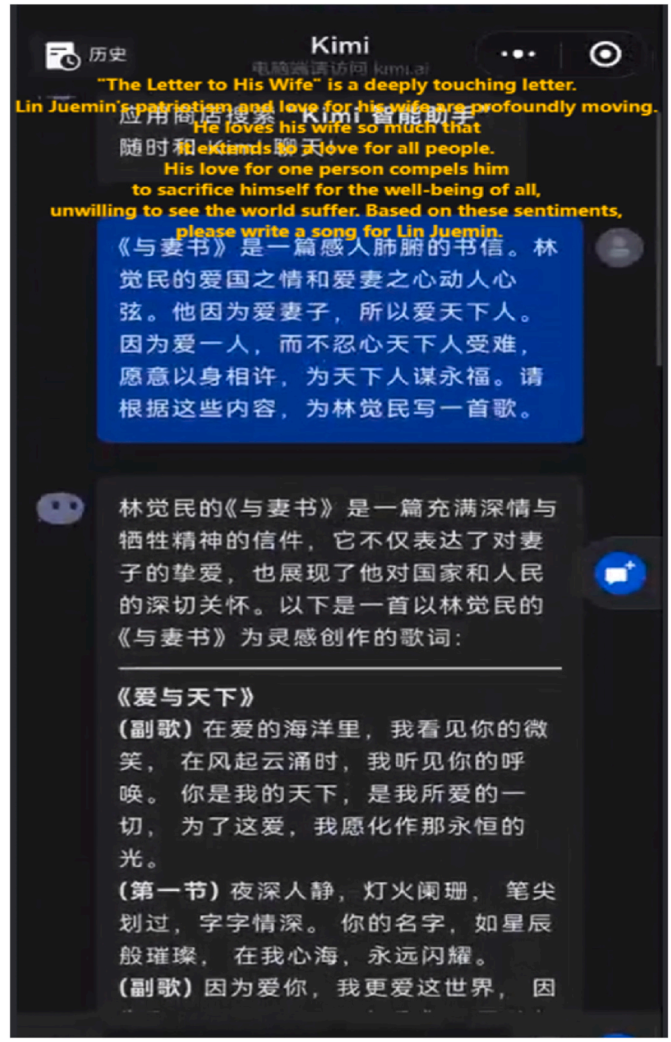

Fig. 9. Example of using GenAI to write lyrics based on a traditional Chinese text.

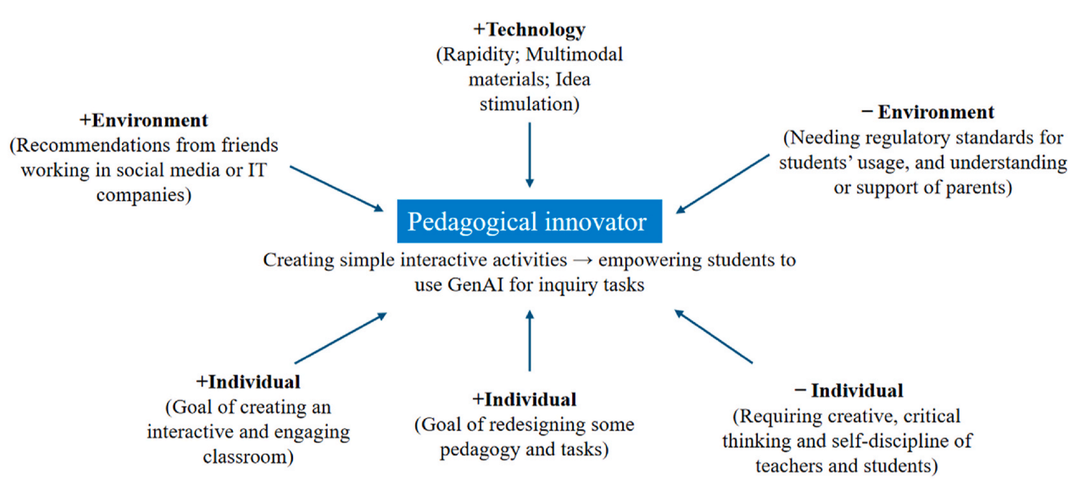

Fig. 8. Factors that influenced Chen's GenAI integration as a Pedagogical Innovator.

before.”

After Chen’s students’ proficiency with GenAI had increased, she began to use it to design some previously “inconceivable” classes and interdisciplinary inquiry-based learning projects, often focused on societal topics like “How will AI impact our generation?” Students used GenAI to gather and organize information, which they then combined with images and discussed as a group. Importantly, Chen required students to critically evaluate GenAI’s content, supported by evidence: “*I need them to develop their own logic and understand that the materials are tools to aid their thinking, not to be copied as final products*.”

Chen’s diversified applications of GenAI for pedagogical tasks also prompted her to reflect on its pitfalls and risks. She acknowledged that if activities like hers were to succeed, the burdens placed on teachers and students would be high. Students who lacked the ability to accurately judge the quality of generated content might misuse it, while teachers who merely aimed to reduce their workloads might fail as guides to such content, causing their classrooms to become disorganized. Chen also hoped schools or broader educational systems would establish clear standards for students’ ethical use of GenAI.

4. Discussion

Our results expand the previous SAMR model into the teachers’ GenAI integration process model detailed in Fig. 10. As well as tying transformation in integration to its levels, this new model incorporates previously unaccounted-for individual, environmental, and technological factors affecting the integration process.

4.1. Types of teachers’ GenAI integration

Most of our participants were identified as cautious adapters, efficiency enhancers, or both. This aligns with earlier findings that teachers’ GenAI use remains largely at the substitution and augmentation stages (Celik et al., 2022; Lee et al., 2024; Muslimin et al., 2024). There are three likely reasons for this. First, teachers typically adopt new technologies gradually, starting with simple tasks; and substitution and augmentation involve minimal changes to existing classroom practices. By the same token, higher levels of integration, such as those seen in technology enthusiasts and pedagogical innovators, tend to require strong digital literacy – among both teachers and students – which may account for these types’ lower representation. And second, at the time of this study, GenAI integration into education was not yet widespread globally.

We have broken new ground by, in the first instance, examining how integration levels were manifested concretely among teachers who fit our four profiles (Fig. 10). For instance, cautious adapters experienced a prohibition phase before reaching substitution, and often went no higher than augmentation; whereas pedagogical innovators started at augmentation and moved up toward modification and redefinition. Notably, teachers at the prohibition level, which classical SAMR does not include, avoided using GenAI themselves for a period of time before they began substitution. They were not unaware of what GenAI could be used for or how it operated; rather, they deliberately refrained from using it based on distrust and/or concerns about threats to their professional competence. This suggests that school leaders should tailor professional-development activities according to teacher type. For example, they could use practical examples of GenAI applications to spark interest and shift beliefs among teachers still at the prohibition stage, while offering those in the modification or redefinition stages workshops in which they can explore issues such as GenAI ethics and the assessment of GenAI-assisted student work, as a means of unlocking their instructional potential within a safe, supportive environment.

Secondly, the extent to which our participants engaged in modification and redefinition was markedly higher than reported in previous research (Liu et al., 2024; Vartiainen & Tedre, 2023). A few previous studies have explored both these levels: e.g., the use of GenAI to redesign complex oral and written instruction (Lan & Chen, 2024) or of AI-teacher collaborative models to enhance students’ writing skills (Kong & Yang, 2024). However, those efforts were not teacher-driven. We, in contrast, found that teachers themselves initiated modification and redefinition through GenAI integration: for example, by designing cooperative learning activities using AI-generated reading materials of varying difficulty, incorporating AI-generated authorial descriptions into classroom discussions, and allowing students to use GenAI to assist with inquiry tasks and presentations (though still acting as guides and supervisors). These changes seem to imply that the *technical* difficulty of GenAI integration was decreasing, and that success thus increasingly depended on teachers’ instructional-design skills and students’ abilities. If so, future GenAI integration is likely to rely more heavily on teachers’ and students’ capacity for inquiry and innovation. Policymakers and school leaders should therefore consider incorporating more tasks aimed at developing these abilities into their curricula.

4.2. Factors influencing teachers’ GenAI integration

Our data also allowed us to synthesize positive and negative factors – individual, technological, and environmental – that influenced teachers’ GenAI-integration processes. First, at the individual level, each of our teacher types exhibited a unique degree of acceptance of GenAI and distinctive attitudes about how it should function in their instruction. This is consistent with Cheah et al.’s (2025) finding that teachers’ beliefs about GenAI’s value were a significant factor in their integration of it. Our cautious adapters typically positioned themselves as conventional teachers who lacked motivation for or experience of teaching with GenAI, and viewed its classroom integration as an indicator of laziness and/or a hindrance to professional skills. These views, in turn, impeded

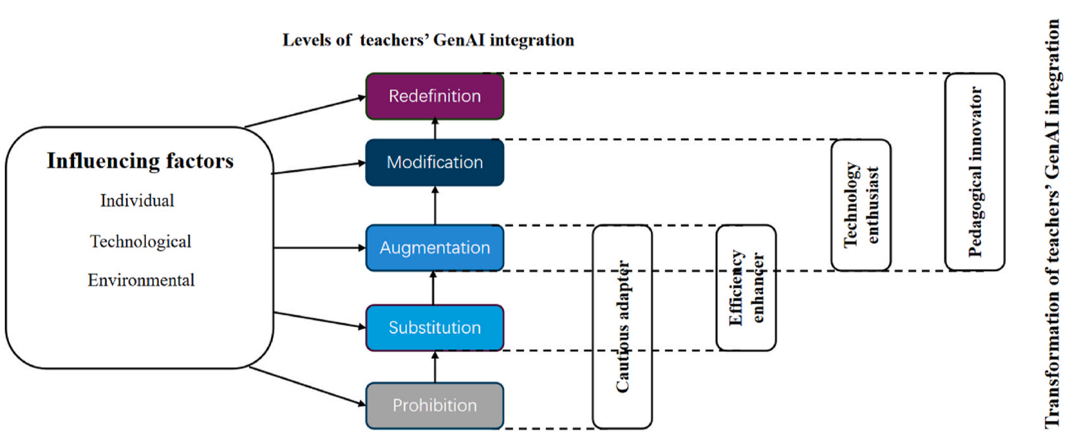

Fig. 10. Model of teachers’ GenAI integration process.

their willingness to include it in their teaching, even if they possessed the necessary TPACK (see also Yang et al., 2025). Our other three teacher types, however, exhibited clear GenAI goals or interests, rooted in beliefs that it could enhance their teaching's effectiveness or creativity; and they used this technology regularly and extensively. This is in line with previous findings (e.g., Al-Mughairi & Bhaskar, 2024; Yang et al., 2025) that teachers who valued GenAI, who had advanced technical skills, and who wanted to further their teaching careers tended to experiment with this technology and integrate it into their work. In terms of challenges, our efficiency enhancers expressed concerns, familiar from other research (Annamalai, 2024; Chan & Hu, 2023), about being replaced by GenAI. The technology enthusiasts and pedagogical innovators, on the other hand, worried about two issues largely ignored in previous studies: GenAI-driven changes in assessment, and students' inadequate AI literacy. As such, researchers and practitioners should recognize teachers' varying levels of GenAI acceptance, interest, and competency, and propose guidance tailored to those levels while also acknowledging teachers' anxieties.

Second, at the technological level, all participants recognized GenAI as an innovative, efficient, and economical tool for enhancing educational effectiveness and augmenting teacher productivity, in line with prior findings that its time- and effort-saving advantages significantly incentivized teachers to use it (e.g., Al-Mughairi & Bhaskar, 2024; Annamalai, 2024). Other studies (e.g., Kohnke & Zou, 2025) have, in keeping with our data, highlighted GenAI's potential and usefulness to student-centered learning activities and differentiated teaching. Our sample's technological *concerns*, meanwhile, were primarily related to system security and information reliability, again in line with prior research (e.g., Al-Mughairi & Bhaskar, 2024). Whereas Cheah et al. (2025) attributed their observed low uptake of GenAI for classroom teaching entirely to teachers' technology-value beliefs and pedagogical principles, we found that inaccuracy in some AI-generated content – and the time spent in checking for this problem – hindered teachers' capacity to employ this emerging technology other than for out-of-class work.

Turning to environmental factors, many of our participants reported that their professional GenAI use was inspired and enhanced by suggestions from head teachers, colleagues, friends, and various social-media platforms. As well as partly redressing the WTSP model's underemphasis on environmental factors, these findings align with the teacher and school readiness model for technology integration proposed by Petko et al. (2018), which emphasizes the key roles of leadership support and informal teacher relationships in influencing teachers' readiness to incorporate varied technologies into the classroom. However, some of our cautious adapters' wished-for technology integration was hindered by school restrictions on students' GenAI use in class. We also identified two factors, i.e., student influence and public discourse on social media, as markedly affecting teachers' adoption of GenAI. This indicates that future teacher trainers could usefully recognize diverse forms of informal teacher-learning types as a means of encouraging and enhancing GenAI utilization by teachers. Additionally, among our participants who worked in more supportive school climates with advanced technological infrastructures, the ethical considerations raised by using GenAI in education emerged as critical (see also Radwan & McGinty, 2024; Yan et al., 2024). This implies that, in addition to technical support, schools and teacher educators should establish ethical guidelines for using GenAI and provide training that combines pedagogical and technological competence, as also recommended by Lan et al. (2025). Finally, our data suggest that previous studies have overlooked teachers' views that GenAI integration requires a baseline level of creativity, self-discipline, and digital literacy, on the part of students as well as teachers. This suggests that teachers should develop their contextual knowledge (Petko et al., 2025) to identify both student competencies and evolving educational policies within their environment, thereby ensuring appropriate and effective GenAI integration.

4.3. Transformation of teachers' GenAI-integration processes

Another facet of GenAI-integration processes that prior research has rarely captured is their dynamism. Our evidence helps fill that gap: showing, firstly, that among all four types of teacher that we identified, such processes typically started at lower levels and gradually transitioned to higher ones. This lower-to-higher shift aligns with previous findings about technology integration in general (Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur, & Sendurur, 2012; Moorhouse & Kohnke, 2024). Initially, teachers may distrust technology or even experience "algorithm aversion" (Dietvorst, Simmons, & Massey, 2015, p. 1), but as their usage increases, their technological knowledge and teaching skills both improve, leading to greater self-efficacy (Adipat, 2021).

Implicitly, the present study's four-part typology of teachers highlights the need to avoid presenting 'one-size-fits-all' pathways to better GenAI integration. Instead, teacher educators, policymakers, and school leaders should tailor their support based on each teacher's type and current stage of integration. For example, if cautious adapters are still at the prohibition stage, schools should place greater emphasis on updating their pedagogical beliefs rather than introducing them to more tools. In contrast, efficiency enhancers who are stuck at the augmentation stage would likely benefit if teacher educators' training sessions provided role models of modification and redefinition, and/or if collaborative projects or workshops offered them opportunities to learn from technology enthusiasts and pedagogical innovators. And for teachers aiming to reach the redefinition stage, schools could offer opportunities to lead GenAI-integrated educational initiatives or create more innovative spaces such as teacher-led AI innovation labs.

We also found that, as teachers progressed from lower to higher integration levels, their focus tended to shift from GenAI's functions to its impact on the teacher-student relationship. Together with our other findings, this suggests that efforts to promote GenAI integration should emphasize enhancing teacher autonomy and digital literacy (Jochim & Lenz-Kesekamp, 2025; Lu et al., 2024), as well as ensuring timely updates to assessment standards, to alleviate concerns about using GenAI in the classroom. Additionally, scholars and policymakers should expand existing professional-development frameworks beyond technical skills by incorporating ethical, pedagogical, and student-engagement dimensions of GenAI use (Kohnke et al., 2023). This is important not only in our study's regional setting, but also potentially in many other places around the world (e.g., Ansari, Ahmad, & Bhutta, 2024).

Finally, as teachers move from lower to higher levels of integration, their use of GenAI tends to shift from single-subject applications to interdisciplinary ones. This may be because interdisciplinary curricula often require greater student participation and broader skills development, which align with our model's modification and redefinition stages (see also Cohen et al., 2024). The same shift also highlights the importance of viewing GenAI as part of broader curriculum-reform efforts, especially in project-based and inquiry-based learning environments. School leaders should allocate more instructional time to interdisciplinary matters and set more interdisciplinary course objectives as a means of facilitating more effective GenAI integration. While our data were drawn from public schools in China, our recommendations may equally apply to teachers in other rapidly digitizing systems where educators are similarly exploring how to integrate novel technological tools while maintaining the integrity of instruction (Samala et al., 2024).

4.4. Limitations and future research directions

This study has several limitations. First, although some of its participants demonstrated cross-disciplinary GenAI integration, its findings may not reflect integration processes in subjects with very different teaching tasks, such as physical education. Future research on GenAI integration in a broader range of disciplines and its influencing factors is therefore warranted. Second, although the SAMR model clearly accounted for individual differences in levels of GenAI integration into teaching, and our findings captured teachers' dynamic evolution across such levels, our approach emphasized teachers' ability to implement the distinct potentials of educational technologies rather than the quality of their teaching. Future researchers of this topic should therefore incorporate teaching quality into their models, analyze more specific and complex classroom environments, and relate those environments to student learning outcomes. Third, although we identified factors influencing teachers' GenAI integration, we did not quantify their extent. Future research could usefully do so. Finally, a longer-term longitudinal study might identify more stable trends and yield clearer insights.

5. Conclusion

This study's results have both theoretical and practical significance. Theoretically, they extend the SAMR model into the PSAMR model by adding a "P"-for-prohibition level, and support it empirically with evidence from K-12 educational settings where GenAI is used. Additionally, they refine traditional SAMR by examining specific integration processes and incorporating personal, contextual, and technological factors, thus enhancing PSAMR's applicability to teachers operating at all stages and under varied conditions.

Practically, our four-part typology of teachers equips stakeholders with unique insights into the GenAI-integration process, which can guide their provision of appropriate support. Specifically, teacher-training content should be tailored to teachers' integration stages: focusing on belief-shifting activities and practical use cases for beginners, while providing advanced workshops on GenAI ethics, student assessment, and inquiry-based task design for those at higher levels. School policies should promote peer collaboration across teacher types, whether in the form of closed-ended projects or innovation spaces; and informal learning channels, such as social media and colleague networks (Jin et al., 2024), should be leveraged to share practical implementation examples and support teachers' ongoing experimentation. Additionally, curriculum designers should integrate GenAI into interdisciplinary learning tasks that foster students' creativity, critical thinking, and self-regulation skills. Finally, clear evaluation standards should be established to guide responsible and pedagogically meaningful use of GenAI. These recommendations are relevant not only to the Chinese K-12 context, but potentially to all education systems undergoing digital transformation.

CRediT authorship contribution statement

Zicong Song: Writing – review & editing, Writing – original draft, Visualization, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jingjing Qin:** Writing – review & editing, Writing – original draft, Resources, Formal analysis, Data curation. **Fangzhou Jin:** Writing – review & editing, Writing – original draft, Formal analysis. **Wai Ming Cheung:** Writing – review & editing, Supervision, Project administration. **Chin-Hsi Lin:** Writing – review & editing, Supervision, Project administration, Conceptualization.

Declaration of competing interest

The authors declare that there is no conflict of interest related to this submission.

Appendix. ASupplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tate.2025.105157.

Data availability

Data will be made available on request

References

Adipat, S. (2021). Developing technological pedagogical content knowledge (TPACK) through technology-enhanced content and language-integrated learning (T-CLIL) instruction. *Education and Information Technologies, 26*(5). https://doi.org/10.1007/s10639-021-10648-3. Article 5.

Al-Mughairi, H., & Bhaskar, P. (2024). Exploring the factors affecting the adoption [of] AI techniques in higher education: Insights from teachers' perspectives on ChatGPT. *Journal of Research in Innovative Teaching & Learning*. https://doi.org/10.1108/JRIT-09-2023-0129. ahead-of-print.

Annamalai, N. (2024). Factors affecting English language high school teachers switching intention to ChatGPT: A push-pull-mooring theory perspective. *Interactive Learning Environments, 33*(2), 1367–1384. https://doi.org/10.1080/10494820.2024.2371928

Ansari, A. N., Ahmad, S., & Bhutta, S. M. (2024). Mapping the global evidence around the use of ChatGPT in higher education: A systematic scoping review. *Education and Information Technologies, 29*(9), 11281–11321. https://doi.org/10.1007/s10639-023-12223-4

Antonietti, C., Schmitz, M.-L., Consoli, T., Cattaneo, A., Gonon, P., & Petko, D. (2023). Development and validation of the ICAP technology scale to measure how teachers integrate technology into learning activities. *Computers & Education, 192*. https://doi.org/10.1016/j.compedu.2022.104648. Article 104648.

Backfisch, I., Lachner, A., Stürmer, K., & Scheiter, K. (2021). Variability of teachers' technology integration in the classroom: A matter of utility. *Computers & Education, 166*. https://doi.org/10.1016/j.compedu.2021.104159. Article 104159.

Bhaskar, P., & Rana, S. (2024). The ChatGPT dilemma: Unravelling teachers' perspectives on inhibiting and motivating factors for adoption of ChatGPT. *Journal of Information, Communication and Ethics in Society, 22*(2), 219–239. https://doi.org/10.1108/JICES-11-2023-0139

Blundell, C. N., Mukherjee, M., & Nykvist, S. (2022). A scoping review of the application of the SAMR model in research. *Computers and Education Open, 3*. https://doi.org/10.1016/j.caeo.2022.100093. Article 100093.

Bower, M., Torrington, J., Lai, J. W. M., Petocz, P., & Alfano, M. (2024). How should we change teaching and assessment in response to increasingly powerful generative artificial intelligence? Outcomes of the ChatGPT teacher survey. *Education and Information Technologies, 29*, 15403–15439. https://doi.org/10.1007/s10639-023-12405-0

Brantley-Dias, L., & Ertmer, P. A. (2013). Goldilocks and TPACK: Is the construct 'just right?'. *Journal of Research on Technology in Education, 46*(2), 103–128. https://doi.org/10.1080/15391523.2013.10782615

Celik, I., Dindar, M., Muukkonen, H., & Järvelä, S. (2022). The promises and challenges of artificial intelligence for teachers: A systematic review of research. *TechTrends, 66*(4), 616–630. https://doi.org/10.1007/s11528-022-00715-y

Chan, C. K. Y., & Hu, W. (2023). Students' voices on generative AI: Perceptions, benefits, and challenges in higher education. *International Journal of Educational Technology in Higher Education, 20*(1). https://doi.org/10.1186/s41239-023-00411-8. Article 43.

Cheah, Y. H., Lu, J., & Kim, J. (2025). Integrating generative artificial intelligence in K-12 education: Examining teachers' preparedness, practices, and barriers. *Computers and Education: Artificial Intelligence, 8*. https://doi.org/10.1016/j.caeai.2025.100363. Article 100363.

Chen, X., Hu, Z., Li, Y., & Wang, C. (2025). The journey of challenges and triumphs: A systematic literature review of the dynamic evolution of human-centered artificial intelligence in education. *Interactive Learning Environments*, 1–26. https://doi.org/10.1080/10494820.2025.2472288

Chi, M. T. H., & Wylie, R. (2014). The ICAP framework: Linking cognitive engagement to active learning outcomes. *Educational Psychologist, 49*(4), 219–243. https://doi.org/10.1080/00461520.2014.965823

Cohen, E., Novis-Deutsch, N., Kashi, S., & Alexander, H. (2024). Interdisciplinary teaching and learning at the K-12 level in the humanities, arts, and social sciences: A scoping review. *Educational Research Review, 44*. https://doi.org/10.1016/j.edurev.2024.100617. Article 100617.

Collie, R. J., & Martin, A. J. (2024). Teachers' motivation and engagement to harness generative AI for teaching and learning: The role of contextual, occupational, and background factors. *Computers and Education: Artificial Intelligence, 6*. https://doi.org/10.1016/j.caeai.2024.100224. Article 100224.

Consoli, T., Désiron, J., & Cattaneo, A. (2023). What is "technology integration" and how is it measured in K-12 education? A systematic review of survey instruments from 2010 to 2021. *Computers & Education, 197*. https://doi.org/10.1016/j.compedu.2023.104742. Article 104742.

Consoli, T., Schmitz, M.-L., Antonietti, C., Gonon, P., Cattaneo, A., & Petko, D. (2025). Quality of technology integration matters: Positive associations with students' behavioral engagement and digital competencies for learning. *Education and Information Technologies, 30*, 7719–7752. https://doi.org/10.1007/s10639-024-13118-8

Dai, D. W., Suzuki, S., & Chen, G. (2025). Generative AI for professional communication training in intercultural contexts: Where are we now and where are we heading? *Applied Linguistics Review, 16*(2), 763–774. https://doi.org/10.1515/applirev-2024-0184

Dietvorst, B. J., Simmons, J. P., & Massey, C. (2015). Algorithm aversion: People erroneously avoid algorithms after seeing them err. *Journal of Experimental Psychology: General, 144*(1), 114–126. https://doi.org/10.1037/xge0000033

Dwivedi, Y. K., Kshetri, N., Hughes, L., Slade, E. L., Jeyaraj, A., Kar, A. K., … Wright, R. (2023). Opinion paper: "So what if ChatGPT wrote it?" multidisciplinary perspectives on opportunities, challenges and implications of generative conversational AI for research, practice and policy. *International Journal of Information Management, 71*. https://doi.org/10.1016/j.ijinfomgt.2023.102642. Article 102642.

Education Bureau of Shenzhen. (2022). *The implementation plan for promoting the group-based management of public elementary, middle, and high schools in shenzhen*. Shenzhen Municipal People's Government. https://www.sz.gov.cn/.

Ertmer, P. A., Ottenbreit-Leftwich, A. T., Sadik, O., Sendurur, E., & Sendurur, P. (2012). Teacher beliefs and technology integration practices: A critical relationship. *Computers & Education, 59*(2). https://doi.org/10.1016/j.compedu.2012.02.001. Article 2.

European Commission. (2013). *Survey of schools: ICT in education. Benchmarking access, use and attitudes to technology in Europe's schools. Final study report*. http://ec.europa.eu/information_society/newsroom/cf/dae/document.cfm?doc_id=1800.

Feldman-Maggor, Y., Blonder, R., & Alexandron, G. (2024). Perspectives of generative AI in chemistry education within the TPACK framework. *Journal of Science Education and Technology, 34*(1). https://doi.org/10.1007/s10956-024-10147-3. Article 1.

Fütterer, T., Scheiter, K., Cheng, X., & Stürmer, K. (2022). Quality beats frequency? Investigating students' effort in learning when introducing technology in classrooms. *Contemporary Educational Psychology, 69*. https://doi.org/10.1016/j.cedpsych.2022.102042. Article 102042.

Gammoh, L. A. (2025). ChatGPT risks in academia: Examining university educators' challenges in Jordan. *Education and Information Technologies, 30*(3), 3645–3667. https://doi.org/10.1007/s10639-024-13009-y

Graham, C. R. (2011). Theoretical considerations for understanding technological pedagogical content knowledge (TPACK). *Computers & Education, 57*(3), 1953–1960. https://doi.org/10.1016/j.compedu.2011.04.010

Hamilton, E. R., Rosenberg, J. M., & Akcaoglu, M. (2016). The substitution augmentation modification redefinition (SAMR) model: A critical review and suggestions for its use. *TechTrends, 60*(5). https://doi.org/10.1007/s11528-016-0091-y. Article 5.

Hsu, P.-S. (2016). Examining current beliefs, practices and barriers about technology integration: A case study. *TechTrends, 60*(1), 30–40. https://doi.org/10.1007/s11528-015-0014-3

Huberman, M., & Miles, M. B. (2002). *The Qualitative Researcher's Companion*. SAGE.

Jaboob, M., Hazaimeh, M., & Al-Ansi, A. M. (2025). Integration of generative AI techniques and applications in student behavior and cognitive achievement in Arab higher education. *International Journal of Human-Computer Interaction, 41*(1), 353–366. https://doi.org/10.1080/10447318.2023.2300016

Ji, H., Han, I., & Park, S. (2024). Teaching foreign language with conversational AI: Teacher-student-AI interaction. *Language, Learning and Technology, 28*(2), 91–108. https://hdl.handle.net/10125/73573.

Jin, F., Song, Z., Cheung, W. M., Lin, C. H., & Liu, T. (2024). Technological affordances in teachers' online professional learning communities: A systematic review. *Journal of Computer Assisted Learning, 40*(3), 1019–1039. https://doi.org/10.1111/jcal.12935

Jin, F., Sun, L., Pan, Y., & Lin, C. H. (2025). High heels, compass, Spider-Man, or drug? Metaphor analysis of generative artificial intelligence in academic writing. *Computers & Education*. https://doi.org/10.1016/j.compedu.2025.105248. Article 105248.

Jochim, J., & Lenz-Kesekamp, V. K. (2025). Teaching and testing in the era of text-generative AI: Exploring the needs of students and teachers. *Information and Learning Sciences, 126*(1/2), 149–169. https://doi.org/10.1108/ILS-10-2023-0165

Kim, J., Yu, S., Detrick, R., & Li, N. (2025). Exploring students' perspectives on generative AI-assisted academic writing. *Education and Information Technologies, 30*, 1265–1300. https://doi.org/10.1007/s10639-024-12878-7

Knezek, G., & Christensen, R. (2016). Extending the will, skill, tool model of technology integration: Adding pedagogy as a new model construct. *Journal of Computing in Higher Education, 28*(3), 307–325. https://doi.org/10.1007/s12528-016-9120-2

Koehler, M., & Mishra, P. (2009). What is technological pedagogical content knowledge (TPACK)? *Contemporary Issues in Technology and Teacher Education, 9*(1), 60–70. https://citejournal.org/volume-9/issue-1-09/general/what-is-technological-pedagogicalcontent-knowledge.

Kohnke, L., Moorhouse, B. L., & Zou, D. (2023). ChatGPT for language teaching and learning. *RELC Journal, 54*(2), 537–550. https://doi.org/10.1177/00336882231162868

Kohnke, L., & Zou, D. (2025). The role of ChatGPT in enhancing English teaching: A paradigm shift in lesson planning and instructional practices. *Educational Technology & Society, 28*(3), 4–20. https://doi.org/10.30191/ETS.202507_28(3).SP02

Kong, S.-C., & Yang, Y. (2024). A human-centered learning and teaching framework using generative artificial intelligence for self-regulate learning development through domain knowledge learning in K-12 settings. *IEEE Transactions on Learning Technologies, 17*, 1588–1599. https://doi.org/10.1109/TLT.2024.3392830

Lachner, A., Backfisch, I., & Franke, U. (2024). Towards an integrated perspective of teachers' technology integration: A preliminary model and future research directions. *Frontline Learning Research, 12*(1), 1–15. https://doi.org/10.14786/flr.v12i1.1179

Lan, Y.-J., & Chen, N.-S. (2024). Teachers' agency in the era of LLM and generative AI: Designing pedagogical AI agents. *Educational Technology & Society, 27*(1), I–XVIII. https://www.jstor.org/stable/48754837.

Lan, G., Feng, X., Du, S., Song, F., & Xiao, Q. (2025). Integrating ethical knowledge in generative AI education: Constructing the GenAI-TPACK framework for university teachers' professional development. *Education and Information Technologies*, 1–24. https://doi.org/10.1007/s10639-025-13427-6

Lee, U., Han, A., Lee, J., Lee, E., Kim, J., Kim, H., & Lim, C. (2024). Prompt aloud!: Incorporating image-generative AI into STEAM class with learning analytics using prompt data. *Education and Information Technologies, 29*(8), 9575–9605. https://doi.org/10.1007/s10639-023-12150-4

Liu, Y., Park, J., & McMinn, S. (2024). Using generative artificial intelligence/ChatGPT for academic communication: Students' perspectives. *International Journal of Applied Linguistics, 34*(4), 1437–1461. https://doi.org/10.1111/ijal.12574

Lu, J., Zheng, R., Gong, Z., & Xu, H. (2024). Supporting teachers' professional development with generative AI: The effects on higher order thinking and self-efficacy. *IEEE Transactions on Learning Technologies, 17*, 1279–1289. https://doi.org/10.1109/TLT.2024.3369690

Luo, J. (2024). How does GenAI affect trust in teacher-student relationships? Insights from students' assessment experiences. *Teaching in Higher Education, 30*(4), 991–1006. https://doi.org/10.1080/13562517.2024.2341005

Merriam, S. B., & Grenier, R. S. (2015). *Qualitative research in practice: Examples for discussion and analysis*. John Wiley & Sons.

Meskó, B., & Topol, E. J. (2023). The imperative for regulatory oversight of large language models (or generative AI) in healthcare. *npj Digital Medicine, 6*(1). https://doi.org/10.1038/s41746-023-00873-0. Article 120.

Mishra, P., Warr, M., & Islam, R. (2023). TPACK in the age of ChatGPT and generative AI. *Journal of Digital Learning in Teacher Education, 39*(4), 235–251. https://doi.org/10.1080/21532974.2023.2247480

Mohamed, A. M. (2024). Exploring the potential of an AI-based Chatbot (ChatGPT) in enhancing English as a foreign language (EFL) teaching: Perceptions of EFL faculty members. *Education and Information Technologies, 29*(3), 3195–3217. https://doi.org/10.1007/s10639-023-11917-z

Mokmin, N. A. M., & Rassy, R. P. (2024). Review of the trends in the use of augmented reality technology for students with disabilities when learning physical education. *Education and Information Technologies, 29*(2), 1251–1277. https://doi.org/10.1007/s10639-022-11550-2

Moorhouse, B. L., & Kohnke, L. (2024). The effects of generative AI on initial language teacher education: The perceptions of teacher educators. *System, 122*. https://doi.org/10.1016/j.system.2024.103290. Article 103290.

Muslimin, A. I., Mukminatien, N., & Ivone, F. M. (2024). Evaluating Cami AI across SAMR stages: Students' achievement and perceptions in EFL writing instruction. *Online Learning, 28*(2). https://eric.ed.gov/?id=EJ1428229.

Petko, D., Mishra, P., & Koehler, M. J. (2025). TPACK in context: An updated model. *Computers and Education Open, 8*. https://doi.org/10.1016/j.caeo.2025.100244. Article 100244.

Petko, D., Prasse, D., & Cantieni, A. (2018). The interplay of school readiness and teacher readiness for educational technology integration: A structural equation model. *Computers in the Schools, 35*(1), 1–18. https://doi.org/10.1080/07380569.2018.1428007

Puentedura, R. (2006). Transformation, technology, and education [Blog post]. Retrieved from http://hippasus.com/resources/tte/.

Radwan, A., & McGinty, J. (2024). Toward a conceptual generative AI ethical framework in teacher education. In M. Searson, E. Langran, & J. Trumble (Eds.), *Exploring new horizons: Generative artificial intelligence and teacher education* (pp. 88–109). Association for the Advancement of Computing in Education (AACE). https://www.learntechlib.org/p/223928/.

Rosenberg, J. M., & Koehler, M. J. (2015). Context and technological pedagogical content knowledge (TPACK): A systematic review. *Journal of Research on Technology in Education, 47*(3), 186–210. https://doi.org/10.1080/15391523.2015.1052663

Roulston, K., & Choi, M. (2018). Qualitative interviews. In U. Flick (Ed.), *The SAGE handbook of qualitative data collection* (pp. 233–249). SAGE.

Samala, A. D., Rawas, S., Wang, T., Reed, J. M., Kim, J., Howard, N.-J., & Ertz, M. (2024). Unveiling the landscape of generative artificial intelligence in education: A comprehensive taxonomy of applications, challenges, and future prospects. *Education and Information Technologies, 30*(3), 3239–3278. https://doi.org/10.1007/s10639-024-12936-0

Sawyerr, A., & Agyei, D. D. (2023). Mathematics teachers' use of ICT in classroom instruction: Exploring the will-skill-tool-pedagogy model in the Ghanaian context. *Education and Information Technologies, 28*(8), 9397–9416. https://doi.org/10.1007/s10639-022-11234-x

Scherer, R., & Teo, T. (2019). Unpacking teachers' intentions to integrate technology: A meta-analysis. *Educational Research Review, 27*, 90–109. https://doi.org/10.1016/j.edurev.2019.03.001

Šumak, B., & Šorgo, A. (2016). The acceptance and use of interactive whiteboards among teachers: Differences in UTAUT determinants between pre- and post-adopters. *Computers in Human Behavior, 64*, 602–620. https://doi.org/10.1016/j.chb.2016.07.037

Szabó, F., & Szoke, J. (2024). How does generative AI promote autonomy and inclusivity in language teaching? *ELT Journal, 78*(4), 478–488. https://doi.org/10.1093/elt/ccae052. Article ccae052.

Vartiainen, H., & Tedre, M. (2023). Using artificial intelligence in craft education: Crafting with text-to-image generative models. *Digital Creativity, 34*(1), 1–21. https://doi.org/10.1080/14626268.2023.2174557

Wang, C., Chen, X., Hu, Z., Jin, S., & Gu, X. (2025). Deconstructing university learners' adoption intention towards AIGC technology: A mixed-methods study using ChatGPT as an example. *Journal of Computer Assisted Learning, 41*(1). https://doi.org/10.1111/jcal.13117. Article e13117.

Yan, L., Sha, L., Zhao, L., Li, Y., Martinez-Maldonado, R., Chen, G., Li, X., Jin, Y., & Gašević, D. (2024). Practical and ethical challenges of large language models in education: A systematic scoping review. *British Journal of Educational Technology, 55*, 90–112. https://doi.org/10.1111/bjet.13370

Yang, Y., Xia, Q., Liu, C., & Chiu, T. K. F. (2025). The impact of TPACK on teachers' willingness to integrate generative artificial intelligence (GenAI): The moderating role of negative emotions and the buffering effects of need satisfaction. *Teaching and*

Teacher Education, 154, Article 104877. https://doi.org/10.1016/j.tate.2024.104877
Yusuf, A., Pervin, N., & Román-González, M. (2024). Generative AI and the future of higher education: A threat to academic integrity or reformation? Evidence from multicultural perspectives. *International Journal of Educational Technology in Higher Education, 21*(1). https://doi.org/10.1186/s41239-024-00453-6. Article 21.
Zhang, P., & Tur, G. (2024). A systematic review of ChatGPT use in K-12 education. *European Journal of Education, 59*(2). https://doi.org/10.1111/ejed.12599. Article e12599.