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Teachers' Stages of Concern in Adopting Generative Artificial Intelligence for Science Education: A Systematic Review

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ABSTRACT

This systematic review, in the context of the Concerns-Based Adoption Model (CBAM) as the theoretical framework, reviewed science teachers' concerns about the implementation of Generative Artificial Intelligence (GenAI) tools in science education. Specifically, the study aimed to investigate the stages of concern science teachers show, analyze the factors that cause concerns and assess the strategies that aid in facilitating the adoption of GenAI in science teaching. A Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework was used to structure the review, and a narrative thematic synthesis was applied to categorize and synthesize the results from the different studies. Literature was identified through Google Scholar by systematically developed search terms that included combinations of the concepts of GenAI tools and teacher concern constructs, as well as science education contexts; the full Boolean search strategy is reported in the Methods section for the purposes of replicability. A total of 432 records were identified and then screened for eligibility and then peer-reviewed empirical studies published from 2022 to 2026 were included. The findings show that the majority of secondary science teachers are at the early CBAM stages (awareness, informational, and personal), suggesting that the majority of teachers are still preoccupied with understanding and managing GenAI rather than understanding how it can influence student learning. The four factors that influence teachers' concern profile were identified as: AI knowledge, institutional policy climate, opportunities for professional development, and personal pedagogical beliefs. Importantly, it was found that concern level and intention to adopt work via different psychological mechanisms: adoptive intentions can be stronger than positive beliefs at high concern stages. Nearly all studies included recommended three strategies: embedding AI literacy in pre-service science teacher education, providing professional development in the context of a specific discipline and on an ongoing basis, and creating explicit institutional GenAI policies. Another methodological gap was found, as no study included in the analysis used the validated Stages of Concern Questionnaire with the adoption of GenAI in secondary science education. This gap indicates the need for theory-based empirical studies on GenAI adoption in secondary science education. As this review drew from a single database and did not include a formal quality appraisal or a prospectively registered protocol, its conclusions should be read as an initial, theory-building synthesis rather than a fully instrument-validated account; these boundaries are made explicit in the Methods and Limitations sections.

INTRODUCTION

The introduction of Generative Artificial Intelligence (GenAI), like ChatGPT, Google Gemini, and Microsoft Copilot, has revolutionized educational systems around the world, offering unprecedented opportunities and pedagogical challenges (Chiu, 2023; Cheah & Kim, 2025). Since its launch in 2022, ChatGPT has undergone a fast and rapid adoption period, generating an estimated monthly viewership of 100 million users in just two months. The unprecedented adoption and launch of ChatGPT in 2022 have led to significant shifts and changes in science education at the secondary level. Despite the potential benefits of GenAI for personalized learning, instructional support, and student engagement in the classroom, teachers' readiness, concerns, and adoption paths are still not well understood, largely because of the limited research on their experiences with GenAI in education (Chen *et al.*, 2025; Kokoç, 2024).

Science education is in a pivotal role in the transition to a technological era. Raising scientific literacy is one of the key objectives of science education in secondary schools, and science teachers are one of the major sources for students' science learning to critically evaluate quality and reliability of scientific information - especially in the context of GenAI technology creating plausible but possibly inaccurate scientific information. However, the empirical evidence of how science teachers adapt GenAI in secondary education is still limited. Current research tends to focus on the higher education sector or to view science teachers as part of a larger group of K-12 teachers, which fails to acknowledge the specific nature of science teaching and the specific issues and concerns that it poses (Garofalo & Farenga, 2024; Ramnarain *et al.*, 2024).

The Concerns-Based Adoption Model (CBAM) by Hall and Hord (2020) is a strong theoretical model to support

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teacher adoption of educational innovations. A key aspect of CBAM is the Stages of Concern, a series of seven types of concerns that may occur when considering an innovation, from the most self-focused concerns about how the innovation will impact job performance to the later impact-focused concerns about how the innovation will impact students and colleagues. Although CBAM has proven valid across various educational settings, it has been used very little to explain how science teachers move through - or stay stuck in - the initial concern phases when facing the ever-changing landscape of AI technologies.

This systematic review addresses that gap. By synthesizing empirical evidence published between 2022 and 2026, it aims to identify the stages of concern science teachers exhibit regarding GenAI adoption, examine the factors influencing those concerns, and evaluate strategies that support progression toward deeper and more confident integration of GenAI in science instruction.

LITERATURE REVIEW

Generative Artificial Intelligence is a disruptive technology that could revolutionize education by providing various new opportunities for personalizing learning, creating content, analyzing data and providing automated feedback. Educators have started to use ChatGPT and similar tools as Large Language Models (LLMs) that can produce human-like text responses to create lesson plans, instructional scaffolding, and design formative assessment tasks (Chiu, 2023). However, its capabilities can be used in ways that benefit teachers and students. ChatGPT can help teachers generate instructional content, facilitate discussions, and provide personalized feedback to students, freeing up time to focus on more creative and interactive teaching.

But the challenges of integrating GenAI into practice in education aren't going away. Academic integrity and plagiarism, particularly when AI-generated material is presented without proper analysis, have become significant issues and are considered academic dishonesty. Academic integrity and plagiarism, especially when a student presents AI-generated content without critical analysis, are salient concerns and widely understood as academic dishonesty. Moreover, issues like the threat of dependence on AI, ethical considerations about data privacy, and the possibility of superficial learning need to be discussed and handled correctly via training and reflection. In science education particularly, these issues are significant, as conceptual understanding and scientific reasoning are central pillars (Garofalo & Farenga, 2024). The literature on science teachers' preparedness to and intentions to utilize GenAI tools has expanded significantly since 2023 but is still relatively limited. They identified that among the pre-service science teachers in South Africa, who were found to have a positive attitude toward the use of AI, the intention to adopt GenAI was significantly influenced by AI literacy, attitude, perceived usefulness, and subjective norms, but not by concern about GenAI, indicating that concern about GenAI and

intention to use it follow different psychological paths. Likewise, Mnguni *et al.* (2024) carried out a comparative study between South Africa and Thailand, and their findings indicated that pre-service science teachers in both countries had positive behavioral intentions towards the use of AI in education, despite the significant socio-economic differences between the two countries in terms of educational infrastructure.

Based on large national surveys, the adoption rate for National K-12 teachers using AI tools is low, with 18% actually using them and 15% trying them. For secondary science teachers, Chen *et al.* (2025) reported that they were less accepting of using an AI chatbot in teaching than their elementary colleagues, and academic integrity and plagiarism were the major concerns. The teacher survey results showed a greater level of concern among secondary science teachers, highlighting the importance of discipline-specific professional learning programs over generic programs focused on AI training.

The quick utilization and convenience of ChatGPT by all levels of the school has led to its adoption across the board and it has been realized that teacher training programs need to adapt to this too. Pre-service science teachers in Nigeria showed significantly low AI literacy scores, especially in the areas of ethical and practical aspects, as highlighted by Tsakeni and Nwafor (2025), which underscores the need for specific and systematic teaching of AI competency in science curricula prior to their use in science classrooms.

Empirical studies show that barriers to GenAI adoption fall into several dimensions that are linked together. Besides, the absence of policies, institutional support, and guidance around the use of AI emerged as the most significant first-order barrier, with second-order barriers (beliefs and pedagogy) also remaining even though teachers believe GenAI has the potential to be beneficial for education. Furthermore, the lack of policies and institutional guidance around the use of AI was identified as the most significant first-order barrier, whereas second-order barriers (beliefs and pedagogy) persisted, even among teachers who do perceive GenAI as having the potential to be educationally beneficial. The barriers to the sustained use of GenAI observed through qualitative interviews were technical infrastructure deficiencies, lack of training, accuracy issues, and reliance issues identified by Kokoç (2024) from the perspective of secondary teachers in Turkey. These studies collectively point out that gaps in infrastructure, policy, and training are cumulative: teachers are not likely to state that they have encountered one single barrier, but rather a combination of institutional and personal barriers that work together to "lock them" into some early CBAM stages.

The issues of professional development emerge again and again in the readings reviewed. Incorporating GenAI tools in education demands new skills for educators, a quick shift in technology that can make them feel less effective and in some cases, risk losing their jobs. This was confirmed by Kaplan-Rakowski *et al.* (2023) in their cross-national study of teachers who wanted to use

GenAI in the USA, UK, and Canada, who reported that the highest need was for professional development on GenAI pedagogy.

The Concerns-Based Adoption Model (Hall & Hord, 2020) has been well validated for understanding the why and how of teacher movement, or lack of it, through adoption processes. Teachers' changes in stages of concern within a variety of national contexts have been used to assess this and have consistently yielded the highest levels of concern in the awareness, management and informational stages, and the lowest in the collaborative and consequence stages. This developmental process suggests that early adopters tend to be concerned about comprehending and controlling the innovation first, and only afterward considering the impact it might have on education.

He and Yusop (2020) validated a 32-item version of the Stages of Concern Questionnaire (SoCQ) based on CBAM framework encompassing the seven stages of concern (namely, unconcerned, informational, personal, management, consequence, collaboration, and refocusing), which is considered reliable for application in technology adoption settings (DOI: 10.1016/j.dib.2020.105230). The CBAM can be used alongside a barrier framework, allowing for a more holistic view of the barriers teachers encounter and their strategies for overcoming them as they implement innovations, which can inform the design of appropriately targeted support interventions for each stage of implementation.

However, there is a lack of systematic application of the CBAM to the adoption of GenAI in secondary science education, and the specific concern trajectories that science teachers take when faced with this transformative technology remain unknown. This systematic review aims to address the gap by synthesizing existing empirical evidence to plot science teachers' stages of concern, identify factors affecting their integration of GenAI in science learning, and highlight evidence-based strategies for supporting deeper and more equitable integration of GenAI in science learning settings. The reviews of the studies in this section suggest that, despite the differences between countries, the issues arising at the early stage of learning with AI are influenced by AI literacy, institutional support and teachers' beliefs and attitudes. The results of the studies reviewed in this section justify the stage-by-stage synthesis which follows this section, by indicating that, irrespective of the country, issues arising at the initial stage of learning with AI are affected by AI literacy, institutional support and teachers' beliefs and attitudes.

MATERIALS AND METHODS

This study utilized the systematic literature review (SLR) method to synthesize existing evidence on science teachers' stages of concern regarding the adoption of Generative Artificial Intelligence (GenAI) in science education, including the factors influencing these concerns, strategies for addressing them, and research gaps to inform future teacher professional development. The review procedure followed the Preferred Reporting

Items for Systematic Reviews and Meta-Analyses (PRISMA) framework (Page *et al.*, 2021), and findings were integrated using narrative thematic synthesis. Article selection was carried out according to the four major phases outlined in the PRISMA flowchart: identification, screening, assessment of eligibility, and final inclusion.

Search Strategy and Database Coverage

In the identification stage, relevant literature was identified from the search engine Google Scholar using the search terms "Stages of Concern" or "Stage of Concern" or "SoC" or "Concerns-Based Adoption Model" or "CBAM" or "teacher concerns" or "innovation concerns" or "adoption concerns" or "technology adoption" or "technology acceptance" or "innovation adoption" or "educational innovation" and ("Generative Artificial Intelligence" or "Generative AI" or "GenAI" or "Artificial Intelligence" or "AI" or "ChatGPT" or "Gemini" or "Claude" or "Copilot" or "Large Language Models" or "LLM" or "chatbots" or "AI tools" or "AI applications") and ("science education" or "science teaching" or "science teachers" or "science classrooms" or "science instruction" or "STEM" or "STEM education" or "biology" or "chemistry" or "physics" or "earth science". These terms were combined into the following reproducible Boolean search string, provided here to support replication.

The date range of 2022–2026 was selected because it brackets the public release of ChatGPT in November 2022 - the event that triggered widespread empirical interest in GenAI adoption in education - through the most recent literature available at the time the search was conducted, thereby capturing the full lifespan of empirical scholarship on this emerging topic.

Database coverage

As per the search strategy outlined above, the records from Google Scholar have been used in this review. A multi-database search is a known limitation of the PRISMA process and indexing and deduplication of education and AI literature are not necessarily consistent in every database, so Google Scholar was chosen for its cross-disciplinary coverage of education and AI literature. Future review should broaden the scope of searches to include Scopus, Web of Science, ERIC, Education Source (EBSCO), Dimensions, ProQuest, and IEEE Xplore, to improve the comprehensiveness of retrieval, focusing especially on education literature in engineering-oriented databases related to AI. This limitation is explicitly continued in the Limitations section.

Eligibility Screening

The relevant literature was identified and approached in the screening stage by peer-reviewed journal articles published in the period 2022–2026. The selected journal articles were then further screened during the eligibility stage, excluding studies that involved only students, administrators or parents, but did not include teachers; studies that examined only non-GenAI technologies

(simulations, virtual reality, robotics or traditional AI); studies that focused only on non-GenAI technologies without a Generative AI component; studies with no concern, adoption, implementation, or readiness measures for teachers and GenAI; non-empirical publications (literature reviews, editorials, opinion papers, commentaries, blogs); duplicate records; and studies that were not written in English or did not have accessible full-text publications. Articles were selected for the inclusion stage if they were published in the past five years (2022-2026), included science teachers at the secondary level as participants, focused on science teachers' stages of concern or adoption of Generative Artificial Intelligence in science education or STEM context, were written in English, used either qualitative, quantitative, and/or mixed methods designs, were peer-reviewed journal articles, and were available in full-text format. Studies that fulfilled the inclusion criteria were analyzed by content analysis, grouped under the following narrative thematic categories presented in the Results and Discussion section.

Screening transparency

PRISMA guidelines suggest that two or more reviewers independently perform screening and eligibility decisions and that interrater agreement statistics such as Cohen's κ be included with the screening and eligibility decisions. There was no independent dual screening of the articles nor any second rater cross check and no interrater reliability statistic was calculated for screening and eligibility assessment in this review. Likewise, a consistent extraction from indicating variables extracted (country, sample, method, stage of CBAM, key findings) should be reported, as well as the individual who extracted the data, whether or not it was a pilot extraction, and how disagreements were resolved. In this review data extraction was also done by one reviewer, with an unpiloted extraction form, without a second reviewer cross checking extracted data. This is a single-reviewer

process as reported here, rather than as a retrospective reconstruction, as it is a real limitation of the review and is continued in the section on Limitations below.

For feasibility reasons, the exclusion of non-English-language studies is required, but is recognised as a potential source of language bias and may have meant that relevant evidence from non-Anglophone education systems was excluded; this is noted as a limitation below.

Quality Appraisal, Risk of Bias, and Protocol Registration

This review did not formally assess the quality of the eleven studies included by using, for example, the Joanna Briggs Institute (JBI) Critical Appraisal Checklists for qualitative study work, Joanna Briggs Institute (JBI) Mixed Methods Appraisal Tool (MMAT) for mixed methods study work, and Joanna Briggs Institute (JBI)/ROBINS-I checklists for quantitative study work, nor did it conduct a structured risk-of-bias assessment of studies for selection, performance, attrition, or reporting bias. The study was also not pre-registered on a platform like OSF or PROSPERO. It was not also prospectively registered on a platform like OSF or PROSPERO. These are all known to improve the transparency, ability to be reproduced and the interpretive confidence of a systematic review, and none of them is an omission to be glossed over. This review does not make retrospective statements of what did or did not occur during the appraisal, but rather the gap is reported directly: readers should view the synthesis results as an inferential, theory-building mapping of the literature with the stages in CBAM, not as a risk-of-bias adjusted, or effect-size pooled result. Based on the variety of qualitative, quantitative, and mixed design studies included, a new protocol for any future review should contain prospective registration and MMAT-based appraisals.

RESULTS AND DISCUSSION

This section presents the findings of the systematic

Table 1: Review of literature on the Teachers' Stages of Concern in Adopting Generative Artificial Intelligence for Science Education

Author/s (Year)	Country / Setting	Field of Study (Level)	Sample Size / Participant Type	Method	CBAM Stage(s) Addressed	Key Findings
Garofalo & Farenga (2024)	USA; secondary science classrooms	Science education (Secondary)	n = 24 secondary science teachers (focus groups); in-service	Mixed methods; focus groups + attitudes survey + epistemic cognition questionnaire	Informational, Personal	Secondary science teachers are cautiously optimistic about GenAI; major concerns center on assessment integrity and content accuracy; no significant disciplinary differences in attitude found across science subjects.

Ramnarin <i>et al.</i> (2024)	South Africa; public university	Science education — pre-service (Secondary-bound)	Survey + interview sub-sample; pre-service	Mixed methods; sequential explanatory design; survey + interviews	Personal, Management	AI literacy, attitude, perceived usefulness, and subjective norm significantly predict adoption intention; concern about GenAI had no significant effect on intention; inquiry-based teaching context strengthens adoption inclination.
Mnguni <i>et al.</i> (2024)	South Africa and Thailand; universities	Science education - pre-service (Secondary-bound)	n = 192 pre-service teachers (97 South African, 95 Thai final-year BEd students); pre-service	Quantitative; non-experimental comparative descriptive survey	Personal, Informational	Pre-service science teachers in both South Africa and Thailand show favorable attitudes and behavioral intentions toward AI integration despite socio-economic differences in educational infrastructure.
Kokoç (2024)	Turkey; secondary schools (K-12)	Science and general secondary education (Secondary)	n = 14 secondary school teachers (8 female, 6 male); in-service	Qualitative; semi-structured interviews; content analysis	Informational, Management	Key opportunities include rich adaptive content generation; primary barriers are technical infrastructure deficiencies, inadequate training, accuracy concerns, and risk of over-reliance; ongoing professional development is critical.
Cheah & Kim (2025)	USA; K-12 public schools, Idaho	General and science secondary education (Secondary)	n = 48 STEM teachers (survey); in-service	Mixed methods; survey + semi-structured interviews	Awareness, Informational	Lack of AI-related policy and institutional guidance is the most critical first-order barrier; teachers who perceive GenAI's value are more likely to adopt it despite other barriers.

Chiu (2023)	Hong Kong; secondary schools	General secondary education including science (Secondary)	n = 88 teachers and leaders (survey + focus group); in-service	Qualitative; focus groups + survey; four-domain thematic analysis	Informational, Personal	GenAI is seen as disruptive but opportunity-rich across learning, teaching, assessment, and administration; concerns about academic integrity and assessment authenticity are most salient; institutional policy guidance is urgently needed.
Kim (2023)	South Korea; secondary STEM and technology schools	STEM and technology education (Secondary)	Not reported in abstract — verify (Korean-language source; sample size not confirmable from available English abstract); in-service	Quantitative; survey using AI education awareness and teaching efficacy scales	Awareness, Informational	High overall awareness of AI education necessity; positive correlation between AI education perception and teaching efficacy; teachers with prior AI training show significantly higher efficacy.
Tsakeni and Nwafor (2025)	Nigeria; pre-service teacher education institution	Science education — pre-service (Secondary-bound)	n = 180 pre-service science teachers (survey); 5 (interview subsample); pre-service	Mixed methods; AI literacy assessment + survey + structured reflection	Personal, Management	Pre-service science teachers exhibit low AI literacy, particularly in ethical and practical dimensions; targeted professional development and curriculum-embedded AI competency development are urgently needed.
Kaplan-Rakowski <i>et al.</i> (2023)	USA, UK, and Canada; K-12 and secondary settings	General and science secondary education (Secondary)	n = 147 teachers (diverse group; recruited internationally via SurveyCircle); in-service	Quantitative; cross-national online survey; descriptive and inferential statistics	Personal, Consequence	Majority of teachers are willing to integrate GenAI; job replacement concerns are consistent across national contexts; professional development on GenAI pedagogy is the highest expressed need.

Alneyadi & Wardat (2023)	UAE; secondary science classrooms (Grade 11)	Science education - Physics (Secondary)	Sample size not verifiable from the available abstract, which describes an eleventh-grade student cohort (experimental vs. control) rather than a teacher sample - review team should confirm this study reports a teacher-participant component consistent with this review's eligibility criteria; quasi-experimental cohort	Mixed methods; quasi-experimental design; pre/post test + survey + interviews	Consequence	ChatGPT significantly improved Grade 11 science achievement; positive teacher and student perceptions; teachers express concern about student over-reliance and reliability of AI-generated scientific content.
Chen <i>et al.</i> (2025)	USA; large urban K-12 school district	General and science secondary education (Secondary)	n = 1,454 teachers (survey respondents; large West Coast urban district); in-service	Quantitative; large-scale survey; subject area and grade-level subgroup analysis	Personal, Management	Secondary science teachers are less willing than elementary teachers to allow AI chatbot use; academic integrity and plagiarism are dominant concerns; professional development on AI-specific strategies is the top identified need.

Note. The sample sizes for this revision were cross checked with the published abstract of the study when available in the public domain and figures verified have been inserted in the table. There are two entries still flagged: The Kim (2023) sample size could not be confirmed from the Korean language source read; the available abstract of the Alneyadi and Wardat (2023) entry suggests an experiment on student achievement, rather than one involving teacher concerns, and this should be verified with the full text before submission by the review team. Crossed with the authors' interpretation, this interpretive column, entitled CBAM Stage(s) Addressed, indicates the stages of concern most strongly implicated by the findings of each study reported in the article; it is a starting synthesis for cross-checking with the authors and should be interpreted in the context of a formal quality appraisal (see Methods).

review, synthesizing empirical evidence drawn from eleven peer-reviewed studies published between 2023 and 2025 from the USA, South Africa, Nigeria, Thailand, Turkey, South Korea, UAE, Hong Kong, and a cross-national sample spanning the USA, UK, and Canada. The studies collectively examine teachers' stages of concern in adopting generative artificial intelligence for science education.

Frequency of CBAM Stages of Concern Across Studies

To make the distribution of evidence more transparent, Table 2 summarizes how many of the eleven included studies reported findings mapping onto each CBAM stage, based on the stage assignments in Table 1.

The frequency pattern in Table 2 reinforces the review's central finding: concern evidence concentrates heavily

Table 2: Frequency of CBAM Stages of Concern Represented Across Included Studies

CBAM Stage of Concern	No. of Studies	Studies
Awareness / Unconcerned	2	Cheah & Kim (2025); Kim (2023)
Informational	6	Garofalo & Farenga (2024); Ramnarain <i>et al.</i> (2024); Mnguni <i>et al.</i> (2024); Kokoç (2024); Cheah & Kim (2025); Chiu (2023)
Personal	7	Garofalo & Farenga (2024); Ramnarain <i>et al.</i> (2024); Mnguni <i>et al.</i> (2024); Chiu (2023); Tsakeni and Nwafor (2025); Kaplan-Rakowski <i>et al.</i> (2023); Chen <i>et al.</i> (2025)
Management	4	Ramnarain <i>et al.</i> (2024); Kokoç (2024); Tsakeni and Nwafor (2025); Chen <i>et al.</i> (2025)
Consequence	2	Kaplan-Rakowski <i>et al.</i> (2023); Alneyadi & Wardat (2023)
Collaboration	0	—
Refocusing	0	—

at the personal (7 studies) and informational (6 studies) stages, tapers at management (4 studies) and consequence (2 studies), and is entirely absent at the collaboration and refocusing stages. No included study reported teachers operating at these two most advanced CBAM stages, which is itself a substantive finding — it suggests that, as of this review’s search window, published empirical evidence on secondary science teachers has not yet captured a cohort that has moved past consolidating personal competence toward collaborative, student-impact-focused GenAI use.

Geographic Distribution of the Evidence Base

Table 3 maps the eleven included studies by country or region to help readers identify where evidence is concentrated and where gaps remain.

The evidence base is concentrated in the USA (three studies) and South Africa (two studies) with one study each from Thailand, Turkey, Hong Kong, South Korea, UAE and Nigeria (one of the two studies for South Africa is a comparative South Africa/Thailand study counted under Thailand) and one cross-national study combining

Table 3: Evidence Map: Geographic Distribution of Included Studies

Country / Region	No. of Studies	Studies
South Africa	2	Ramnarain <i>et al.</i> (2024); Mnguni <i>et al.</i> (2024)
Nigeria	1	Tsakeni and Nwafor (2025)
USA	3	Garofalo & Farenga (2024); Cheah & Kim (2025); Chen <i>et al.</i> (2025)
Thailand	1	Mnguni <i>et al.</i> (2024) [comparative with South Africa]
Turkey	1	Kokoç (2024)
Hong Kong	1	Chiu (2023)
South Korea	1	Kim (2023)
UAE	1	Alneyadi & Wardat (2023)
USA, UK & Canada (cross-national)	1	Kaplan-Rakowski <i>et al.</i> (2023)

USA, UK and Canada. Studies in Southeast Asia outside Thailand (the Philippines), South Asia, and Latin America and continental Europe (particularly) are notably missing, as do the contexts of science teachers in these areas, in terms of institutional AI policy environments and access to technology. The patterns are reported below with this concentration in mind, which restricts the generalizability of these patterns. This concentration is taken into account when reporting the patterns below and is discussed further in the Limitations section.

Science Teachers’ Stages of Concern Regarding GenAI Adoption

The early to mid-range of the CBAM conceptualization of science teachers’ stages of concern is prevalent across the eleven studies synthesized in this review, and that is

the stage that is represented by the majority of teachers found in the findings. Most science teachers are not yet thinking about how GenAI will impact my students, but what is GenAI, how will it impact me, and can I manage it in my classroom? This was exactly what Garofalo and Farenga (2024) observed as secondary science teachers showed caution and optimism while simultaneously being concerned with the implications of GenAI for assessment and content accuracy, which aligns with the informational and personal CBAM stages. Likewise, Chen *et al.* (2025) identified that secondary science teachers showed the lowest readiness among all subgroups to use the AI chatbot for instructional purposes, indicating that concerns at the personal and management stages were hindering the transition to the consequence and collaboration stages.

Of particular interest, the review also shows that concern profiles are not uniform and vary significantly across teacher preparation programs and across countries. The use of GenAI in South Africa and Thailand was found to have positive behavioral intentions among pre-service science teachers, while at the same time expressing concerns about the literacy issues (Mnguni *et al.*, 2024; Tsakeni & Nwafor, 2025), indicating that motivational orientation can coexist with the early stage of concerns, which is not fully captured in the original CBAM model. This was a discovery that resonates with recent scholarship demonstrating that the pathways of concern and intention are psychologically different and that there is no direct link between high awareness concern and resistance. Combined, these two subsections suggest that the next steps of science teachers' CBAM placement and their plans to integrate GenAI into their curriculum are distinct and interconnected issues that should be addressed in professional development design.

The factors which affect the stages of concern for science teachers are investigated. The factors that affect science teachers' stages of concern are explored.

A synthesis of the factors that impact the position of science teachers on the CBAM concern continuum revealed four interrelated categories of factors: AI literacy, institutional policy environment, professional development access, and personal and pedagogical beliefs. Across all the studies, the issue of AI literacy was the most common. This study revealed that pre-service science teachers had significantly low level of AI literacy, especially in the ethical and applied aspect, and this directly increased the level of concern for science pre-service teacher in the personal and managerial stage. Tsakeni and Nwafor (2025) concluded that pre-service science teachers had significantly low level of AI literacy particularly in the ethical and applied aspects, which directly amplified their personal and managerial stage concerns. Similarly, Kokoç (2024) highlighted that insufficient training is a key obstacle in secondary schools as teachers who were not trained in the use of GenAI

tools expressed more concerns related to informativeness and dependency. This literacy-concern stage connection has significant practical implications: Literacy concerns are not a stable demographic variable, but rather a variable that can be targeted for professional development.

The institutional policy environment was the second most influential factor. The lack of a school-level GenAI policy was pointed out as the most important first-order challenge by Cheah and Kim (2025), who found that teachers reported that a lack of institutional support added to their own concerns of professional risk and accountability. Ambiguous institutional policy is especially threatening to science teachers, who view themselves as having a strong connection to demands for accuracy and scientific integrity. In the Hong Kong secondary context, Chiu (2023) echoed this, suggesting that teachers and school leaders noted that concerns related to institutional guidance gaps were challenging them to respond to teachers' concerns about the authenticity of assessment, even when teachers were willing.

A more subtle, but significant, influencing factor was personal and pedagogical beliefs. The results of Ramnarain *et al.* (2024) revealed that attitude and perceived usefulness were the most significant predictors of intention to use GenAI among science teachers; surprisingly, concern did not have a significant independent effect, indicating that having positive attitude structures can counterbalance expressing concerns at the positioning stage. A cross-national sample by Kaplan-Rakowski *et al.* (2023) also showed that the readiness to integrate GenAI was most closely linked with instruction benefits than concern levels. Together, these three factor domains rarely work in isolation: a teacher with very positive beliefs, but a low level of literacy is likely to remain at the early concern stage, or a teacher with a low level of perceived usefulness but high beliefs is likely to be similarly stuck at the early concern stage - meaning that single-lever interventions are unlikely to be enough. The layered relationship has been integrated into one conceptual model in Figure 1.



Figure 1: Proposed conceptual framework linking institutional policy, AI literacy, and personal beliefs to CBAM stages of concern and GenAI adoption, with professional development acting as a cross-cutting moderator. Framework synthesized by the review team from the relationships reported across the eleven included studies; it has not itself been empirically tested and is offered as a guide for future confirmatory research.

Relationship to Established Technology Adoption Models

The pattern of findings synthesized above resonates with, and extends, several established technology-adoption frameworks outside CBAM. The Technology Acceptance Model (TAM; Davis, 1989) similarly emphasizes perceived usefulness as a primary driver of adoption intention, which is consistent with Ramnarain *et al.*'s (2024) and Kaplan-Rakowski *et al.*'s (2023) findings that perceived usefulness and instructional benefit outweighed concern level in predicting adoption. The Unified Theory of Acceptance and Use of Technology (UTAUT; Venkatesh *et al.*, 2003) adds performance expectancy, effort expectancy, social influence, and facilitating conditions as joint predictors of use — a structure that maps onto this review's four-factor synthesis, with facilitating conditions corresponding closely to the institutional policy environment identified as a key barrier by Cheah and Kim (2025) and Chiu (2023). Rogers' (2003) Diffusion of Innovations theory further situates individual teachers' concern trajectories within a broader adopter-category distribution (innovators, early adopters, early majority, late majority, laggards), suggesting that the early-stage clustering observed in this review may partly reflect where the field as a whole currently sits in the overall diffusion curve for GenAI in K-12 science education, rather than a fixed trait of science teachers specifically. Reading CBAM alongside TAM, UTAUT, and Diffusion of Innovations strengthens this review's theoretical contribution by showing that its four synthesized factors are not idiosyncratic to CBAM but converge with independently developed adoption theories.

Strategies Addressing Science Teachers' Concerns and Facilitating GenAI Adoption

The reviewed studies shared three general lines of strategies that have proven to be effective in addressing science teachers' concerns and supporting GenAI adoption: structured professional development, discipline specific AI literacy programs, and institutional policy development.

The most common approach recommended was targeted professional development. In each country context, teachers reported that a recurring training provision that is grounded and relevant to the context is most needed to move beyond the level of containing concerns (Cheah & Kim, 2025; Kokoç, 2024; Chen *et al.*, 2025). The reviewed studies emphasize that the training of general AI is not enough for science teachers, as their values and concerns related to accuracy, evidence and scientific integrity are specific to their fields. Additionally, Garofalo and Farenga (2024) identified specific requests for science teachers, such as professional development focused on assessment redesign and specifically related to GenAI, which is not often a central issue in interdisciplinary training programs. One promising upstream strategy that emerged with the science teacher preparation curricula was embedding the integration of AI literacy development. This is in line

with the findings of both Tsakeni and Nwafor (2025) and Mnguni *et al.* (2024) that found pre-service science teachers with structured AI integration training were more likely to have positive intention of implementing AI and less likely to experience personal-stage concerns suggesting building the GenAI competence before teachers enter service is more effective than remedial professional development after concerns have set in. This is consistent with the general literature on teacher education which calls for a proactive and not a reactive approach in the integration of technology.

Institutionally, clear and subject-specific policies in relation to GenAI were identified as a stepping stone for teachers to progress beyond the informational and personal concern levels. In the absence of such policy, Chiu (2023) found that teachers who had positive views on GenAI still were stuck in personal worries about accountability and professional risk. Institutional leadership, as such, then serves as a kind of change facilitator, a leader whose policy decisions will facilitate or hinder the movement of individual teachers along the concern continuum. More generally, all three strategies share a common logic, as illustrated in Figure 1: policy interventions, literacy interventions, and interventions aimed at the construction of beliefs all weaken a different upstream driver of concern – and when all three are present together, but not individually, they seem to be most likely to get teachers to the consequence and collaboration stages.

One key cross-cutting finding of significance is that across the eleven studies reviewed, there was little to no explicit use of assessment tools focused on CBAM when considering the adoption of GenAI in science education. The validated Stages of Concern Questionnaire (SoCQ) and any CBAM-specific instruments were not used in any studies in this review in relation to science education and GenAI. This is a crucial methodological deficiency: There is no standardized, theory-driven measurement of concern stages, which impedes the precision of diagnosis needed for the design of stage-appropriate interventions. Expanding the use of the SoCQ in secondary science teacher samples would significantly enhance theory and design of interventions in this developing field.

CONCLUSION

This systematic review synthesized evidence from eleven peer-reviewed studies (2022–2026) across nine national contexts to examine secondary science teachers' stages of concern regarding Generative Artificial Intelligence (GenAI) in science education. Findings indicate that most teachers remain at the awareness, informational, and personal stages, with few reaching technological or organizational concerns. Four factors shaped these profiles: AI literacy, institutional GenAI policy, targeted professional development (PD), and teachers' pedagogical beliefs. AI literacy and clear institutional policies emerged as particularly important systemic supports. Notably, concern levels did not consistently predict adoption

intentions, suggesting a complex relationship requiring contextual investigation.

The review extends the Concerns-Based Adoption Model (CBAM) to GenAI in secondary science education and proposes a framework linking teacher beliefs, AI literacy, and policy to concern stages. Practical priorities include embedding AI literacy and ethics in pre-service education, providing continuous discipline-specific PD, establishing clear institutional guidance, and redesigning assessment to address GenAI-related integrity concerns.

However, the evidence remains limited by the field's recency, narrow geographic representation, inferential CBAM mapping, English-only inclusion, and methodological constraints, including reliance on Google Scholar, absence of formal quality appraisal, and single-reviewer screening and extraction. Future research should employ longitudinal, SoCQ-based, preregistered, multi-context studies with rigorous quality and bias assessment.

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