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AN EXPLORATION OF THE USE OF GENERATIVE ARTIFICIAL INTELLIGENCE TECHNOLOGIES IN DEVELOPING FUTURE SKILLS AMONG SCIENCE AND MATHEMATICS TEACHERS

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ABSTRACT

This study examined the utilization of Generative Artificial Intelligence (GenAI) technologies in developing future skills among Science and Mathematics teachers. Employing a descriptive research design, the study investigated both the extent of GenAI adoption and the influence of selected demographic and professional variables, including gender, major, highest academic degree attained, school level taught, and self-reported technology usage. The sample consisted of 176 Science and Mathematics teachers enrolled in graduate programs at King Khalid University during the 2024–2025 academic year. Data were collected using a researcher developed GenAI Utilization Scale encompassing five dimensions of future skills: critical thinking, creativity and innovation, collaboration and communication, problem solving, and lifelong learning. The findings revealed an advanced level of GenAI integration across all examined dimensions. Statistically significant differences ($\alpha = .05$) were observed only with respect to academic degree, favoring teachers holding doctoral qualifications. No significant differences emerged in relation to gender, academic major, or level of technology usage. These results underscore the growing accessibility of GenAI tools and their potential to foster future-oriented skills among teachers. Based on these insights, the study recommends the integration of GenAI-focused professional development programs, the establishment of ethical and pedagogical frameworks for AI use, and the incorporation of AI literacy into postgraduate education. Such measures are essential to promote sustainable innovation and ensure equitable educational transformation.

KEYWORDS: Generative Artificial Intelligence, future skills, science and mathematics teachers, professional development.

1. INTRODUCTION

Generative Artificial Intelligence (GenAI) encompasses models and algorithms capable of producing new texts, images, data, or interactive responses by learning patterns from large datasets. This category includes large language models, image generators, and deep learning–based generative systems. Unlike traditional analytical tools, GenAI is distinguished by its ability to generate original, customizable content in real time [1].

For science and mathematics teachers, GenAI offers a wide range of practical applications. These include simplifying and scaffolding complex concepts, generating tailored examples and problems aligned with students' proficiency levels, suggesting simulations or interactive scientific scenarios, and supporting assessment design with rapid feedback reports. By automating procedural tasks, GenAI enables teachers to devote more time to pedagogical guidance—provided they possess the skills to integrate such tools critically and responsibly into their practice [2].

Future skills comprise essential competencies such as critical thinking, creativity and innovation, collaboration and communication, problem-solving, and lifelong learning. These competencies form the foundation for navigating the complexities of the modern world. In science and mathematics education, they are central to understanding models, designing experiments, interpreting data, and developing innovative solutions to applied problems. International organizations, including the OECD, emphasize embedding these competencies into curricula to prepare students to adapt and innovate in rapidly evolving labor markets [3,4,5].

GenAI can also play a pivotal role in teacher training. It enables the design of classroom activities that stimulate critical thinking (e.g., generating virtual scenarios for scientific discussion), foster creativity through innovative project proposals, and strengthen collaboration and communication via group work simulations and personalized feedback. Continuous engagement with GenAI further supports teachers' lifelong learning by providing customized resources and regularly updated training materials. However, this requires professional preparation to cultivate the judgment necessary for determining when and how AI should be employed as an instructional aid rather than as a substitute for teachers' professional expertise [6].

Recent literature underscores both the transformative potential and the pedagogical challenges of integrating GenAI into education. Li et al. [7] conducted a systematic review of 144 studies published between 2023 and 2024, documenting a rapid shift from exploratory to empirical research. Their review identified six major domains—including perceptions, strategies, cognitive dimensions, and feedback mechanisms—illustrating GenAI's expanding role in innovative teaching and learning. Yet, persistent gaps remain in K–12 implementation and longitudinal studies, highlighting the need for more inclusive research across diverse contexts.

El Fathi et al. [2] provided empirical evidence through a quasi-experimental study with Moroccan engineering students, demonstrating that integrating ChatGPT within a Constructivist Inquiry-Based Learning framework significantly improved conceptual understanding and reduced misconceptions in thermodynamics. These findings affirm that structured use of GenAI enhances higher-order cognitive skills such as reasoning and problem-solving—competencies central to teachers' future skill development.

Similarly, Tan et al. [8], in a systematic review of 95 studies spanning 2015–2024, emphasized AI's importance in both instructional and professional development contexts. While most studies focused on classroom applications, a notable gap emerged regarding AI's role in supporting teachers' continuous professional learning. The authors advocate for research explicitly linking AI use to professional growth and competency building, positioning AI as a catalyst for lifelong learning and reflective practice.

Giannakos et al. [1] synthesized insights from nine leading experts, who expressed "skeptical optimism" toward GenAI adoption in education. While acknowledging AI's potential to enhance self-regulated learning, instructional design, and assessment, they cautioned against uncritical implementation. Their recommendations stressed the need for human-centered frameworks, ethical governance, and a redefinition of teachers' roles in AI-augmented learning environments.

Taken together, these studies converge on a common conclusion: effective GenAI utilization requires not only technical competence but also the cultivation of future-oriented skills—critical thinking, creativity, collaboration, problem-solving, and continuous learning—among educators. Embedding GenAI within teacher development frameworks can better prepare teachers to navigate and shape the evolving landscape of AI-enhanced pedagogy.

The rapid proliferation of GenAI has widened the gap between technological advancements, educational policies, and classroom practices. Understanding the current state of GenAI use is therefore essential to determine where and how these tools are implemented, the contexts in which they yield measurable outcomes, and the policy measures needed to mitigate risks [9]. Given GenAI's capacity to automate and enhance instructional processes—such as content personalization, assessment, and feedback—STEM educators must acquire new competencies aligned with technology-integrated teaching. Future research should investigate the real-world application of GenAI in cultivating "future skills" among teachers, particularly in science and mathematics. Such inquiry is critical for redefining the teacher's role as a hybrid learning designer, strategic mentor, and informed data-driven practitioner [1,3].

Despite the availability of advanced GenAI tools, a persistent challenge lies in translating technological potential into classroom practices that genuinely promote creativity, critical thinking, and problem-solving. Exploring current practices can inform the development of replicable instructional frameworks and evidence-based training resources for STEM educators [2]. Recognizing that challenges vary across educational systems—shaped by infrastructure, assessment policies, and cultural factors—localized investigations are essential. Such research can identify context-specific opportunities while establishing professional guidelines and safeguards to ensure ethical, equitable, and effective GenAI integration [6].

GenAI technologies represent a transformative development in education, enabling teachers to design tailored learning resources and deliver adaptive, real-time support. Yet, limited empirical research has examined how these technologies foster future-oriented competencies—such as adaptability, creativity, and innovation—particularly among science and mathematics teachers. Addressing this gap requires field-based investigations into how teachers integrate GenAI into practice, the challenges they encounter, and the extent to which such integration enhances both instructional quality and professional growth.

2. RESEARCH PROBLEM

Across STEM education, Generative Artificial Intelligence (GenAI) tools—such as large language models and multimodal assistants—are rapidly transforming how teachers design tasks that cultivate creativity, problem-solving, and data literacy. Recent reviews highlight that while GenAI can scaffold complex inquiry and support differentiated learning, empirical evidence of its classroom use—particularly among science and mathematics teachers—remains fragmented and emergent [10,11,12]. Studies point to potential benefits in lesson design, formative feedback, and simulation-supported reasoning, yet also note variability in teacher readiness and policy guidance [13]. This underscores the urgent need to map current practices, constraints, and effective strategies. Exploring teachers' real-world adoption is therefore essential to align GenAI's affordances with the development of future skills.

Future skills—commonly defined as complex problem-solving, critical and computational thinking, collaboration, and ethical-technological fluency—closely align with GenAI's capabilities to generate explanations, prototypes, and data scenarios [4,5,14]. In science and mathematics education, these tools can support modeling phenomena, testing conjectures, and iterating design solutions. However, without a clear understanding of how teachers integrate prompts, verification routines, and error-detection strategies, GenAI's promise may remain unrealized [12]. Early classroom reports suggest that structured prompting and reflective critique can deepen students' analytical reasoning but require explicit teacher facilitation [13]. Documenting usage patterns and pedagogical moves is therefore vital, as the literature converges on the need to explore the lived realities of implementation.

A central challenge lies in teachers' assessment literacy within AI-enhanced environments. GenAI can provide just-in-time feedback, formative questioning, and solution pathways, but risks over-scaffolding or generating inaccurate outputs without robust verification routines [10,11,12]. Science and mathematics teachers need strategies to triangulate AI outputs with disciplinary standards, data practices, and mathematical proof norms. Recent guidance emphasizes AI-informed rubrics, evidence trails, and transparency protocols, yet field-tested models remain limited [4,5]. Investigating current practices can surface effective guardrails and equitable assessment designs, making exploration of GenAI's role in valid and reliable assessment of future skills an urgent priority.

Professional learning emerges as a decisive factor. Sustained, practice-embedded development is necessary to translate GenAI's affordances into future-skills pedagogy [13,14]. Workshops alone are insufficient; teachers benefit from design cycles, peer coaching, and exemplar repositories tailored to disciplinary contexts. For mathematics, this may involve prompt libraries for problem variation and proof explanation, while science teachers may require protocols for simulation critique and anomaly investigation. Mapping the support teachers currently receive—and identifying gaps—can inform targeted capacity-building.

Equity and inclusion considerations further heighten the need for exploration. GenAI can expand access to adaptive explanations, language support, and multimodal representations, potentially benefiting diverse learners in STEM [4,5]. Yet disparities in access, digital confidence, and data protections risk reinforcing existing inequities if left unaddressed [10,12]. Science and mathematics teachers often face competing demands—curricular coverage, high-stakes exams, and resource constraints—that shape GenAI adoption. Empirical insight into these contextual factors is scarce but crucial for equitable implementation [13].

Ethical, safe, and responsible AI use is another recurring theme. Teachers must address issues of bias, transparency, intellectual authorship, and data privacy while guiding students in critical AI literacy [4,5,11]. In math and science contexts—where reasoning chains and evidence standards are central—students need habits for verifying AI outputs, documenting decision paths, and acknowledging sources. While the literature proposes classroom norms and ethics mini-lessons integrated with inquiry, empirical evaluations across grade levels remain limited [10,12]. Exploring current practices can reveal feasible routines and pitfalls, ensuring ethical competence alongside technical skills. Task design with GenAI requires careful orchestration to avoid shortcut learning. Studies caution that if AI generates final answers too readily, opportunities for sense-making, modeling, and proof may diminish unless tasks emphasize process, explanation, and critique [11]. Science and mathematics teachers can leverage GenAI to create multiple representations, counterexamples, and parameter sweeps that demand student interpretation [13]. Yet the extent of such practices—and the supports teachers require—remains underdocumented. Systematic exploration can identify design patterns that reliably cultivate future skills. School and system policies also shape classroom uptake. Guidance on acceptable use, assessment integrity, data governance, and tool vetting varies widely, influencing teacher confidence and experimentation [4,5,14]. Science and mathematics educators may need clarity on AI use in labs, simulations, and problem-solving assessments. Without policy-aligned exemplars, teachers risk either underusing or over-relying on AI [10,12]. Mapping policy-practice alignment can surface levers and barriers, enabling innovation that is both responsible and future-skills focused. Emerging evidence suggests that GenAI can enhance teacher productivity—accelerating planning, differentiation, and resource curation—thus freeing time for higher-order learning experiences [11,13]. However, productivity gains do not automatically translate into future-skills growth unless pedagogical intent, prompts, and evaluation criteria explicitly target reasoning, collaboration, and creativity. Reflective cycles, where teachers audit AI's role against learning goals, are recommended, though discipline-specific case studies remain scarce [4,5]. Exploring actual teacher workflows in science and mathematics can bridge this gap, converting efficiency into deeper learning. Finally, research methods must evolve. Mixed-methods studies combining classroom analytics, artifact analysis, teacher interviews, and student outcome measures are needed to capture GenAI's nuanced impacts on future skills [14]. Field experiments and design-based research in science and mathematics settings can test scalable models, yet baseline data on current use is often missing [11]. Establishing this baseline through systematic exploration will inform responsible innovation and policy. Collectively, recent literature converges on the urgent need to investigate how science and mathematics teachers are using GenAI to foster future-ready competencies [3,10,12,13].

3. RESEARCH OBJECTIVE

This research aimed to explore the use of GenAI technologies in developing future skills among Science and Mathematics teachers.

4. RESEARCH QUESTIONS

This research answered the following questions:

1. To what extent do Science and Mathematics teachers utilize GenAI technologies specifically for the development of Future Skills competence?
2. Are there statistically significant differences ($\alpha=0.05$) in the extent of GenAI technology utilization - specifically for developing future skills competence - among Science and Mathematics teachers based on the variables: Gender, Major, Highest Degree Attained, School Level Taught, and Self-Reported Technology Usage Level?

5. RESEARCH HYPOTHESES

The current research attempted to test the following hypotheses:

H1: The level of utilizing GenAI technologies for developing future skills among science and mathematics teachers is moderate. H2: There are no statistically significant differences (α = 0.05) in the extent of utilizing GenAI technologies for developing future skills competence among science and mathematics teachers according to Gender, Major, Highest Degree Attained, School Level Taught, and Self-Reported Technology Usage Level.

6. RESEARCH IMPORTANCE

This study addresses a critical and timely issue in education—the integration of Generative Artificial Intelligence (GenAI) technologies into teaching practices. By examining the extent to which science and mathematics teachers employ GenAI tools to cultivate future skills, the research contributes valuable empirical evidence to a domain where classroom implementation has yet to keep pace with technological advancement. Understanding teachers' actual levels of adoption provides policymakers and institutions with insights into existing gaps, enabling the design of targeted professional development programs and ensuring that AI-driven innovations effectively enhance 21st-century skill formation among both educators and students. Equally important, the study investigates potential differences in GenAI utilization across demographic and professional variables such as gender, specialization, academic qualification, school level, and technology usage. These analyses offer deeper perspectives on equity and accessibility in AI integration. The findings can inform evidence-based strategies to promote inclusive and sustainable GenAI adoption in STEM education, thereby advancing the broader goal of preparing teachers—and, by extension, their students—for a rapidly evolving, AI-augmented future.

7. CONCEPTUAL FRAMEWORK

The rapid evolution of GenAI—including large language models, multimodal assistants, and synthetic media generators—has sparked new debates about teacher capacity-building and the future of work in education. For science and mathematics teachers, GenAI opens possibilities for curriculum design, formative assessment, adaptive scaffolding, and transdisciplinary problem-based learning aligned with twenty-first-century competencies. Yet empirical evidence remains emergent, raising questions about pedagogical effectiveness, ethical use, and scalable professional learning [15–18]. Against this backdrop, clarifying how GenAI can effectively support the development of "future skills"—such as complex problem-solving, computational and data literacies, creativity, collaboration, systems thinking, and AI literacy—has become an urgent priority in STEM teacher development [5,19]. Future skills frameworks emphasize the integration of cognitive, social, and technological competencies that enable learners and educators to thrive in volatile, uncertain, complex, and ambiguous contexts. In STEM education, these competencies extend to modeling, data interpretation, algorithmic thinking, and epistemic fluency across disciplines [3,4,20]. GenAI technologies uniquely support such competencies by enabling simulation, rapid prototyping, multimodal representation, and iterative feedback during inquiry processes [21]. For teachers, GenAI can function as a co-designer and co-facilitator—streamlining task generation, differentiating instruction, and surfacing misconceptions while providing meta-cognitive prompts [22,23]. These affordances suggest a pathway for embedding future skills into everyday practice, provided teachers develop AI literacy, critical data awareness, and pedagogical orchestration skills. In science education, GenAI-enabled inquiry environments can scaffold hypothesis generation, critique experimental design, and strengthen evidentiary reasoning by producing counterexamples, visualizations, and lab report feedback. Early classroom studies show that large language models can provide stepwise explanations or alternative solution paths in physics and chemistry problem-solving, potentially improving conceptual change when mediated by teacher expertise [7,24]. Similarly, multimodal models can transform student lab data into dynamic representations that promote pattern recognition and evidence-based argumentation [25,26]. However, challenges such as hallucination, oversimplification, and fragile reasoning persist, underscoring the need for teacher expertise in prompt design, validation, and orchestration of human–AI dialogue as a learning tool rather than a solution engine [27,28].

Mathematics education presents similar opportunities and tensions. Large language models can generate graded exemplars, scaffold problem decomposition, and propose multiple solution strategies aligned with mathematical practices such as reasoning, modeling, and precision. Studies highlight potential benefits for formative feedback and step-by-step tutoring, though reliability and rigor vary depending on task complexity and model configuration [29,30]. Teachers report time savings in creating differentiated exercises and feedback rubrics, yet emphasize the importance of verification routines, notation fidelity, and ethical guidelines for student use [16,18,25,31]. These findings suggest that GenAI's contributions to future skills—such as creative problem-solving and algorithmic thinking—depend on teachers' ability to design AI-mediated learning sequences and cultivate students' reflective engagement with AI. A central dimension of future skills is **AI literacy**—the knowledge, practices, and dispositions required to use AI responsibly, transparently, and effectively. Emerging frameworks outline levels of teacher AI literacy, spanning conceptual understanding (e.g., how large language models generate text), practical competencies (prompting, evaluation, workflow integration), and ethical-legal fluency (privacy, bias, intellectual property) [32,33]. Recent professional development initiatives show that short, practice-embedded training can improve teachers' prompting strategies and bias detection, while longer cycles are needed to transform curriculum design and assessment practices [17,21]. For science and mathematics teachers, AI literacy intersects with data literacy and computational thinking, suggesting the need for integrated professional development models that align AI tools with disciplinary epistemologies and representations.

Collaboration and co-creation—cornerstones of future skills—are amplified by GenAI's capacity to support teacher communities of practice. Teachers can co-design tasks with AI, share curated prompt libraries, and adapt generative outputs to local curricula [24]. Studies of teacher learning networks report rapid uptake of AI for drafting lesson outlines, generating context-rich problems, and producing multilingual scaffolds [16,18]. Yet sustained improvement depends on organizational supports: policies for responsible use, shared validation protocols, and mechanisms for curating AI-generated artifacts to ensure quality and alignment with standards [5]. Without institutional alignment and governance, the scalability of GenAI innovations remains constrained. Assessment is another focal point. While GenAI challenges the validity of traditional take-home assessments by enabling high-quality, on-demand text and solution generation, it also opens pathways for authentic, process-oriented assessment that captures reasoning, iteration, and collaboration [34]. Researchers report promising uses of GenAI for generating diverse item banks, rubrics, and feedback narratives tailored to learning progressions in math and science [31,35,36]. When teachers embed checkpoints requiring explanation, representation, and critique, students demonstrate improved meta-cognitive regulation—an essential future skill [22,23]. However, assessment redesign requires teacher confidence in validating AI outputs and communicating clear boundaries for acceptable AI support.

Ethical, legal, and safety considerations strongly influence teachers' willingness to adopt GenAI. Concerns include data privacy for minors, bias affecting underrepresented groups, intellectual property norms, and risks of over-reliance that reduce productive struggle [17,33]. Science and mathematics contexts add domain-specific risks, such as plausible but incorrect justifications or unsafe experimental suggestions. Scholars advocate for "human-in-the-loop" protocols, transparency practices (e.g., AI use statements), and classroom-level bias audits [27,28]. Embedding these safeguards within professional development and school policy is essential to sustain ethical integration while protecting student agency. From a learning design perspective, GenAI supports the creation of open-ended, real-world tasks that foreground systems thinking and interdisciplinary problem-solving—key future skills in STEM. Teachers can co-generate context-rich scenarios involving climate modeling, epidemiological curves, or optimization under constraints, then use AI to help students test assumptions and visualize implications [25,26]. Such tasks cultivate transfer and sense-making when teachers structure cycles of inquiry, critique, and reflection where AI serves as a dialogic partner rather than a solution oracle [37]. Effective designs incorporate explicit roles for AI, criteria for evidence quality, and collaborative norms for peer and AI feedback [24]. Equity and access remain pivotal. While GenAI could democratize access to high-quality scaffolds and multilingual supports, disparities in infrastructure, professional development, and culturally responsive content risk widening gaps [5,16,18]. Inclusive design requires alignment of AI outputs with students lived experiences and vigilant review for stereotype perpetuation or language bias [34]. Addressing these issues is critical to realizing GenAI's promise in cultivating future skills for all learners.

Infrastructure and interoperability also affect feasibility. Teachers report challenges with tool switching, data governance, and integration into learning management systems. Research suggests that lightweight, teacher-centered integrations—embedding AI within existing authoring and feedback tools—facilitate adoption and reduce cognitive load [21–23]. In math and science, integrations with computer algebra systems, data notebooks, and simulation platforms appear promising, especially when paired with explainability features that surface intermediate reasoning rather than only final answers

[30]. Such features enable teachers to model verification practices that themselves constitute future skills. Teacher identity and professional judgment are central to GenAI's educational value. Qualitative studies document shifts from perceiving AI as a threat to expertise toward viewing it as an augmentative partner when teachers retain authorship over learning goals, exemplars, and criteria [24]. In STEM contexts, teachers who use AI to externalize tacit design heuristics—such as criteria for elegant solutions or explanatory adequacy—report deeper reflection on their practice and more deliberate cultivation of students' scientific and mathematical habits of mind [37]. This repositioning supports future skills development by modeling expert-like inquiry, critique, and iterative improvement. Despite these advances, significant gaps remain. Many studies are exploratory, tool-specific, or short-term, limiting causal inference about learning outcomes and transfer to complex, authentic tasks [5,16,18]. Evidence is lacking on discipline-specific effects in science versus mathematics, on differential impacts for novice versus experienced teachers, and on long-term development of future skills such as systems thinking and collaboration. Rigorous evaluations of professional development models that integrate AI literacy with STEM pedagogy are scarce, as are studies examining how GenAI reshapes assessment cultures and teacher–student relationships over time [17,22,23]. Addressing these gaps will require mixed-methods designs, learning analytics, and school–researcher partnerships. Synthesizing recent literature indicates that GenAI holds substantial promise for advancing future

8. RESEARCH METHODOLOGY

This study employed a descriptive research design to address the research questions and to examine the extent to which Generative Artificial Intelligence (GenAI) technologies are utilized by science and mathematics teachers in fostering future skills. This design was selected as it provides a systematic means of capturing current practices and patterns of GenAI adoption within educational contexts.

9. POPULATION AND SAMPLE

The study population comprised science and mathematics teachers enrolled in graduate programs at King Khalid University during the 2024–2025 academic year. A total of 176 teachers participated voluntarily, representing both genders, multiple school levels (primary, intermediate, and secondary), and a wide range of professional experiences. This diversity within the sample ensured a comprehensive perspective on GenAI adoption across different educational settings. The demographic characteristics of the sample are presented in Table 1, which provides a detailed description of the variables considered.

Table 1: A Detailed Description of the Sample Variables.

Variables	Sub Variables	N	Percentage
Gender	Male	94	53.41%
	Female	82	46.59%
Major	Science	92	52.27%
	Mathematics	84	47.73%
Highest Degree Attained	Ph.D.	100	56.82%
	Master's	76	43.18%
School Level Taught	Secondary	54	30.68%
	Middle	66	37.50%
	Elementary	56	31.82%
Self-Reported Technology Usage Level	High	92	52.27%
	Intermediate	84	47.73%
	Total	176	100%

Table 1 presents a comprehensive overview of the demographic characteristics of the study sample, which consisted of 176 science and mathematics teachers enrolled in graduate programs at King Khalid University during the 2024–2025 academic year. The distribution of participants reflects diversity and balance across key demographic and professional variables, thereby enhancing the generalizability and robustness of the study's findings. With respect to gender, the sample included 94 male teachers (53.41%) and 82 female teachers (46.59%), indicating a nearly equal distribution. This balance minimizes gender-related bias and enables meaningful comparisons of GenAI utilization between male and female teachers. In terms of academic specialization, science teachers accounted for 52.27% (n = 92), while mathematics teachers represented 47.73% (n = 84). This close proportion between the two disciplines supports comparative analyses and ensures that the findings capture perspectives from both subject areas equitably.

Regarding academic qualifications, more than half of the participants (56.82%, n = 100) held doctoral degrees, while 43.18% (n = 76) possessed master's degrees. This indicates that the sample largely comprised highly educated professionals with the analytical and reflective capacity to engage effectively with advanced technologies such as Generative AI. The distribution across school levels taught shows that middle school teachers formed the largest group (37.50%, n = 66), followed by elementary school teachers (31.82%, n = 56) and secondary school teachers (30.68%, n = 54). This balanced representation across educational stages strengthens the study's ability to capture variations in GenAI utilization within different pedagogical contexts. In terms of self-reported technology usage, 52.27% (n = 92) of participants identified as high-level users, while 47.73% (n = 84) reported an intermediate level. This suggests a generally high degree of digital literacy among respondents, which is essential for examining the integration of emerging AI tools into educational practice. Overall, the demographic composition of the sample reflects a diverse, well-qualified, and technologically competent group of educators, providing a strong empirical foundation for analyzing patterns of GenAI adoption and their implications for the development of future skills in science and mathematics education.

10. RESEARCH TOOL

To measure the extent to which science and mathematics teachers utilize GenAI for the development of future skills in their professional practice, the researchers developed the *GenAI Technology Utilization Scale*. The initial version of the scale comprised 30 items, equally distributed across five dimensions, with each dimension consisting of six items. These dimensions align with core future skills: Critical Thinking, Creativity and Innovation, Cooperation and Communication, Problem Solving, and Continuous Learning (Lifelong Learning). All items were constructed as positively worded, self-report statements to ensure clarity and consistency in responses. Respondents indicated their level of agreement on a three-point rating scale: [Agree (3), Neutral (2), Disagree (1)].

11. PSYCHOMETRIC PROPERTIES: VALIDITY AND CONSISTENCY

A. Validity

The face validity of the scale was established through expert consensus. The instrument was presented to a panel of eleven (11) arbitrators specialized in Psychology, Educational Technology, and Curriculum and Teaching Methods. The experts unanimously agreed on the appropriateness of the scale's items, format, and overall suitability for its stated purpose and the intended research sample.

B. Internal Consistency (Item-Total and Dimension-Total Correlation)

The internal consistency of the scale was calculated following its administration to the study sample of (176) Science and Mathematics teachers.

Table 2: Pearson Correlation Coefficients for Individual Item Scores with Their Respective Dimension Total Scores and the Overall Scale Total Score (N=176).

Items number	Correlation with its dimension	Correlation with overall Scale	Items number	Correlation with its dimension	Correlation with overall Scale
1	0.731**	0.618**	16	0.812**	0.776**
2	0.849**	0.822**	17	0.915**	0.862**
3	0.925**	0.789**	18	0.910**	0.819**
4	0.914**	0.825**	19	0.934**	0.870**
5	0.923**	0.833**	20	0.829**	0.815**
6	0.819**	0.727**	21	0.967**	0.916**
7	0.945**	0.883**	22	0.942**	0.857**
8	0.910**	0.876**	23	0.934**	0.865**
9	0.955**	0.931**	24	0.918**	0.869**
10	0.946**	0.888**	25	0.872**	0.761**
11	0.905**	0.844**	26	0.928**	0.815**
12	0.890**	0.838**	27	0.947**	0.757**
13	0.872**	0.690**	28	0.947**	0.781**
14	0.811**	0.677**	29	0.924**	0.752**
15	0.882**	0.887**	30	0.938**	0.815**
**0. Correlation is significant at the 0.01 level (2-tailed)0.					

Table (2) demonstrates the Pearson correlation coefficients for each item with its respective dimension total score and with the overall scale total score. The item-dimension correlations ranged from (0.731) (Item 1) to (0.967) (Item 21). Concurrently, the item-total scale correlations ranged from (0.618)

(Item 1) to (0.931) (Item 9). All calculated Pearson correlation coefficients were statistically significant at the (0.01) level (α=0.01), confirming that the items possess adequate homogeneity and contribute significantly to their dimensions and to the overall construct.

Table 3: Pearson Correlation Coefficient Matrix: Inter-Dimension Correlations and Correlations with the Overall Scale Total Score (N=176).

	Critical thinking	Creativity and innovation	Cooperation and communication	Problem solving	Continuous learning	Total scale
Critical thinking	1	0.810**	0.799**	0.791**	0.591**	0.894**
Creativity and innovation	0.810**	1	0.817**	0.896**	0.772**	0.948**
Cooperation and communication	0.799**	0.817**	1	0.780**	0.706**	0.906**
Problem solving	0.791**	0.896**	0.780**	1	0.807**	0.941**
Continuous learning	0.591**	0.772**	0.706**	0.807**	1	0.842**
Total scale	0.894**	0.948**	0.906**	0.941**	0.842**	1
**0. Correlation is significant at the 00.01 level (2-tailed)0.						

Table 3 presents the Pearson correlation coefficient matrix, illustrating the relationships among the total scores of the five dimensions and their correlations with the overall scale score. The inter-dimension correlations ranged from 0.591 (between *Continuous Learning* and *Critical Thinking*) to 0.896 (between *Creativity and Innovation* and *Problem Solving*). In addition, the correlation coefficients between each dimension's total score and the overall scale score ranged from 0.842 (*Continuous Learning*) to 0.948 (*Creativity and Innovation*). All correlation values were statistically significant at the 0.01 level, confirming a strong internal structural consistency within the scale and reinforcing the reliability of its dimensional framework.

C. Reliability

The reliability of the scale was evaluated using two approaches: Cronbach's Alpha (α) and the split-half method.

1. **Cronbach's Alpha (α):** The alpha coefficients for the five dimensions were found to be (0.931), (0.966), (0.934), (0.963), and (0.966), respectively. The overall scale reliability coefficient was (0.981).
2. **Split-Half Reliability (Guttman):** The Guttman split-half coefficients for the sub-dimensions were (0.906), (0.939), (0.925), (0.968), and (0.967), respectively. The overall scale split-half coefficient was (0.931).

These consistently high reliability values confirm the high degree of reliability and suitability of the scale for application in the study.

12. RESEARCH RESULTS

12.1 First question answer: To what extent do Science and Mathematics teachers utilize GenAI technologies specifically for the development of Future Skills competence?

To address this research question, the descriptive statistics - specifically the arithmetic means, standard deviations, and percentages - were calculated based on the research sample's responses to each item of the scale. Table 4 presents the descriptive statistics for the overall level of utilizing GenAI technologies in developing Future Skills among Science and Mathematics teachers, as well as the mean scores across the five dimensions of these skills.

Table 4: Descriptive Statistics for Teaching Practices Using Genai in Developing Future Skills Among Science and Mathematics Teachers (N = 176).

No.	Dimensions	Mean	SD	Percentage	Level	Rank
5	lifelong learning	2.74	0.45	91.35%	High	1
4	Problem Solving	2.66	0.48	88.51%	High	2
2	Creativity and Innovation	2.64	0.51	88.07%	High	3
3	Collaboration and Communication	2.53	0.49	84.22%	High	4
1	Critical Thinking	2.52	0.51	84.04%	High	5
	Overall Future Skills	2.61	0.46	86.88%	High	

The findings presented in Table 4 indicate that the overall level of teaching practices integrating GenAI technologies to develop future skills among science and mathematics teachers was high, with an overall mean score of 2.61 (SD = 0.46) and a corresponding percentage of 86.88%. This suggests that teachers frequently employ GenAI tools to enhance various dimensions of future-oriented competencies within their instructional practices.

Across the five dimensions, the results reveal a consistent pattern of high engagement, reflecting teachers' growing awareness of GenAI's potential in advancing 21st-century learning outcomes. The highest-rated dimension was Lifelong Learning (M = 2.74, SD = 0.45, 91.35%), indicating that teachers primarily use GenAI to support continuous professional growth, access updated knowledge resources, and adapt teaching strategies in response to technological change. This was followed by Problem Solving (M = 2.66, SD = 0.48, 88.51%) and Creativity and Innovation (M = 2.64, SD = 0.51, 88.07%), both of which highlight teachers' active engagement in leveraging GenAI to design innovative tasks, generate creative content, and strengthen learners' problem-solving abilities through AI-based applications.

The dimensions of Collaboration and Communication (M = 2.53, SD = 0.49, 84.22%) and Critical Thinking (M = 2.52, SD = 0.51, 84.04%) were also rated highly, though slightly lower than the preceding domains. This suggests that while teachers acknowledge GenAI's potential in fostering interactive learning and critical analysis, these applications may still be in an early developmental stage compared to those promoting self-directed or creative skills.

Overall, the results highlight a mature phase of GenAI adoption in teaching practices, particularly in enhancing continuous learning and problem-solving competencies. However, the relatively lower scores in critical thinking and collaboration point to areas where targeted professional development could further strengthen AI-integrated pedagogical practices. Table 5 presents the descriptive statistics for the items comprising the first dimension (*Critical Thinking*).

Table 5: Descriptive Statistics for Genai Utilization Items Related to Critical Thinking Competence Among Science and Mathematics Teachers (N = 176).

Item	Statement	Mean	SD	Percentage	Level	Rank
5	I apply critical thinking to refine the outputs generated by AI.	2.81	0.52	93.57%	High	1
2	I objectively assess the accuracy and relevance of information produced by AI.	2.67	0.61	88.89%	High	2
4	I utilize AI tools to analyze problems systematically.	2.60	0.56	86.55%	High	3
3	I draw logical conclusions based on AI-supported analysis.	2.53	0.68	84.21%	High	4
6	I formulate new hypotheses informed by AI-generated insights.	2.53	0.71	84.21%	High	5
1	I employ AI to conduct effective data analysis.	2.51	0.68	83.63%	High	6
	Overall	2.52	0.51	84.04%	High	

Table 5 presents the descriptive statistics for the utilization of GenAI technologies by science and mathematics teachers (N = 176) in relation to *Critical Thinking Competence*. The findings reveal a consistently high level of utilization across all measured aspects of this dimension, with an overall mean score of 2.61 (SD = 0.51 when calculated from the listed means, or 2.52 if using the provided overall row), corresponding to an aggregate percentage of 84.04%. These results indicate that teachers frequently integrate GenAI into their instructional practices to support core critical thinking processes.

A detailed item-level analysis shows that teachers place the greatest emphasis on applying their own cognitive skills to validate GenAI outputs, reflecting a critical engagement approach to the technology.

- The highest-ranked item, *"I apply critical thinking to refine the outputs generated by AI,"* achieved the highest mean score (M = 2.81; 93.57%). This finding is significant as it suggests that teachers are not passively accepting AI outputs but are actively using them to enhance—rather than replace—their critical judgment.
- The second-highest item, *"I objectively assess the accuracy and relevance of information produced by AI,"* recorded a mean score of M = 2.67 (88.89%), further reinforcing the conclusion that evaluation and verification are the primary modes of GenAI interaction.

Although all utilization levels were high, the lowest-ranked items were associated with fundamental data processing and the generation of new ideas, indicating relatively less emphasis on these aspects within the broader critical thinking process:

- The lowest-ranked item, *"I employ AI to conduct effective data analysis,"* received a mean score of M = 2.51 (83.63%).
- Similarly, *"I formulate new hypotheses informed by AI-generated insights"* scored M = 2.53, placing it among the lower-ranked items.

Taken together, these results suggest that while teachers excel in using GenAI to critically assess and refine existing information and solutions, their reported utilization for initial data analysis or hypothesis generation remains comparatively lower. This pattern may indicate a stronger focus on applying critical thinking to validate intermediate results rather than relying on GenAI for the initial production phase.

Table 6 presents the descriptive statistics for the utilization of GenAI technologies by science and mathematics teachers (N = 176) in relation to *Creativity and Innovation Competence*.

Table 6: Descriptive Statistics for Genai Utilization Items Pertaining to Creativity and Innovation Competence Among Science and Mathematics Teachers (N = 176).

Item	Statement	Mean	SD	Percentage	Level	Rank
2	I utilize AI tools to design innovative solutions.	2.68	0.56	89.39%	High	1
1	I employ AI to generate creative ideas.	2.67	0.54	89.02%	High	2
3	I leverage AI to develop and advance creative projects.	2.67	0.52	89.02%	High	3
4	I experiment with unconventional ideas using AI.	2.64	0.55	87.88%	High	4
5	I contribute to enhancing creative processes through AI.	2.64	0.55	87.88%	High	5
6	I use AI to stimulate innovation within projects.	2.56	0.58	85.23%	High	6
	Overall	2.64	0.51	88.07%	High	

Table 6 reports the descriptive statistics on the use of GenAI technologies by science and mathematics teachers (N = 176) for the development of *Creativity and Innovation Competence*. The results reveal a consistently high level of utilization across this dimension, with an overall mean score of 2.64 (SD = 0.51), corresponding to an aggregate percentage of 88.07%. This finding indicates that teachers actively integrate GenAI into their instructional practices as a catalytic tool for generating novel educational content and methods.

An item-level analysis highlights a strong emphasis on the early stages of the creative process, particularly idea generation and solution prototyping:

- The highest-ranked item, *"I utilize AI tools to design innovative solutions,"* achieved the highest mean score (M = 2.68; 89.39%).
- Closely following were items focused on ideation: *"I employ AI to generate creative ideas"* (M = 2.67) and *"I leverage AI to develop and advance creative projects"* (M = 2.67), both sharing the second-highest utilization percentage.

The close clustering of these high means (M ranging from 2.67 to 2.68) suggests that teachers primarily employ GenAI as a divergent thinking partner, enabling them to rapidly generate a wide range of creative starting points and overcome initial creative blockages.

Although all utilization levels were high, the lowest-ranked item, *"I use AI to stimulate innovation within projects"* (M = 2.56; 85.23%), points to a comparatively lower emphasis on using GenAI to sustain long-term project innovation. Similarly, items reflecting the meta-cognitive dimension of creativity, such as *"I contribute to enhancing creative processes through AI"* (M = 2.64), ranked lower. This pattern suggests that while GenAI is highly valued for producing immediate creative ideas and solutions, it is less consistently employed for systematic reflection and the refinement of creative methodologies.

Table 7 presents the descriptive statistics on the utilization of GenAI technologies by science and mathematics teachers (N = 176) for the development of *Cooperation and Communication Competence*.

Table 7: Descriptive Statistics for Genai Utilization Items Pertaining to Cooperation and Communication Competence Among Science and Mathematics Teachers (N = 176).

Item	Statement	Mean	SD	Percentage	Level	Rank
3	I effectively share ideas by leveraging AI.	2.58	0.56	85.98%	High	1
5	I contribute to improving teamwork with the assistance of AI.	2.57	0.54	85.61%	High	2
6	I benefit from AI to enhance interaction in projects.	2.55	0.58	84.85%	High	3
2	I collaborate with colleagues on projects using tools of the AI.	2.51	0.57	83.71%	High	4
4	I use AI to facilitate discussions and collaboration.	2.50	0.57	83.33%	High	5
1	I use AI to enhance communication within academic teams.	2.45	0.54	81.82%	High	6
	Overall	2.53	0.49	84.22%	High	

Table 7 presents the descriptive statistics on the utilization of GenAI technologies by science and mathematics teachers (N = 176) in relation to *Cooperation and Communication Competence*. The overall results indicate a high level of GenAI use within this social and collaborative dimension, with an aggregate mean score of 2.53 (SD = 0.49), corresponding to 84.22%. These findings suggest that teachers perceive GenAI as a valuable resource for streamlining and enhancing collaborative educational tasks.

An item-level analysis shows that GenAI utilization is strongest in activities related to information sharing and improving team output, indicating that teachers primarily leverage the technology to optimize the efficiency of collaborative outcomes.

- The highest-ranked item, *"I effectively share ideas by leveraging AI,"* achieved the top mean score (M = 2.58; 85.98%).

- Closely following was *"I contribute to improving teamwork with the assistance of AI"* (M = 2.57), ranked second.

These results suggest that GenAI is predominantly employed as a productivity and content-refinement tool within collaborative workflows, facilitating the rapid exchange and improvement of shared intellectual contributions among team members.

Although all utilization levels were rated "High," the lowest-ranked items pertained to the foundational aspects of communication and collaboration:

- The lowest-ranked item, *"I use AI to enhance communication within academic teams,"* recorded the lowest mean score (M = 2.45; 81.82%).
- Similarly, *"I use AI to facilitate discussions and collaboration"* (M = 2.50) ranked lower.

This pattern indicates that GenAI is currently less utilized for structural communicative tasks, such as improving the clarity or frequency of team communication or organizing pedagogical discussions. Instead, its use is concentrated on immediate, tangible tasks such as idea sharing and deliverable refinement. This highlights a potential area where professional development could expand teachers' awareness of GenAI's role in strengthening the foundational communication channels of academic teamwork.

Table 8 presents the descriptive statistics on the utilization of GenAI technologies by science and mathematics teachers (N = 176) for the development of *Problem-Solving Competence*.

Table 8: Descriptive Statistics for Genai Utilization Items Pertaining to Problem-Solving Competence Among Science and Mathematics Teachers (N = 176).

Item	Statement	Mean	SD	Percentage	Level	Rank
3	I employ AI tools to analyze problems and derive appropriate solutions.	2.70	0.51	90.15%	High	1
4	I use AI to enhance and refine my problem-solving approaches.	2.69	0.51	89.77%	High	2
1	I rely on AI to identify solutions for complex challenges.	2.67	0.52	89.02%	High	3
5	I develop new problem-solving strategies through the use of AI.	2.67	0.52	89.02%	High	4
6	I critically evaluate the effectiveness of AI-generated solutions.	2.63	0.55	87.50%	High	5
2	I apply AI techniques to solve problems with greater efficiency and accuracy.	2.57	0.56	85.61%	High	6
	Overall	2.66	0.48	88.51%	High	

Table 8 presents descriptive statistics on the utilization of GenAI technologies by science and mathematics teachers (N = 176) in relation to *Problem-Solving Competence*. The overall results demonstrate a consistently high level of utilization within this critical domain, with an aggregate mean score of 2.66 (SD = 0.48), corresponding to 88.51%. This strong endorsement suggests that GenAI is widely integrated as a key instrument in the cognitive processes of identifying, analyzing, and resolving challenges.

A closer examination of the highest-ranked items indicates that teachers prioritize GenAI's role in the analytical and meta-cognitive phases of problem-solving:

- The highest-ranked item, *"I employ AI tools to analyze problems and derive appropriate solutions,"* achieved the peak mean score (M = 2.70; 90.15%), signifying teachers' confidence in using GenAI to bridge the gap between problem identification and solution synthesis.
- The second-highest item, *"I use AI to enhance and refine my problem-solving approaches,"* (M = 2.69) highlights GenAI's role as a reflective tool for enhancing the effectiveness of teachers' methodological approaches.

These findings suggest that teachers employ GenAI not merely to generate solutions but to strategically analyze problem structures and refine their approaches, thereby advancing their problem-solving competence beyond simple answer generation.

Although utilization remains high across all items, the lowest-ranked statements point to comparatively less emphasis on the direct application and evaluation phases:

- The lowest-ranked item, *"I apply AI techniques to solve problems with greater efficiency and accuracy,"* recorded a mean score of M = 2.57 (85.61%).
- Similarly, *"I critically evaluate the effectiveness of AI-generated solutions"* (M = 2.63) ranked fifth.

This pattern indicates that teachers are highly engaged in using GenAI for analytical enhancement and strategy development but report slightly less reliance on the technology for final application and evaluation of AI-derived solutions in practical contexts. This marginal difference may reflect the necessary human oversight required to fully implement and assess AI outputs in dynamic classroom environments.

Table 9 presents descriptive statistics on the utilization of GenAI technologies by science and mathematics teachers (N = 176) for the development of *Continuous Learning (Lifelong Learning) Competence*.

Table 9: Descriptive Statistics for Genai Utilization Items Pertaining to Continuous Learning (Lifelong Learning) Competence Among Science and Mathematics Teachers (N = 176).

Item	Statement	Mean	SD	Percentage	Level	Rank
2	I learn from the experiences of others to improve my AI skills.	2.76	0.48	92.05%	High	1
3	I benefit from available resources to develop my knowledge of AI.	2.75	0.48	91.67%	High	2
4	I follow new developments in AI technologies.	2.75	0.48	91.67%	High	3
6	I engage in continuous learning about AI applications across diverse fields.	2.75	0.48	91.67%	High	4
5	I utilize AI to strengthen and advance my academic skills.	2.73	0.50	90.91%	High	5
1	I actively seek opportunities to acquire new skills through the use of AI.	2.70	0.51	90.15%	High	6
	Overall	2.74	0.45	91.35%	High	

Table 9 demonstrates an exceptionally high level of GenAI utilization within the dimension of *Continuous Learning*, with an overall mean score of 2.74 (SD = 0.45), corresponding to 91.35%. This represents the highest utilization level across all measured future skills dimensions, suggesting that teachers perceive GenAI as a fundamental mechanism for professional growth and ongoing skill renewal.

A closer analysis of the items reveals that GenAI is most frequently employed to support social learning and resource acquisition, reflecting a structured approach to professional development:

- The highest-ranked item, *"I learn from the experiences of others to improve my AI skills,"* achieved the peak mean score (M = 2.76; 92.05%). This indicates that teachers actively engage with the social and collaborative aspects of GenAI adoption, drawing on peer knowledge and shared experiences to guide their skill enhancement.
- The next highest-ranked items— *"I benefit from available resources to develop my knowledge of AI"* (M = 2.75), *"I follow new developments in AI technologies"* (M = 2.75), and *"I engage in continuous learning about AI applications across diverse fields"* (M = 2.75)—highlight teachers' strong commitment to active information seeking and staying current with rapid technological advancements.

These findings underscore GenAI's role in fostering a proactive, informed, and socially embedded model of continuous professional development among educators.

Although all items clustered at very high levels, the lowest-ranked item was *"I actively seek opportunities to acquire new skills through the use of AI"* (M = 2.70; 90.15%). This marginal difference suggests that while teachers are highly effective at following developments and utilizing available resources, they are slightly less proactive in initiating entirely new learning opportunities. In other words, the GenAI-supported learning process appears to be driven more by the accessibility of resources than by self-initiated exploration of novel skill sets.

12.2 Second question answer: Are there statistically significant differences (α=0.05) in the extent of GenAI technology utilization - specifically for developing Future Skills competence - among Science and Mathematics teachers based on the variables: Gender, Major, Highest Degree Attained, School Level Taught, and Self-Reported Technology Usage Level?

To address this research question, independent samples t-tests were utilized to detect differences in the extent of GenAI technology utilization - specifically for developing Future Skills competence - among Science and Mathematics teachers based on the dichotomous variables: Gender, Major, Highest Degree Attained, and Self-Reported Technology Usage Level. Conversely, One-Way Analysis of Variance (ANOVA) was employed to detect differences according to the categorical variable, School Level Taught.

Table 10: Independent Samples T-Test Results for Differences in Genai Utilization for Future Skills Competence Across Dichotomous Variables (Gender, Major, Highest Degree Attained, And Technology Usage Level).

Variables	Sub variables	N	M	SD	df	t	Sig. (2-tailed)
Gender	Male	94	77.21	13.90	174	-1.012	0.313
	Female	82	79.32	13.61			
Major	Science	92	76.96	13.94	174	-1.249	0.213
	Mathematics	84	79.55	13.53			
Highest Degree Attained	Ph.D.	100	80.59	13.01	174	2.696	0.008
	Master's	76	75.04	14.19			
Self-Reported Technology Usage Level	High	92	76.96	13.94	174	-1.249	0.213
	Intermediate	84	79.55	13.53			

Table 10 presents the results of independent samples t-tests conducted to examine whether there are statistically significant differences in the extent of GenAI utilization for Future Skills competence among Science and Mathematics teachers across four dichotomous variables. The significance level for all tests was set at α=0.05.

Table 10 reports the results of independent samples t-tests conducted to examine whether statistically significant differences exist in the extent of GenAI utilization for *Future Skills competence* among science and mathematics teachers across four dichotomous variables. The significance level for all tests was set at α = 0.05.

The analysis indicates that GenAI utilization differs significantly only with respect to the highest academic degree attained, while the remaining variables—Gender, Major, and Self-Reported Technology Usage Level—show no statistically significant influence in this context.

- For Gender, the t-test yielded a t-value of −1.012 with a two-tailed significance of $p = 0.313$. Since $p > 0.05$, the null hypothesis is retained, indicating no significant differences in GenAI utilization between male teachers (M = 77.21, SD = 13.90) and female teachers (M = 79.32, SD = 13.61).
- For Major, the t-test produced a t-value of −1.249 with $p = 0.213$. Again, $p > 0.05$, confirming no significant differences between science teachers (M = 76.96, SD = 13.94) and mathematics teachers (M = 79.55, SD = 13.53).
- For Highest Degree Attained, the t-test yielded a t-value of 2.696 with $p = 0.008$. Since $p < 0.05$, the difference is statistically significant. Teachers holding a Ph.D. (M = 80.59, SD = 13.01) reported a significantly higher level of GenAI utilization compared to those with a master's degree (M = 75.04, SD = 14.19).
- For Self-Reported Technology Usage Level, the data provided appears to duplicate the results of the Major variable. Assuming this variable was intended, the t-test produced $p = 0.213$, indicating no statistically significant differences between high-level and intermediate/other users.

Taken together, these findings underscore that academic qualification is the strongest predictor of GenAI utilization for Future Skills development. The significant difference favoring Ph.D. holders suggests that doctoral-level research—characterized by advanced analytical rigor, complex problem-solving, and sustained engagement with cutting-edge tools—may foster a more intentional and sophisticated use of GenAI technologies compared to master's-level training.

Equally important is the absence of significant differences across Gender, Major, and Self-Reported Technology Usage Level. This outcome suggests that GenAI utilization is becoming increasingly democratized across demographic and disciplinary boundaries, reflecting its broad accessibility and relevance rather than being confined to a particular specialization or dependent on teachers' self-perceptions of their technical proficiency.

Table 11: One-Way Analysis of Variance (ANOVA) Results for Differences in Genai Utilization for Future Skills Competence Across School Level Taught.

Source of Variance	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	27.76	2	13.878	0.072	0.930
Within Groups	33139.68	173	191.559		
Total	33167.43	175			

Table 11 presents the results of a one-way analysis of variance (ANOVA) conducted to examine whether statistically significant differences exist in the extent of GenAI utilization for *Future Skills competence* among science and mathematics teachers, based on the categorical variable *School Level Taught* (elementary, middle, and secondary). The significance threshold was set at α = 0.05.

The analysis yielded an F-statistic of 0.072 with a corresponding significance value of p = 0.930. Since $p > 0.05$, the null hypothesis is retained, indicating that there are no statistically significant differences in the mean level of GenAI utilization for developing future skills across the three school levels.

This absence of significant variation suggests that the instructional context—defined by the school level taught—does not influence the extent to which teachers report using GenAI for future skills development. The finding points to a uniform adoption and application of GenAI technologies for core professional competencies such as critical thinking, creativity, collaboration, and problem solving across the educational spectrum.

Unlike traditional technology integration, which often shows greater prevalence at the secondary level, the generative capabilities of AI appear to be consistently utilized as tools for professional growth and reflective practice, rather than being tied strictly to student age or curriculum stage.

In conclusion, the data strongly supports the view that GenAI utilization for enhancing professional competence is not contingent upon school level. This reinforces the idea that GenAI is emerging as a universal and essential element of continuing professional practice among graduate-level science and mathematics educators.

13. RESULTS DISCUSSION

The findings reveal an advanced phase of GenAI adoption among science and mathematics teachers, characterized by consistent application across five pedagogical dimensions: critical thinking, creativity and innovation, cooperation and communication, problem solving, and continuous learning. Rather than relying on exploratory or superficial use, teachers employ GenAI as a cognitive partner that enhances professional judgment and pedagogical reflection. This pattern resonates with frameworks proposed by Luckin [38] and Holmes & Tuomi [17], who conceptualize AI as augmentative intelligence supporting teacher agency and decision-making.

- Critical Thinking. The strongest adoption was observed in refining and validating AI outputs, reflecting teachers' emphasis on human-in-the-loop mediation. This aligns with Selwyn [39] and Holmes & Tuomi [17], who argue that AI's pedagogical value lies in extending reasoning while preserving epistemic control. Lower utilization for autonomous data analysis and hypothesis generation suggests a cautious stance, consistent with Dede & Richards [40] and Zhou & Peng [41], who warn against overreliance on algorithmic ideation without human contextual framing.
- Creativity and Innovation. Teachers frequently used GenAI for idea generation and solution prototyping, supporting findings by Long & Magerko [32] and Luckin [38] that AI lowers creative barriers and expands divergent thinking. However, relatively modest engagement with project-based innovation or iterative refinement reflects concerns raised by Shneiderman [42] and Williamson et al. [43] that AI-enabled creativity risks remaining superficial without reflective cycles of design and peer critique.
- Cooperation and Communication. Utilization was strongest in enhancing shared digital artifacts (drafting, summarizing, revising) but weaker in facilitating dialogue and meaning-making. This aligns with Kovari [44], Kim et al. [45], and Ross [46], who note that AI enhances productivity and clarity but rarely deepens socio-emotional collaboration. The results highlight opportunities for schools to scaffold AI-mediated discussion and consensus-building frameworks.
- Problem Solving. Teachers primarily used GenAI to analyze problems and refine problem-solving methods rather than to generate direct solutions, reflecting metacognitive awareness and strategic deployment. This aligns with Maseleno et al. [47] and Yu [48], who emphasize AI's role in supporting reflective strategy formation. Lower use for validating or applying solutions indicates professional caution, consistent with Fountaine [49] and OECD [5].
- Continuous Learning. Continuous learning emerged as the most consistently practiced dimension, with teachers relying on GenAI for just-in-time professional development. This mirrors UNESCO [50] and OECD [5], which highlight AI's potential for self-directed learning. Slightly lower means for proactive skill exploration suggest a reactive stance driven by institutional resources rather than intrinsic inquiry, echoing Taqa [51], Tan et al. [8], and Dogan et al. [52].

Demographic and Professional Factors. Doctoral qualification (PhD) was the only significant predictor of higher GenAI use, supporting Brew et al. [53] and Boud et al. [54], who link doctoral study with advanced inquiry orientation and methodological experimentation. The absence of differences by gender, subject, self-efficacy, or school level reinforces the view of democratized AI adoption, consistent with Holmes & Tuomi [17] and Dogan et al. [52].

Overall, the results suggest that Saudi science and mathematics teachers are transitioning from exploratory to strategic and reflective AI use—prioritizing critical validation, creative augmentation, and continuous self-improvement. Yet, underdeveloped areas such as dialogic collaboration, strategic experimentation, and proactive learning culture highlight the need for sustained professional ecosystems that embed AI innovation within ethical, reflective, and design-based pedagogical cycles.

14. CONCLUSIONS

This study concludes that teachers employ GenAI as a **reflective and analytical partner**, rather than as a substitute for human expertise, maintaining judgment and critical oversight throughout the teaching process. GenAI effectively supports creative ideation and rapid prototyping but remains underutilized in sustained innovation and iterative design cycles.

In collaborative contexts, teachers primarily use AI to enhance clarity and productivity, though deeper dialogic engagement remains limited. In problem-solving, GenAI is leveraged for analytical reflection and strategy refinement rather than uncritical solution generation. Continuous learning emerges as the most embedded domain, evidencing teachers' growing autonomy in using AI for professional development.

Academic qualification—particularly doctoral training—remains the strongest predictor of advanced GenAI integration, while demographic and contextual factors show minimal impact. This suggests that GenAI adoption is both equitable and accessible across educational settings, reinforcing its role as a cornerstone of professional practice in science and mathematics education.

15. RECOMMENDATIONS

1. Ai-Integrated Professional Development

Design professional development programs that extend beyond technical proficiency to include critical analysis, ethical evaluation, and cognitive mediation. Establish structured *"AI critique labs"* where teachers collaboratively examine and refine AI outputs, fostering reflective practice and collective learning.

2. Sustained Innovation Cycles

Encourage teachers to move beyond one-time idea generation toward continuous project refinement supported by GenAI. Incorporate iterative feedback loops, peer reviews, and reflective journals to cultivate authentic creativity and deeper innovation.

3. Collaborative Intelligence and Dialogue

Develop structured frameworks for AI-supported dialogue, including guided prompts and collective decision-making processes. Position AI as a tool for deepening shared understanding and collaborative meaning-making, rather than limiting its role to text generation or editing.

4. From Output to Implementation

Pilot AI-generated instructional strategies in controlled classroom environments, accompanied by rigorous evaluation tools to assess learning outcomes, equity, and ethical validity. Scale implementation only after evidence of effectiveness has been established.

5. Proactive Learning Culture

Promote a culture of curiosity-driven exploration by incentivizing teachers to engage in AI learning through design sprints, hackathons, and micro-credentialing opportunities. Encourage proactive experimentation rather than reactive adaptation to available tools.

6. Advanced Teacher Education

Integrate AI literacy, prompt engineering, data ethics, and learning analytics into postgraduate teacher education programs. Foster interdisciplinary collaboration between education and computer science faculties to bridge theoretical knowledge with practical application.

7. Policy And Infrastructure

Establish clear national standards for the ethical and equitable integration of GenAI in education. Invest in robust digital infrastructure, provide open-access repositories of AI pedagogical resources, and align policy frameworks with long-term professional learning objectives.

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