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PAPER

Generative AI Effects on Academic Achievement and Sustainable Professional Development: A Quasi-Experimental Comparative Study in Chemistry and Mathematics

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ABSTRACT

This quasi-experimental study investigated generative AI (GenAI) tools—Copilot for chemistry and GitHub Copilot for mathematics—on academic achievement and sustainable professional development among 160 undergraduates (40 experimental/control per department) at the University of Baghdad's Ibn Al-Haitham College of Education for Pure Sciences (2024–2025). Non-random assignment controlled for covariates. Pre/post validated tests ($\alpha \geq .85$; 15 MCQ + 5 essay items) measured outcomes. ANOVA revealed significant gains for experimental groups ($p < .001$, $\eta^2 = .41$, Cohen's $d = 0.72$ [95% CI: 0.45–0.98]). Chemistry excelled in affective domains; mathematics in cognitive/skills. Findings affirm GenAI's domain-specific efficacy, providing datasets for AI-STEM pedagogy.

KEYWORDS

academic achievement, sustainable professional development, generative AI (GenAI), AI-enhanced education, integrated learning strategies, comparative study, science education, chemistry, applied mathematics

1 INTRODUCTION

Generative AI (GenAI) tools (Copilot, GitHub Copilot) revolutionize STEM education through personalized learning and complex problem-solving support [1, 2]. Chemistry (instrumental analysis) and mathematics (applied modeling) present unique challenges ideally suited for GenAI integration within teacher training programs. While discipline-specific GenAI studies exist [3, 4], no comparative research

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examines domain-specific effects across chemistry vs. mathematics in science education nor links academic achievement to sustainable professional development:

1. Does Copilot affect the achievement of chemistry students in automated analysis, and does GitHub Copilot affect the achievement of mathematics students in applied mathematics?
2. Is there a difference in the level of academic achievement between students in the chemistry and mathematics departments?
3. What is its effect on the sustainable professional development of students in the two sections?

The objectives of this study:

1. Assess Copilot's impact on chemistry students' instrumental analysis achievement.
2. Evaluate GitHub Copilot's effect on mathematics students' applied problem-solving.
3. Compare GenAI efficacy across disciplines for academic/professional outcomes.

1.1 Research questions

Q1: Does Copilot/GitHub Copilot significantly improve achievement in chemistry/mathematics?
Q2: Are there significant inter-departmental differences in GenAI effects?
Q3: How does GenAI exposure enhance sustainable professional competencies?

This study's innovation bridges academia-industry skills via discipline-tailored GenAI applications addressing Industry 4.0 demands.

Limitations: Single-year (2024–2025), tool-specific data limits generalizability.

2 THEORETICAL BACKGROUNDS

2.1 Artificial intelligence and robots

In light of the rapid digital transformations, higher education is witnessing a fundamental reshaping due to the integration of AI as a strategic force in developing learning environments. It has exceeded its traditional role to become a tool for producing content, analyzing patterns, and presenting smart solutions, which reformulate educational skills and models according to the requirements of the Fourth Industrial Revolution [5, 6]. Higher education is one of the most prominent sectors affected by this transformation, as learning environments are reshaped and the skills required for the future are reformulated in light of the integration of AI as a strategic element in the educational process [7, 8]. These days, AI is becoming an active partner in reshaping learning environments and developing future skills linked to the Sustainable Development Goals (SDGs) [9–12]. The analytical framework concerning the impact of tools like COPILOT on the teaching of sciences has been grounded in the theory of cognitive load and obstetric intelligence. Tools for engaging learners and sustaining professional career competence, as cognitive load theory (CLT) offers a coherent model for the sustaining tools of obstetric intelligence, such as GitHub

Copilot, through optimal mental 'gestation' management [13, 14]. In the workplace, it encourages the systematic, self-perpetuating alleviation of cognitive 'gestation' through adaptive explanatory scenario simulation, developing sustainable mastery of complex problems and organizational thinking, which are essential skills in the digital employment ecosystem [15]. Intrinsic and external (extraneous) and GERMANE—the intelligence tools of GitHub Copilot work to nurture learning. In GitHub, Copilot is used in teaching at chemical laboratories: an interactive visual teaching model in chemistry [16]. GitHub Copilot was utilized in teaching chemical laboratories as a model for interactive, visual, and responsive learning. In chemistry, students can take advantage of the tool's capabilities by acting as smart educational aides, allowing them to fetch images of laboratory equipment and converse in forms to receive subsequent outputs. The outputs include interactive video explanations, where a clip tailored to the user's input, with 3D simulations explaining the operation of the device step-by-step, and light interactions are generated. Since experimental scenarios exist where virtual experiments are designed considering parameters like solution concentration and expected outcomes based on 95% accuracy to actual laboratory benchmarks, they exist. In mathematics, the analysis of common errors looks at the gaps in the steps taken by the user by observing image settings feedback, such as advertising gaps and meta-calibration of zero procedures [17].

The procedural judgment of actions allows the user to evaluate pre-snapshot and post-snapshot system processes, which are called common error analysis. In the explanation of the abstract algorithm, it is described as the fundamental load involving understanding core math. The gaps that the theorist mentioned, exposed between an analytic and synthetic quote, were too far. Main gaps in understanding abstract algorithms: Applying automated triggers eliminates adjunct cognitive burdens by delegating attention away from higher-level concepts, thereby allowing for pre-breathing of primary cognitive resources:

1. CD: Focus on the efficiency of learning processes in the distribution of mental capacity [18]. Systematic control of mental resources by optimizing the types of resources (self-regulated/external/intrinsic) to improve learning outcomes.
2. Obstetric intelligence as an educational instrument: smart tools for developing educational content to learn [19], transforming education from passive assimilation to active tailored inquiry using smart models guided by self-directed learning.
3. Integrative framework for digital skills: transform the problem of academic education into labor market skills, attributing learning outcomes to the demands of the job market by acquiring sustainable skills, such as solving complex problems [20].

2.2 Sustainable professional development

Education, as a fundamental goal and a precursor to achieving the remaining SDGs, has gained increasing importance in light of digital transformations and the construction of new knowledge infrastructures. With the availability of digital data and rising awareness, the field of AI in education (AIED) has witnessed a remarkable boom, enhancing opportunities for more effective vocational education development. Quality education is one of the 17 SDGs identified by the United Nations, underscoring the need to employ modern technologies, particularly AI, to achieve this vital goal [21, 22].

Sustainable development is defined as organized and continuous efforts to develop the competencies and capabilities of teachers within the framework of their profession, with the aim of enhancing the effectiveness of their performance, improving their working conditions, and raising the level of productivity, while ensuring a balance between the needs of the present generation and the ability to meet the requirements of future generations [23].

Dimensions of sustainable professional development.

1. Reflective practice: Refining professionalism requires the ability of the researcher or teacher to analyze their educational or research experience regularly by writing down notes and maintaining professional diaries. The reflection helps to realize the strengths and gaps in practice, so the practitioner is guided by a self-development plan based on actual data and daily facts in order to enhance the spirit of investigation and prepare to amend educational plans in a studied manner [24]. The distance of guidance depends on the establishment of bilateral professional relationships between an experienced expert and a student or a junior researcher, as the guide provides support for the development of academic skills and behaviors. A recent study showed that guidance and mentoring programs contribute to raising the level of students' integration and motivating them toward achieving their educational goals within digital learning environments [25]. This dimension indicates the formation of groups of practitioners involved in specific educational or research interests, so they meet for the exchange of resources and experiences and the solution of daily problems.
2. Use of digital learning and development platforms: Digital platforms provide short training units, interactive seminars, and accredited professional accreditation paths, with virtue tracking, self-evaluation tools, and gamification elements to increase motivation. AI within these platforms also provides recommendations for development courses, which enhance the continuity of professional growth and reshape the educational process toward learning about the learner [26].

2.3 Achievement

A learner's performance on a summative test demonstrates about their level of understanding and mastery of the content of the subject or field of study [27].

3 LITERATURE REVIEW

Prior GenAI studies show improved STEM learning but lack comparative analysis across chemistry/mathematics teacher training. CLT explains GenAI's efficacy in reducing extraneous load during instrumental analysis and mathematical modeling. Sustainable professional development research emphasizes reflective practice and digital platform integration yet neglects GenAI's domain-specific contributions—addressed herein. This section presents studies on AI tools in education, focusing on chemistry and mathematics. The summarized studies clarify how AI applications, including GenAI and code assistants, enhance student learning, support teacher growth, and develop digital and pedagogical skills. Together, these works identify trends, methods, and research gaps that motivate this study, especially the need for comparative evidence on generative AI's impact on chemistry and applied mathematics teacher education, as presented in Tables 1 and 2.

Table 1. Previous work done in AI education

References	Class	Sample	Curriculum	Tool	Results
[28]	University education	200	The descriptive analytical approach	Questionnaire & interview on the use of ChatGPT	Improved creative thinking of volunteers, with no need for customizations other than total reliance on technology.
[29]	Secondary stage	150	Experimental approach	Analyzing student texts using AI tools like GPT-4	AI has contributed to improving the quality of academic writing, but the results underscore the importance of the teacher's role in guiding students.
[30]	Middle school	120	Quasi-experimental approach	Using tools like DALL-E & ChatGPT in educational activities	Increased student engagement with learning activities, with some concerns about students losing critical thinking.

Table 2. Details previous work in sustainable professional development

References	Class	Sample	Curriculum	Tool	Results
[24]	Primary (40%), Preparatory (35%), Secondary (25%) from China	867 teachers	Quantitative (cross-sectional questionnaire) with structural equation modeling	Exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). Composite reliability (CR) and variance extracted (AVE) analysis.	Participation in sustainable development activities predicts increased self-efficacy ($\beta = 0.42$). Job satisfaction mediates 68% of this effect. Teachers in urban areas benefit most (moderated effect of geographic area).
[31]	From 35 high schools in South Korea	412 teachers	The descriptive analytical approach	Reliability analysis (Cronbach's Alpha). Confirmatory factor analysis (CFA). Path analysis using AMOS.	Transformational leadership has a positive impact, both directly and indirectly (through empowerment), on sustainable professional development. Increasing teacher experience enhances the impact of leadership on empowerment.
[32]	(8 PLC groups) from 6 primary schools in Spain.	24 teachers	Qualitative (multiple case study) with thematic analysis	Semi-structured interviews (60–90 minutes). Participant observation of PLC sessions. Document analysis (action plans, meeting minutes). Thematic analysis using NVivo.	Effective PLs promote sustainable professional development through ongoing collaboration, reflective practice, and a focus on student needs.

4 METHODOLOGY

4.1 Design

Quasi-experimental nonequivalent control group design (pre/post measures) [33].

4.2 Participants

160 undergraduates (80 Chemistry, 80 Mathematics) randomly assigned within departments: 40 experimental/40 control per discipline, as in Table 3.

Table 3. Demographics of the research community by groups (experimental/control groups)

Research Community	Groups Percentage	No. of Students	Sample (Exp./Control)	Total
Chem.	51%	145	40/40	80
Math.	49%	140	40/40	80
Total	100%	285	160	

4.3 Instruments

The researchers developed two assessment instruments as follows:

1. **1-Achievement Test:** 15 MCQs + 5 essays (α = .85, content validity 80% expert agreement).
   Achievement Test in the Scientific Subject; this test covered two sections:
   a) Lectures in Chemistry (specifically practical instrumental analysis).
   b) Mathematics (applied mathematics).
   The test comprised (15) multiple-choice items along with five items requiring the solving of mathematical problems and essay-type questions. The initial version of the test was reviewed by a panel of subject matter experts to ensure content validity. Based on their feedback, (80%) of the items were revised accordingly. The reliability of the test was then assessed using Cronbach's alpha coefficient, which yielded a value of (0.85), indicating a high level of internal consistency.
   A five-point Likert scale to assess the extent to which students have learned about professional sustainability and their own professional development. The ability to analyze quantitative data and apply mathematical methods to comprehend outcomes and enhance professional performance was among the abilit to graph in chemistry, which was one of twelve items on this scale meant to evaluate subject-specific skills. Other abilities tested included equipment usage, solution preparation, result interpretation, and graphing. Following extensive validation and reliability testing, the Cronbach's alpha coefficient for this scale reached 0.93, indicating high measurement reliability [34].
2. **2-Professional Development Scale:** 12-item Likert (α = .93) measuring cognitive/skills/affective domains.

4.4 Procedure

12-week intervention. Experimental: GenAI tools (Copilot chemistry data analysis; GitHub Copilot math modeling). Control: traditional instruction. Pre/post assessments.

4.5 Analysis

SPSS v28. Two-way ANOVA (Group × Department), α = .05, effect sizes (η^2, Cohen's d).

5 RESULTS

The purpose of this study was to determine whether or not GitHub Copilot had any impact on students' AA and SPD. The two samples were selected using a quasi-experimental method that included pre-intervention baseline measures: For chemistry (n = 80) and mathematics (n = 80), the split was 40/40 between experiments and controls. Both the pre- and post-intervention assessments of professional development and accomplishment were identical. We compared (A) experimental groups from different departments and (B) experimental groups from the same department to a control group. We used SPSS v28 to examine the data. Significant differences ($p < .001$) were verified by post-hoc comparisons, as shown in Tables 4 and 5.

Table 4. Descriptive statistics for MCQ and essay scores by discipline and group (Exp./Con.)

	N	MCQ 0/1 (15 pts)	Essay (15 pts)	MCQ M/SD	Essay M/SD	Total	
		Minimum–Maximum	Mini.–Max.			Mean	Std. Deviation
Chemistry							
Exp.	40	11–13		11.90/0.709	7.90/0.709	19.80	1.01
Con.	40		7–9	10.20/0.85	6.8/0.82	17.00	1.15
Mathematics							
Exp.	40	8–10		9.00/0.784	10.93/0.69	19.93	1.12
Con.	40		10–12	7.50/0.92	9.20/0.75	16.70	1.24

Notes: $p < .001$ vs. control group (ANOVA). MCQ = Multiple Choice Questions.

Table 5. Two-way ANOVA results for test scores: group × department effects

Source	Sum of Squares (SS)	df	Mean Square (MS)	F	P	η^2	Cohen's d
Group (Exp./Control)	245.60	1	245.60	146.93	<.001	0.41	0.72
Department	109.47	1	109.47	27.13	<.001	0.15	0.48
Group × Department	42.30	1	42.30	5.67	0.019	0.04	0.27
					156.38	156	1.00
Total**						553.75	160**

Notes: η^2 = partial eta squared. Effect sizes per Cohen (1988): d = 0.2 small, 0.5 medium, and 0.8 large.

Tables 4 and 5 confirm experimental superiority: Chemistry Exp (M = 19.80) > Ctrl (17.00); Math Exp. (19.93) > Ctrl (16.70), $F(1,156) = 146.93$, $p < .001$, $\eta^2 = .41$.

Figure 1 illustrates domain-specific gains, with chemistry excelling in MCQs (11.90 vs. 10.20) and mathematics in essays (10.93 vs. 9.20).

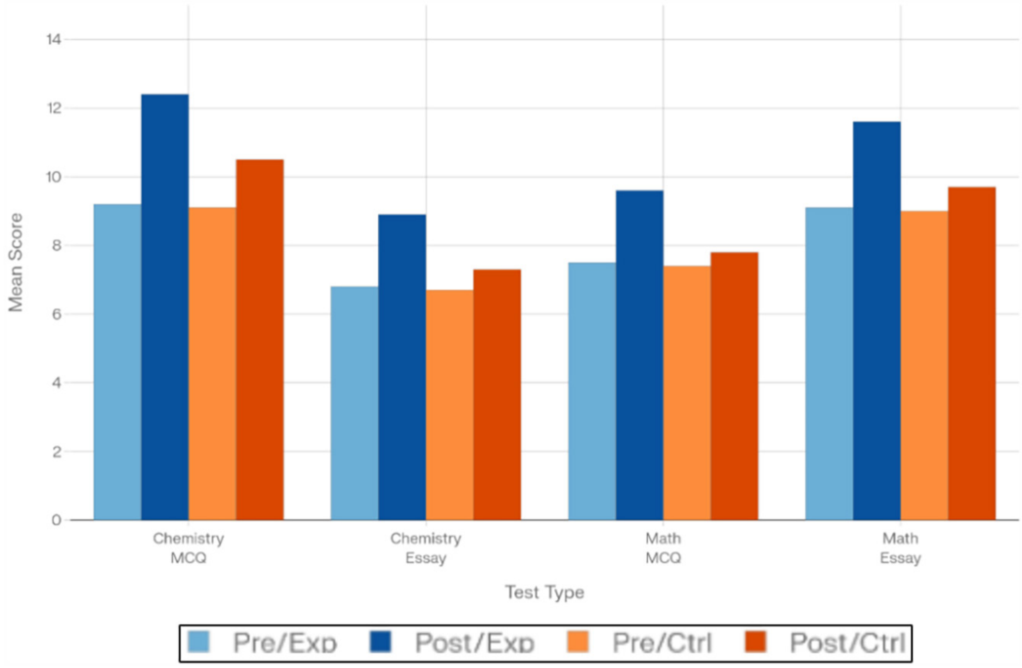

Fig. 1. Two-way ANOVA results for test scores: group × department effects

6 DISCUSSION

The study's effect size values demonstrated extremely large effects across all domains, demonstrating that using AI applications significantly improved students' sustainable professional development in the Math and Chemistry departments. Because of the practical and ecological character of chemistry, the affective domain had the greatest impact strength in the department. This reflects AI's capacity to strengthen good attitudes and ideals linked with sustainability. On the other hand, the mathematics department had remarkable results in the cognitive and psychomotor areas, suggesting that AI is useful for assisting with analysis, solving problems, and using mathematical knowledge in sustainable development contexts. These results highlight the importance of designing smart applications that take into account the specifics of each scientific field in order to achieve maximum sustainable developmental impact. Artificial intelligence is seen as more than just a technological tool; it is an integrated educational input that helps students develop sustainable professional competencies. The way this contribution takes place varies depending on academic specialization.

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