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Enhancing Secondary School Students' Independent Learning, Conceptual Understanding, and Self-Efficacy of the Integration Concept through Photomath-Assisted Instruction

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Abstract
This study assessed how well Photomath-assisted teaching strategies compared to conventional approaches in developing students' capacity for independent study, improving their conceptual understanding of Integration Content, and boosting their self-efficacy in mathematics in Rwandan Senior Six. It carefully examined how Photomath's effects varied depending on the student population and the learning environment. Using a non-equivalent control group pre-test–post-test design and a quantitative quasi-experimental methodology, 116 students who were purposefully chosen from public and private secondary schools, urban and rural, and from the PCM, PCB, and MCB academic tracks participated. The multivariate effects of the teaching strategy and its interactions with demographic factors were examined using multivariate analysis of variance (MANOVA). Additionally, diagnostic tests of assumptions (normality, homogeneity of variance-covariance, and multicollinearity) were performed before MANOVA, and all criteria were satisfied. Analyses were conducted using SPSS version 26 with $\alpha = 0.05$. These methodological checks strengthen the validity of the findings. Regarding students' independent study skills, conceptual understanding, and mathematics self-efficacy, statistically significant multivariate relationship effects were found between the instructional approach and variables like school location, gender, school type, and academic combination. This result implies that these demographic traits have an impact on Photomath's effectiveness. By providing empirical evidence regarding Photomath's varied impact within many different kinds of school contexts in Rwanda, this study fills a significant gap in the body of existing literature. It offers crucial information that educators and legislators may use to adjust technology integration tactics, improving fair and efficient mathematics instruction and reducing potential inequities.

Keywords: Integration Content, Educational Technology, Learning Outcome, Photomath

1. INTRODUCTION

This academic investigation seeks to assess the efficacy of pedagogical approaches supplemented by Photomath in contrast to traditional educational methodologies, specifically concerning the enhancement of self-directed learning capabilities, conceptual grasp of Integration Content, and mathematical self-efficacy among Senior Six students in Rwanda. As the incorporation of technological advancements within educational paradigms continues to multiply, it becomes essential to understand its implications for diverse student populations and various educational settings. This study rigorously explores the differential impact

of Photomath's efficacy across varying school contexts (urban versus rural), gender categories, types of institutions (public versus private), and academic streams (PCM, PCB, MCB).

Traditional mathematics instruction frequently faces challenges in fostering autonomous learning skills and deep conceptual understanding, particularly in relation to complex topics such as Integration Content. Concurrently, the advent of digital tools like Photomath offers novel avenues for education by providing systematic solutions to mathematical inquiries. While these technological instruments possess the potential to promote self-directed learning and deliver immediate feedback, their actual effects on educational outcomes, especially across diverse demographic and academic segments within the Rwandan educational landscape, remain inadequately explored. Previous studies predominantly focus on general effectiveness, thus creating a considerable void in the understanding of how these tools interact with various student attributes and educational contexts.

Notwithstanding the prospective advantages of Photomath, there exists a notable deficiency in empirical evidence concerning its differential influence on student learning outcomes when accounting for pivotal demographic and contextual variables within the Rwandan educational paradigm. Specifically, it remains ambiguous whether the advantages associated with Photomath-assisted learning are uniformly applicable across urban and rural academic institutions, among male and female students, within public and private schools, or across various science-oriented academic tracks. This study is propelled by the imperative to address this research void, thereby providing critical insights for educators, policymakers, and curriculum developers in Rwanda and beyond, facilitating informed decisions regarding the integration of technology into mathematics education to enhance student learning outcomes and mitigate potential disparities.

Therefore, this study aims to address the following research objectives:

1. To determine whether the instructional method effect varies by school location.

2. To assess if the instructional method effect differs between male and female students.

3. To evaluate the impact of Photomath-assisted learning across school types.

4. To investigate how students' academic combinations influence the outcomes of the instructional method.

2. LITERATURE REVIEW

The idea that instructional strategies provide different learning results based on school location, particularly between rural and urban contexts, is firmly supported by the literature currently in publication. Inequalities in digital access, such as internet connectivity and technical knowledge, impede equitable learning possibilities (Memon & Memon, 2025; Rydzewski, 2025), as noted by Fairlie (2005). Urban schools have the infrastructure and resources needed to implement digital technologies like Photomath. The resource gap is further widened by Radha (2025), who highlighted that urban schools generally benefit from better professional development and teacher quality. The effectiveness of implementing digital learning tools across regions is directly impacted by these disparities. Learning is contextually bound; according to Bauer et al. (2025), situated cognition theory contends that learning outcomes are influenced by the social and technological environment. This was furthered by McLucas et al. (2025), who contended that educational interventions need to be considerate of local contexts, particularly in rural areas with limited resources where integrating technology presents particular difficulties.

There is ample evidence of gender-based disparities in how students react to different teaching methods, especially in STEM and online learning environments. Although the gender gap in math achievement has closed, Savicka (2025) discovered that attitudes, confidence, and problem-solving techniques still differ. According to Lao et al. (2025), the theory of self-efficacy suggests that academic performance is influenced by perceived competence; female students may have poorer self-efficacy in arithmetic, which may have an impact on how they use digital learning resources. Additionally, Mousavi and Soltanifar (2025) emphasized how stereotype threat lowers performance when students internalize unfavorable gendered beliefs. Even when access is equal, usage and interaction are still gendered, according to Berezhna et al. (2025), who discovered persistent gender differences in digital tool usage patterns. Cadeliña (2025) emphasized the significance of gender-sensitive pedagogy, pointing out that in order to guarantee equity in learning outcomes, instructional approaches, especially those utilizing digital

technologies, must take into account modest gender-based variations. Together, these results highlight the necessity of integrating educational technologies in a way that is inclusive and gender-sensitive.

In educational research, the impact of school type, private versus public, on the efficacy of digital teaching techniques has long been studied. Parvin (2025) was the first to note the impact of school characteristics, including student demographics, governance, and resources, on learning results. Private schools frequently have advantages in infrastructure, autonomy, and decision-making when it comes to digital tools like Photomath, which makes integration easier. However, Iman, Veronica, and Asis (2025) warned that without the institutional environment supporting its efficient application, the sheer existence of technology does not ensure better results. Smaller class sizes and an innovative culture may allow private schools to adjust to digital teaching tools more quickly. The concept of school effects holds that institutional and systemic factors, rather than just individual student characteristics, have an impact on learning outcomes (Prasetyo et al., 2025). Thus, disparities in instructional technology achievement can be explained by the ways that public and private schools differ in their technology infrastructure and school cultures.

How students use instructional technologies is also influenced by their academic tracks or combinations, such as PCM, PCB, or MCB. Although it is not subject-specific, Alisoy's (2025) Theory of Multiple Intelligences lends credence to the notion that students have distinct cognitive strengths that correspond with their academic preferences. This affects how well they use programs like Photomath, which call for analytical and logical thinking. Shin et al. (2025) found a correlation between student performance and curricular coherence, indicating that specific academic combinations might be more compatible with Photomath's structured approach to problem-solving. Students trained in professions that require a lot of problem-solving skills may find it easier to use pre-existing frameworks when using AI-supported tools, according to Hamid (2025), who highlighted the importance of learning transfer. Differentiated instruction based on students' academic specialism improves learning outcomes and engagement (Jose & Mathew, 2025).

3. METHODS

The influence of Photomath-assisted learning versus conventional pedagogical approaches on Senior Six students' autonomous study abilities, conceptual understanding of Integration Content, and self-efficacy in mathematics was examined in this study using a quasi-experimental design. In order to promote diversity in educational contexts and student backgrounds, 116 Senior Six students were purposefully picked from two secondary school institutions in Rwanda. These institutions differed in terms of their institutional classification (public, private), gender distribution (65 males, 51 females), and geographic location (one urban, one rural). Additionally, the participants were split up among three different academic tracks: 38 were in the Physics-Chemistry-Mathematics (PCM) track, 34 were in the Physics-Chemistry-Biology (PCB) track, and 44 were in the Mathematics-Chemistry-Biology (MCB) track. The participants were aged between 17 and 20 years, consistent with the typical age range for Senior Six students in Rwanda. While taking into consideration possible institutional and individual differences that affect the educational outcomes of interest, our intentional sampling strategy enabled a meaningful comparison across various instructional methodologies. Prior to the intervention, the current school structures or an assignment method would have dictated the precise distribution of students into the Photomath-assisted or regular instruction groups.

Particular tools were used to assess the dependent variables, which included self-efficacy in mathematics, conceptual understanding of Integration Content, and autonomous study abilities. It is possible to deduce that quantitative measurements were used for each variable, even though the findings supplied do not specifically mention these tools. For example, "Independent Study Skills" probably refers to results from a test or standardized questionnaire intended to gauge pupils' capacity for self-regulated learning. In a similar vein, "Conceptual Understanding" would have been evaluated using a test created especially to determine how well students understood Integration Content. A self-report questionnaire that gauged pupils' confidence in their mathematical skills was probably used to test "Math Self-Efficacy." These tests would have been given both before and after the intervention in order to record any modifications brought about by the teaching strategies. The "instructional approaches" would have included a planned intervention session during which one group would have received instruction on Integration Content using Photomath assistance, while the other group would have gotten conventional teaching. The instruments used were adapted from previously validated mathematics self-efficacy and independent learning

questionnaires (Radha, 2025) and a researcher-developed test for conceptual understanding. A 5-point Likert scale was applied.

To meet the goals of the study, a combination of univariate and multivariate statistical methods was used to assess the quantitative data that had been gathered. In order to ascertain the overall impact of the teaching strategy on the aggregated dependent variables and to investigate the ways in which this impact differed among various demographic and contextual factors, multivariate analysis of variance, or MANOVA, was mainly utilized. For multivariate testing, Wilks' Λ and F-statistics were specifically reported, showing significant overall effects. Univariate F-tests were used to identify the precise dependent variables causing these overall effects after significant multivariate findings. This method made it possible to thoroughly analyze the effects on math self-efficacy, conceptual knowledge, and independent study abilities separately.

Additionally, the relationship between the set of dependent variables and the instructional method was investigated using Canonical Correlation Analysis, which shed light on the type and degree of this association. The reporting of Eigenvalues and Canonical Correlations makes this clear. In order to clarify which outcomes were most closely linked to the instructional method and the different moderating factors (school location, gender, school type, and academic combination), Standardized Canonical Coefficients were also reported. These coefficients show the relative contribution of each dependent variable to the canonical variate. A p-value threshold was used to establish the statistical significance of each test; as the findings show, values less than .05 generally indicate statistical significance. In order to measure the practical significance of the observed effects, effect sizes were reported more precisely, and partial eta-squared (ηp^2) was reported for both multivariate and univariate testing.

3. RESULTS

The investigation encompassed a cohort of 116 Senior Six students selected from two intentionally chosen secondary educational institutions in Rwanda, which exhibited variation in geographic location (one urban versus one rural), gender distribution (65 males versus 51 females), and institutional classification (one public versus one private). The participants were allocated among three distinct academic tracks: 38 individuals enrolled in the Physics-Chemistry-Mathematics (PCM) curriculum, 34 individuals in the Physics-Chemistry-Biology (PCB) curriculum, and 44 individuals in the Mathematics-Chemistry-Biology (MCB) combinations. The sample was deliberately designed to ensure heterogeneity in educational contexts and student backgrounds to examine the multivariate impacts of instructional methodologies (Photomath-assisted versus traditional pedagogical approaches) on students' autonomous study competencies, conceptual grasp of Integration Content, and self-efficacy in mathematics. This demographic structure facilitates a substantive comparison across differing instructional methodologies while considering potential institutional and individual variances that may affect the desired educational outcomes. Before conducting MANOVA, assumptions were tested (normality via Shapiro–Wilk, homogeneity via Box's M, and multicollinearity through correlation diagnostics), all of which were satisfied. Analyses were carried out using SPSS v26, applying a significance threshold of $\alpha = 0.05$.

Objective 1: To determine whether the instructional method effect varies by school location

A highly significant effect was found in the multivariate analysis for Objective 1, which examined the relationship between teaching style and school location (rural vs. urban) (Wilks' $\Lambda = 0.85$, p<.001, $\eta p^2 = 0.15$). This moderate effect size and strong statistical significance make it abundantly evident that the geographic location of the school significantly moderates the combined effects of the instructional methodology on independent study skills, conceptual understanding of Integration Content, and math self-efficacy. The robustness of this interaction is further demonstrated by the F-statistic of 6.58. This implies that the benefits of a Photomath-assisted approach are not evenly distributed and instead vary depending on the urban or rural nature of the learning environment.

By using univariate tests to examine the individual dependent variables, significant interactions between the three outcomes were found. Math self-efficacy (F=5.63, p=.019, ηp^2=.05), conceptual comprehension (F=10.12, p=.002, ηp^2=.08), and independent study skills all showed statistically significant interactions (F=8.24, p=.005, ηp^2=.07). The constantly low p-values confirm that school location does, in fact, act as a mediator between the teaching style and each of these important learning features. The modest

effect sizes indicate a significant practical difference in the ways that students from urban vs rural schools benefit from Photomath integration, especially for conceptual understanding and independent study skills.

Table 1. Instruction vs. Location

Analysis Type	Effect	Statistic	Value	df$_1$	df$_2$	p-value	Effect Size (ηp^2)
Multivariate Test	Instruction vs. location	Wilks' Λ	0.85	3	112	< .001	.15
		F	6.58	3	112	< .001	—
Univariate Tests	Independent Study Skills	F	8.24	1	114	.005	.07
	Conceptual Understanding	F	10.12	1	114	.002	.08
	Math Self-Efficacy	F	5.63	1	114	.019	.05
Canonical Correlation	Eigenvalue	—	0.18	—	—	—	—
	Canonical Correlation	—	0.41	3	—	< .001	—
	Wilks' Λ	—	0.85	3	—	< .001	—
Standardized Canonical Coefficients	Independent Study Skills	Coefficient	0.52	—	—	—	—
	Conceptual Understanding	Coefficient	0.60	—	—	—	—
	Math Self-Efficacy	Coefficient	0.45	—	—	—	—

With a strong canonical correlation of 0.41 (p<.001), the canonical correlation analysis further supports the existence and magnitude of this interaction. This suggests that the collection of outcome variables and the combination of location and instructional technique have a strong multivariate relationship. The relative contributions of each outcome to this overall interaction are shown by the standardized canonical coefficients, which are as follows: Math Self-Efficacy (0.45), Independent Study Skills (0.52), and Conceptual Understanding (0.60). According to this hierarchy, pupils' conceptual understanding of Integration Content is where the differences in impact by school location are most noticeable.

These findings necessitate a deep understanding of Rwanda's unique rural and urban learning contexts. Improved infrastructure, increased digital knowledge among teachers and children, or increased parental exposure to technology can all help to maximize Photomath's benefits in urban classrooms. However, in rural schools, where there may be limitations on internet access, device availability, or teacher professional development in educational technology, the influence might be mitigated or take a different form. The notable interaction highlights the importance of tailored implementation techniques that address these contextual disparities to ensure equitable access to the benefits of technology-enhanced learning.

The results for Objective 1 basically demonstrate that while technology-assisted learning has a lot of promise, there are vast variations in its effectiveness. The geographic location of a school acts as a significant mediator, indicating that careful consideration of the particular resource and environmental characteristics that are typical in both urban and rural settings is necessary for the proper integration of Photomath and other technologies. This calls for legislative actions and teacher preparation programs that are aware of these particular circumstances in order to maximize educational achievements for all students.

The statistically significant interaction between instructional technique and school location indicates that the effects of Photomath-assisted learning on independent study skills, conceptual knowledge of Integration Content, and math self-efficacy differ between urban and rural schools. This implies that the Photomath intervention may have different effects on children in urban settings than on those in rural ones, or vice versa. The strength of this interaction implies that students' responses to technology-assisted instruction are significantly influenced by environmental factors such as socioeconomic origins, access to technology, or disparities in pedagogical techniques between urban and rural settings.

The impact of the instructional technique on learning outcomes varies significantly depending on the school location (rural vs. urban), which provides strong support for existing research on the digital gap and educational equity. Research by authors like Rydzewski (2025) and other studies has shown that differences in access to technology, internet connectivity, and digital literacy between urban and rural locations have a significant impact on educational possibilities and outcomes. The current study provides empirical evidence

of these phenomena in the specific context of Rwanda, showing how these systemic characteristics can modify the effectiveness of a particular educational technology.

Furthermore, this conclusion aligns with sociological and geographic research that highlights the disparities in resource environments between urban and rural schools. Studies on infrastructure development, teacher quality distribution, and school finance have shown that urban schools tend to have more resources and better access to professional development opportunities (e.g., Radha, 2025). These resource disparities, which can have a direct impact on a school's capacity to properly integrate and use new technologies like Photomath, can account for the observed unequal impact on student learning outcomes in the current study.

Additionally, the interaction supports contextual learning and situated cognition theories, which maintain that learning is closely related to the environment in which it occurs (Bauer et al., 2025). The distinct social, economic, and technological environments of urban and rural schools can produce different learning environments that can either strengthen or weaken the benefits of a particular teaching method. For example, urban students may adjust to Photomath more easily if they are exposed to digital tools more frequently. This would maximize the learning benefits of Photomath, a notion that is reinforced by the affordances of technology in a variety of settings.

Lastly, the findings add to the current debate concerning the applicability of educational interventions. Numerous studies conducted in wealthy nations demonstrate the benefits of integrating technology, but it is sometimes questioned if these findings apply to emerging situations, especially rural places with distinct difficulties. Researchers like McLucas et al. (2025) have expressed concerns about the significance of local context in the implementation of educational technology, and the current study offers a tangible example that, despite Photomath's benefits, its effects are not always consistent across different geographic locations.

By offering solid empirical evidence from Rwandan Senior Six students that the impact of Photomath-assisted instruction on independent study skills, conceptual understanding of Integration Content, and math self-efficacy is significantly moderated by school location (rural vs. urban), this study makes a unique contribution to the body of knowledge. This emphasizes how crucial context-specific factors and focused interventions are for fair technology integration in a range of educational settings.

Objective 2: To assess if the instructional method effect differs between male and female students.

Table 2. Instruction vs. Gender

Analysis Type	Measure/Variable	Value	df_1	df_2	p-value	ηp^2
Multivariate Test	Wilks' Λ	0.88	3	112	.002	.12
	F	5.12	–	–	–	–
Univariate Tests	Independent Study Skills	F = 6.45	1	114	.012	.05
	Conceptual Understanding	F = 7.28	1	114	.008	.06
	Math Self-Efficacy	F = 4.02	1	114	.048	.03
Canonical Correlation Analysis	Eigenvalue	0.15	–	–	–	–
	Canonical Correlation	0.38	3	–	.001	–
	Wilks' Λ	0.88	3	–	.001	–
Standardized Canonical Coefficients	Independent Study Skills	0.48	–	–	–	–
	Conceptual Understanding	0.55	–	–	–	–
	Math Self-Efficacy	0.39	–	–	–	–

The purpose of the multivariate analysis for Objective 2 was to determine whether the impact of the teaching strategy on student outcomes differed according to gender. A statistically significant interaction was found in the results (Wilks' Λ = 0.88, p=.002, ηp^2=.12). This noteworthy result, along with a moderate effect size, suggests that male and female students do not experience the same overall effects of the instructional technique on their independent study abilities, conceptual grasp of Integration Content, and math self-efficacy. The existence of this significant interaction is further supported by the F-statistic of 5.12.

Significant interactions were found for each of the individual dependent variables after additional analysis using univariate testing. A significant interaction was found for independent study skills (F=6.45, p=.012, ηp^2=.05). Additionally, there was a statistically significant interaction between conceptual understanding (F=7.28, p=.008, ηp^2=.06) and math self-efficacy (F=4.02, p=.048, ηp^2=.03). Even though

each variable's effect size is modest, the fact that they are consistently statistically significant for all three outcomes especially when considering the entire multivariate interaction indicates that gender mediates the advantages of Photomath-assisted learning.

This interaction was further supported by the canonical correlation analysis, which showed a significant canonical correlation of 0.38 (p=.001). A significant shared variation between the measured student results, gender, and the teaching technique is indicated by this high association. The relative contributions of each outcome to this overall interaction are shown by the standardized canonical coefficients: Math Self-Efficacy (0.39), Independent Study Skills (0.48), and Conceptual Understanding (0.55). According to this arrangement, the conceptual understanding of difficult mathematical concepts, such as Integration Content, by male and female students is where gender differences are most noticeable.

These results force academics and educators to think about the complex ways that gender may affect how students use and benefit from technology-enhanced learning. Some potential explanations for these observed differences include preexisting gender biases regarding mathematics, varying levels of comfort or prior experience with digital tools, or distinct learning styles that are often associated with gender. For example, one gender may benefit more from Photomath's capabilities if they are more prone to visual learning or immediate feedback.

In summary, the results for Objective 2 show that while Photomath-assisted learning offers a number of benefits, its effectiveness is not entirely gender-neutral. Understanding these small but statistically significant differences is necessary for creating and implementing inclusive educational solutions. Educational strategies that are cognizant of gender-specific learning patterns and potential barriers are necessary to guarantee that male and female students can equally maximize their learning potential through technology.

The statistically significant interaction between gender and the teaching method indicates that male and female students do not benefit equally from Photomath-assisted learning in terms of independent study skills, conceptual understanding of Integration Content, and math self-efficacy. This suggests that one gender may be more or less affected by the Photomath intervention than the other. This interaction implies that gender-specific traits, such as pre-existing confidence levels in mathematics, digital literacy, or preferred learning styles, limit pupils' responses to technology-assisted instruction.

The conclusion that male and female students respond differently to the teaching approach is consistent with a large body of research examining gender variations in learning, especially in STEM fields and technology use. Subtle differences in certain mathematical subjects, approaches to problem-solving, or attitudes toward technology may still exist, even when overall gender discrepancies in mathematics achievement have decreased in many areas (e.g., Savicka, 2025). By offering context-specific proof of these variations inside the Rwandan educational system with reference to an AI-powered learning tool, the current study adds to this conversation.

Additionally, this result is consistent with psychological ideas regarding academic performance, stereotype threat, and self-efficacy. According to Lao et al. (2025), social cognitive theory, persistence, and task engagement are influenced by self-efficacy. For example, gender variations in math self-efficacy may already exist and may influence how students use and benefit from a technology such as Photomath, which provides real-time feedback and assistance with problem-solving. Perceived gender stereotypes in math may also affect learning and performance in technologically advanced settings, according to research on stereotype threat (Mousavi & Soltanifar, 2025).

A pertinent backdrop is also provided by studies on the relationship between gender and technology adoption. Gender inequalities in specialized technology applications, comfort levels, and engagement patterns persist even when the gap in fundamental technology availability has narrowed (e.g., Berezhna et al., 2025). These distinctions may help to explain why male and female students may use Photomath's features like step-by-step instructions or instant answer verification in somewhat different ways, which could have varying effects on their capacity for independent study and conceptual comprehension.

Lastly, the findings support gender-sensitive pedagogy, which is supported by educational research. For education to be egalitarian, it is essential to acknowledge that different genders may be affected by instructional practices differently. Researchers like Cadeliña (2025) have highlighted that learning results can be impacted by even minor biases or different classroom interactions. The current study explicitly provides

empirical support for the need for this sensitivity when integrating digital learning tools into mathematics instruction.

This study makes a significant contribution by empirically demonstrating a statistically significant interaction between student gender and the instructional method (traditional vs. Photomath-assisted) on math self-efficacy, independent study skills, and conceptual understanding of Integration Content among Senior Six students in Rwanda. This provides insightful and comprehensive data from a Sub-Saharan African context, highlighting the need to consider gender as a moderating factor in the creation and implementation of technology-enhanced maths courses.

Objective 3: To evaluate the impact of Photomath-assisted learning across public and private school settings.

Table 3. Instruction vs. School Type

Analysis Type	Measure	Value	df_1	df_2	p-value	ηp^2
Multivariate Test	Wilks' Λ	0.87	3	112	.001	.13
	F	5.84	–	–	–	–
Univariate Tests	Independent Study Skills	F = 7.10	1	114	.009	.06
	Conceptual Understanding	F = 8.55	1	114	.004	.07
	Math Self-Efficacy	F = 4.78	1	114	.031	.04
Canonical Correlation Analysis	Eigenvalue	0.16	–	–	–	–
	Canonical Correlation	0.40	3	–	< .001	–
	Wilks' Λ	0.87	3	–	< .001	–
Standardized Canonical Coefficients	Independent Study Skills	0.50	–	–	–	–
	Conceptual Understanding	0.58	–	–	–	–
	Math Self-Efficacy	0.42	–	–	–	–

Objective 3 sought to determine whether Photomath-assisted learning had different effects in public and private school settings. The multivariate analysis revealed a highly significant interaction (Wilks' Λ = 0.87, p=.001, ηp^2=.13). The moderate effect size and strong statistical significance show that the combined influence of the teaching strategy on students' independent study skills, conceptual understanding of Integration Content, and math self-efficacy varies between public and private educational institutions. The severity of this interaction is further indicated by the F-statistic of 5.84.

A more detailed understanding of this interaction was offered by univariate testing, which revealed statistically significant variations in each of the three dependent variables. Math self-efficacy (F=4.78, p=.031, ηp^2=.04), conceptual comprehension (F=8.55, p=.004, ηp^2=.07), and independent study skills showed a significant interaction (F=7.10, p=.009, ηp^2=.06). The fact that these results are consistently significant raises the possibility that the benefits of Photomath-assisted education may be mediated by the type of school, with different public and private institutions having different contexts that influence the effectiveness of technology integration.

The canonical correlation analysis, which yielded a significant canonical correlation of 0.40 (p<.001), further supported this relationship. This implies a substantial correlation between the observed student outcomes, the teaching strategy, and the type of school. The standardized canonical coefficients, which are as follows: Math Self-Efficacy (0.42), Independent Study Skills (0.50), and Conceptual Understanding (0.58), indicate the relative contributions of each outcome to this overall interaction. This suggests that Photomath's varied benefits by school type are particularly evident in students' conceptual knowledge of challenging mathematical concepts like Integration Content.

The structural differences between Rwanda's public and private schools are called into question by these findings. Increased financial independence might enable private schools to make larger investments in technological infrastructure, offer more individualized attention by reducing class sizes, or develop a more adaptable curriculum that can quickly adopt new teaching strategies. However, the effectiveness of Photomath's use and integration in public schools may be hampered by problems, including homogeneous curricula, larger class numbers, and a lack of money for educational technology professional development.

In conclusion, the results for Objective 3 unequivocally demonstrate that the institutional context, whether a school is public or private, has a substantial impact on the effectiveness of Photomath-assisted

instruction. This highlights the significance of adopting a nuanced approach to technology integration, realizing that strategies that are effective in one institutional setting may require adjustments or additional support to yield similar outcomes in another. These structural disparities should be taken into consideration by educators and policymakers to ensure that instructional technologies are applied equitably and successfully across all school types.

The statistically significant interaction between instructional technique and school type suggests that the impact of Photomath-assisted learning on independent study skills, conceptual knowledge of Integration Content, and math self-efficacy differs across public and private school settings. This suggests that students in a certain type of school (public vs. private, for instance) may benefit from the Photomath intervention to differing degrees or in different ways. This relationship implies that inherent characteristics of public versus private schools, such as resource availability, teacher preparation, student-teacher ratios, or institutional autonomy, significantly mediate the efficacy of technology-assisted instruction.

Numerous studies on educational inequality and the diverse impacts of educational systems support the conclusion that the influence of instructional style varies by school type (private vs. public). The impact of school characteristics, including student makeup, governance, and resources, on academic outcomes has long been highlighted by Parvin (2025) and other studies. Smaller class numbers, greater curriculum flexibility, and greater funding for technology are common in private schools; these factors may make it easier to include technologies like Photomath and explain a differential impact.

Additionally, this finding is consistent with research on technology uptake and educational change in other institutional settings. Scholars like Iman (2025) have warned that just implementing technology does not ensure better results, particularly if the institutional setting is not supportive of its successful integration. Private schools may be better able to adjust to and maximize the use of new pedagogical tools due to their frequently more efficient decision-making procedures and stronger emphasis on innovation, which would encourage the interaction seen in the current study.

The results also pertain to the idea of school effects, which holds that academic achievement is influenced by institutional variables rather than the personal traits of individual students. How well an educational intervention like Photomath is implemented and used by teachers and students can be greatly impacted by differences in public and private schools' technology infrastructure, school culture, and teacher professional development. This is consistent with studies that highlight the significance of school-level elements in enhancing education (e.g., Prasetyo et al., 2025).

Lastly, the findings add to the continuing worldwide conversation on fair access to high-quality education, especially in developing countries. The current study raises concerns about digital inclusion and the need for targeted policies to ensure that all students, regardless of their school's classification, can benefit from technological advancements, despite the fact that technology holds promise for closing educational gaps. They also suggest that the benefits of technology may not be evenly distributed across different school types.

By showing a statistically significant interaction between the instructional method (photomath-assisted vs. traditional) and school type (public vs. private), this study makes a unique contribution to the empirical literature. It examines the effects of these factors on the independent study skills, conceptual understanding of Integration Content, and math self-efficacy of Senior Six students in Rwanda. This provides particular insights for educational policy in underdeveloped nations and emphasizes the critical role that institutional context and resource allocation play in mitigating the advantages of technology-enhanced learning.

Objective 4: To investigate how students' academic combinations influence the outcomes of the instructional method.

Finding out how students' academic combinations, Physics-Chemistry-Mathematics [PCM], Physics-Chemistry-Biology [PCB], and Mathematics-Chemistry-Biology [MCB], impacted the instructional method's results was the goal of Objective 4. A statistically significant interaction was found using the multivariate test (Wilks' Λ = 0.88, p=.027, ηp²=.06). The significant p-value suggests that the specific academic track a student is pursuing does, in fact, subtly moderate the combined impact of the instructional method on independent study skills, conceptual understanding of Integration Content, and math self-efficacy, even

though the effect size of 0.06 is relatively small. This connection is further supported by the F-statistic of 2.45.

Table 4. Instruction vs. Academic Combination

Analysis Type	Measure / Variable	Value	df₁	df₂	p-value	ηp²
Multivariate Test	Wilks' Λ	0.88	6	226	.027	.06
	F	2.45	–	–	–	–
Univariate Tests	Independent Study Skills	3.12	2	113	.048	.05
	Conceptual Understanding	4.01	2	113	.021	.07
	Math Self-Efficacy	1.95	2	113	.146	.03
Canonical Correlation Analysis	Eigenvalue	0.10	–	–	–	–
	Canonical Correlation	0.30	6	–	.014	–
	Wilks' Λ	0.88	6	–	.014	–
Standardized Canonical Coefficients	Independent Study Skills	0.34	–	–	–	–
	Conceptual Understanding	0.42	–	–	–	–
	Math Self-Efficacy	0.29	–	–	–	–

Significant interactions for independent study skills (F=3.12, p=.048, ηp²=.05) and conceptual understanding (F=4.01, p=.021, ηp²=.07) were found by a more thorough analysis using univariate testing. Notably, though, the math self-efficacy interaction was not statistically significant (F=1.95, p=.146, ηp²=.03). This distinct pattern indicates that although academic combination has a subtle impact on the instructional method's efficacy in fostering independent study habits and conceptual understanding of difficult mathematical concepts like Integration Content, its effect on a student's confidence in mathematics seems to be more constant across different academic streams.

Additional information was revealed by the canonical correlation analysis, which revealed a significant canonical correlation of 0.30 (p=.014). This suggests a significant underlying relationship between the academic combination, the instructional approach, and the assessed outcomes, even though the correlations are not as strong as those for the prior objectives. The relative contributions of each outcome to this overall interaction are indicated by the standardized canonical coefficients, which are as follows: Math Self-Efficacy (0.29), Independent Study Skills (0.34), and Conceptual Understanding (0.42). This lends more credence to the idea that conceptual knowledge is where the relationship is strongest.

Given how nuanced this interaction is, it is important to take into account how the academic combinations differ in terms of attention and cognitive demands. For example, PCM students may interact with Photomath in a way that optimizes its conceptual advantages since they are heavily involved in rigorous mathematics and scientific problem-solving. On the other hand, even though PCB or MCB students excel in science, they may approach mathematics from a somewhat different perspective, which could account for the subtle variations in how they benefit from the technology-assisted education for particular outcomes.

In summary, the findings for Objective 4 indicate that although the teaching approach generally has advantages, students' academic choices have a small but statistically significant moderating effect on specific learning outcomes, particularly conceptual understanding and independent study abilities. This suggests that although widespread use of technology-assisted learning is beneficial, educational benefits could be further maximized by adjusting pedagogical approaches to recognize the unique cognitive profiles and learning requirements of students in various academic combinations.

The effectiveness of Photomath-assisted learning on independent study skills and conceptual understanding of Integration Content varies slightly across these different academic tracks, according to the statistically significant interaction between the instructional method and students' academic combinations (PCM, PCB, and MCB). The overall multivariate effect indicates that the particular focus, prior knowledge, and innate problem-solving techniques associated with each academic combination influence how students engage with and benefit from the Photomath intervention, especially in terms of their capacity to study independently and understand complex mathematical concepts, even though math self-efficacy did not show a significant interaction.

Research on the specialization of learning and cognitive abilities across several academic disciplines is consistent with the idea that academic combinations affect how successful an educational approach is. According to Alisoy (2025), which does not specifically address academic combinations, students who

choose particular academic streams, such as PCM, PCB, or MCB, frequently have unique learning styles, interests, and strengths that fit the requirements of those fields. These innate distinctions may influence how well students use and gain from particular teaching resources.

This result is also in line with studies on the impact of curriculum design on student learning. Different academic combinations are intended to support the growth of specific knowledge and abilities. For instance, a PCM curriculum's emphasis on analytical and abstract mathematical reasoning can increase students' openness to Photomath's exacting, systematic approaches to conceptual understanding and problem-solving. This is in line with research on the connection between student achievement and curriculum consistency (e.g., Shin et al., 2025).

The measurable effects of academic combinations are also connected to theories of learning transfer. When presented with new mathematical problems, students from different academic programs may use their current conceptual frameworks and problem-solving strategies in a variety of ways. If Photomath encourages a specific type of problem-solving that students in a particular academic combination are more likely to absorb due to their specialized training, then that could account for the small but significant impact on independent study skills and conceptual understanding. Hamid (2025) discusses the conditions under which learning is transferable across contexts.

Finally, the findings contribute to the discussion of differentiated education and individualized learning. The fact that students in different academic tracks might respond differently to a given teaching strategy highlights how important it is to adapt instructional strategies to meet a variety of learning needs. Even if a software like Photomath offers universal benefits, Jose and Mathew (2025) contend that targeted strategies that consider each student's particular needs and learning preferences could help it reach its full potential.

Students' academic combinations (PCM, PCB, MCB) subtly but significantly moderate the effectiveness of Photomath-assisted instruction on independent study skills and conceptual understanding of Integration Content, according to this study's unique empirical data from Rwandan Senior Six students. This offers useful details on a particular setting regarding how curricular specialization may impact the uptake and benefits of technology-enhanced learning materials in mathematics education. The significant multivariate relationships indicate that contextual and demographic factors interact meaningfully with the instructional approach. For example, Photomath's effectiveness varied across school location, gender, school type, and academic combination, underscoring how digital equity, gender-responsive pedagogy, and institutional capacity shape outcomes.

4. CONCLUSION

This study provides strong evidence that the teaching approach has a significant impact on students' self-efficacy in math, independent study skills, and conceptual understanding of Integration Content. These effects vary depending on the school location, student gender, and school classification (private vs. public). In particular, the Photomath-assisted method seems to be a more successful teaching tool in promoting these important learning objectives, despite differences in institutional and demographic settings. The continuous beneficial impact across many settings highlights the potential of technology-integrated learning to improve mathematics education, even while the academic combination of students also exhibits a considerable, albeit smaller, influence on the success of the instructional technique.

In light of these findings and conclusions, the following recommendations are wished-for: Include Photomath or comparable technology-assisted learning resources in the national mathematics curriculum for all secondary schools in Rwanda, with a particular emphasis on topics like Integration Content. Give teachers specialized professional development so they can use technology-assisted teaching techniques successfully and make the most of these resources to improve students' conceptual understanding and independent study. Use qualitative studies and longitudinal designs to investigate the precise mechanisms by which Photomath-assisted learning enhances conceptual understanding and self-efficacy. Create tailored teaching methods that take into account how technology-assisted learning affects certain academic combinations, guaranteeing that every student benefits equally.

These findings have important implications for stakeholders. Teachers can leverage Photomath to foster independent learning and immediate feedback, while administrators should consider digital equity and resource allocation in both public and rural schools. Policymakers and curriculum developers may integrate technology-supported mathematics instruction as part of equitable reform. Limitations of this study include its focus on a single topic (Integration Content), the reliance on quantitative methods only, and the purposive sampling from two schools, which may restrict generalizability. Future studies should explore longitudinal effects, qualitative insights into learner experiences, and the integration of other digital mathematics tools across diverse content areas.

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