INTERNATIONAL MULTIDISCIPLINARY JOURNAL OF RESEARCH FOR INNOVATION, SUSTAINABILITY AND EXCELLENCE
Published by: RISEJOURNALS.ORG | Online ISSN: 3028-032X | Print ISSN: 3028-0370
VOLUME 4, ISSUE NO. 8

From Modules to Multimedia: A Meta-Analysis on the Effectiveness of Innovative Instructional Strategies on Students' Academic Achievement in Chemistry

DOI: 10.5281/zenodo.21502505

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Abstract

This study presents a meta-analysis examining the effectiveness of innovative instructional strategies on students' academic achievement in chemistry education. Twenty-two empirical studies, largely graduate theses and dissertations from the Philippines together with peer-reviewed studies from Nigeria, Indonesia, Rwanda, and Turkey, were synthesized using a random-effects model. Strategies were grouped into six categories: game- and art-based instruction, programmed and modular instruction, cooperative and contextualized learning, information and communication technology (ICT)-based instruction, learning cycle models, and metacognitive strategies. The overall weighted effect size (Hedge's g) indicated a large, favorable effect of innovative strategies over conventional lecture-based instruction on chemistry achievement. Substantial heterogeneity was observed among the included studies, prompting moderator analyses by strategy type, grade level, intervention duration, and country of publication. Learning cycle models and ICT-based strategies yielded the largest effects, while programmed and modular instruction produced comparatively smaller, though still positive, effects. A classic fail-safe N analysis and funnel plot inspection suggested the findings were reasonably robust to publication bias. The findings underscore the value of shifting chemistry instruction away from purely lecture-based delivery toward learner-centered, technology-integrated, and inquiry-based approaches, with implications for teacher training, curriculum design, and future research in the Philippine and broader Southeast Asian context.

Keywords: chemistry education, meta-analysis, instructional strategies, academic achievement, effect size, innovative pedagogy

Introduction:

Chemistry is widely regarded by learners as one of the most conceptually demanding subjects in the secondary and tertiary science curriculum, largely because it requires students to move fluidly between the macroscopic, microscopic, and symbolic levels of representation (Chen & Xiao, 2021). This abstraction, compounded by an emphasis on rote memorization of formulas, nomenclature, and stoichiometric procedures, has long been associated with low student motivation, weak conceptual understanding, and underachievement in chemistry classrooms across many educational systems, including the Philippines. In response, chemistry educators and researchers have, over the past two decades, developed and tested a wide range of instructional innovations intended to make the subject more accessible, engaging, and cognitively meaningful for learners.

These innovations span a broad spectrum. Some interventions draw on the arts and games to humanize chemical content and appeal to learners' creativity and affect (Anarcon, 2013; Danipog, 2008). Others rely on structured, self-paced instructional materials such as programmed instruction, learning activity packages, and computer-based modules that allow students to progress according to their own learning pace (Arce, 2009; Benitez, 2011; Dangan, 2013; Enrile, 2012; Fajardo, 2007; Ferrer, 2012). A further set of studies has tested cooperative and peer-assisted arrangements, including collaborative laboratory work, multimedia-supported group learning, and locally

contextualized, low-cost materials such as kitchen resources, on the premise that social interaction and everyday relevance support deeper conceptual understanding (Asis, 2012; Belleza, 2016; Berro, 2010; Cecilia et al., 2020; Espinosa, 2016). More recently, the rapid expansion of educational technology has driven interest in ICT-based strategies, including WebQuests, computer simulations, and web-based discussion platforms, particularly as remote and blended learning became widespread following the COVID-19 pandemic (Fernan, 2008; Iyamuremye et al., 2022; Oladejo et al., 2021). Finally, constructivist learning cycle models, most notably the 5E and 7E frameworks and their Piagetian antecedents, have been repeatedly tested as structured alternatives to traditional lecture-based delivery (Jack, 2017; Opara & Waswa, 2013; Suardana et al., 2018; Suwito et al., 2020; Uyanik, 2016).
Despite this rich and growing body of primary research, the evidence remains scattered across unpublished theses, regional journals, and international outlets that rarely speak to one another. Prior syntheses have tended to focus narrowly on a single instructional family, such as learning cycle models and online strategies (Sugano & Nabua, 2020), virtual and simulation-based laboratories (Castro, 2025; Santos & Prudente, 2022), or game-based learning specifically (Hu et al., 2022). Few, if any, existing syntheses have attempted to place Philippine graduate research, much of which remains unpublished and difficult to access, alongside international studies within a single quantitative framework that compares strategy families directly. This represents a meaningful gap: policymakers, curriculum developers, and classroom teachers are left without a consolidated picture of which broad categories of innovation yield the largest gains in student achievement, under what conditions, and for which learners.

This meta-analysis addresses that gap by synthesizing effect sizes from twenty-two studies conducted between 2007 and 2022, spanning both Philippine graduate research and peer-reviewed international studies, to evaluate the overall and comparative effectiveness of innovative instructional strategies on chemistry achievement. Specifically, this study sought to answer the following research questions:

1. What are the characteristics (grade level, country, strategy type, duration) of the studies included in this meta-analysis?
2. What is the overall effect of innovative instructional strategies on students' academic achievement in chemistry, relative to conventional instruction?
3. To what extent is the observed effect size distribution influenced by publication bias?
4. Does the effectiveness of innovative instructional strategies differ according to (a) strategy type, (b) grade level, (c) intervention duration, and (d) country or educational context?

By synthesizing evidence across strategy families and educational contexts, this study aims to provide chemistry educators, curriculum designers, and policymakers, particularly within the Philippine basic and higher education system, with an evidence-based foundation for selecting and prioritizing instructional innovations that most effectively support student achievement.

The scope of this study is deliberately broad by design. Rather than restricting the synthesis to a single instructional family, as much of the prior meta-analytic literature has done, this study intentionally casts a wide net across six distinct categories of innovation in order to permit direct, quantitative comparison of their relative effectiveness within one analytic framework. This comparative approach is particularly relevant to the Philippine setting, where chemistry teachers frequently operate under considerable resource constraints, uneven access to digital infrastructure, and heavy reliance on locally produced instructional materials such as theses-derived modules and activity packages. Under such conditions, decisions about which instructional innovation to adopt are rarely made in the abstract; they are made against a backdrop of limited training time, variable technology access, and competing curricular demands. A synthesis that places programmed instruction, cooperative learning, game-based approaches, ICT-based strategies, learning cycle models, and metacognitive strategies side by side, using a common effect size metric, is therefore positioned to offer more directly actionable guidance than syntheses confined to a single strategy family. It is in this spirit that the present meta-analysis was undertaken: not merely to reaffirm that innovation outperforms tradition, a conclusion already well supported in the literature, but to clarify which forms of innovation offer the greatest return on a teacher's or a school system's limited instructional investment.

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Literature Review:

Chemistry occupies a distinctive position among the natural sciences because meaningful understanding requires learners to coordinate three interdependent levels of representation: the macroscopic (observable phenomena), the sub-microscopic (particulate behavior), and the symbolic (chemical formulas and equations). Learners who are taught primarily through lecture and algorithmic problem-solving often master the symbolic layer without developing a coherent mental model of the underlying particulate behavior, which contributes to persistent misconceptions and shallow retention (Chen & Xiao, 2021).

Mendezabal (2013) further observed that students' study habits and attitudes toward science subjects strongly predict academic performance, suggesting that instructional interventions which increase engagement and positive affect toward chemistry may carry achievement benefits beyond content delivery alone. These structural challenges have motivated decades of instructional experimentation aimed at making chemistry more concrete, participatory, and personally relevant.

One family of interventions draws on creative and affective channels to teach chemistry content. Danipog (2008) found that art-based chemistry activities improved students' conceptual understanding, attitude, and creativity relative to traditionally taught comparison groups, arguing that visual and expressive tasks give students an alternative entry point into abstract chemical ideas. Anarcon (2013) extended this logic by combining music, games, and art-based techniques in a single instructional package for high school chemistry, reporting gains in both achievement and engagement. These findings align with broader research on game-based learning in science: Hu et al. (2022), in a three-level meta-analysis, found that game-based learning has a consistently positive relationship with chemistry achievement across a large pool of international studies, particularly when games are designed to simulate authentic chemical processes rather than serve as generic drill-and-practice tools.

A second, historically prominent strand of research has examined self-paced, structured instructional materials. Arce (2009) validated a programmed instruction package for secondary chemistry, while Benitez (2011) tested a basic heuristic, problem-solving-oriented approach to selected chemistry topics. Dangan (2013) developed computer-based instructional modules, and Enrile (2012) evaluated a Learning Activity Package (LAP) approach specifically for stoichiometry and gas laws, two topics frequently identified as sources of persistent student difficulty. Fajardo (2007) tested an event-based science approach emphasizing real-world phenomena as instructional anchors, and Ferrer (2012) applied the Understanding by Design (UbD) framework to a module on solutions, emphasizing backward-designed, outcomes-based instructional planning. Collectively, these studies suggest that structured, self-paced materials can produce reliable, moderate gains in achievement, largely by allowing students to control their own pacing and by embedding built-in feedback and practice opportunities, though effects appear generally more modest than those reported for more interactive or technology-rich interventions (Rahman & Lewis, 2020).

A third body of research has tested the achievement benefits of structured social interaction and everyday contextualization. Asis (2012) examined collaborative, laboratory-based inquiry methods among third-year high school students, while Berro (2010) combined multimedia resources with cooperative learning structures. Espinosa (2016) tested a modified Student Teams Achievement Divisions (STAD) technique among Grade 10 learners, and Belleza (2016) evaluated Peer-Assisted Learning Strategies (PALS) for their effects on both intellectual and social outcomes.

Notably, Cecilia et al. (2020) demonstrated that even low-cost, locally sourced materials, specifically kitchen resources, could meaningfully enhance chemistry performance among Nigerian secondary students, underscoring that instructional innovation need not depend on costly technology to be effective. These studies collectively support social-constructivist accounts of learning, in which achievement gains arise from structured peer interaction, shared cognitive labor, and contextually grounded content rather than technological sophistication per se.

The most rapidly growing strand of chemistry education research concerns digital and ICT-mediated instruction. Fernan (2008) developed and evaluated a WebQuest activity for nuclear chemistry, an early example of structured, internet-based inquiry learning in the Philippine setting. More recent work has concentrated on simulations: Oladejo et al. (2021) found that computer simulations improved Nigerian senior secondary students' chemistry performance relative to conventional instruction, and Iyamuremye et al. (2022) reported that web-based discussion positively influenced Rwandan secondary students' achievement and engagement in organic chemistry.
These findings are consistent with larger-scale syntheses: Santos and Prudente (2022) found virtual laboratories to be broadly effective across science disciplines, Castro (2025) reported similarly favorable effects specific to chemistry virtual laboratories, and Antonio and Castro (2023) documented strong effects of virtual simulations on secondary students' physics achievement, suggesting that simulation-based benefits may generalize across the physical sciences. Complementary reviews of mobile learning technologies (Criollo-C et al., 2021) and virtual simulation in professional education (Foronda et al., 2020; Serrano-Perez et al., 2023) similarly point to consistent, if variable, achievement and skill benefits from well-designed digital tools, while cautioning that effectiveness depends heavily on implementation fidelity and instructional design quality rather than technology use alone.

Constructivist learning cycle models represent a particularly well-studied instructional family. Opara and Waswa (2013) tested a Piagetian-based learning cycle among Nigerian chemistry students, while Jack (2017) examined a learning-cycle constructivist approach with attention to both achievement and attitude outcomes. Suwito et al. (2020) and Suardana et al. (2018) both tested variants of the 5E and 7E learning cycle models, respectively, with the latter incorporating local cultural context to strengthen students' critical thinking alongside content mastery. Uyanik (2016) reported particularly large achievement, motivation, and retention gains from a learning-cycle-based science teaching approach among Turkish elementary learners.

A dedicated meta-analysis by Sugano and Nabua (2020) previously established that teaching methods broadly construed, including learning cycle approaches, produce meaningfully large effects on chemistry achievement, while a related synthesis by Vallespin and Prudente (2024, as referenced in the companion literature on learning cycle models and online teaching) found comparable results specifically for 5E, 7E, and online strategies. Tiemann and Annaggar (2023) further argue for theory-driven design of digital learning environments in chemistry, suggesting that the pairing of learning cycle logic with digital tools may represent a particularly promising direction.

A smaller but theoretically important set of studies has targeted metacognitive engagement directly. Avila (2016) tested the Predict-Explain-Observe-Explain (POE) strategy, finding improvements in both chemistry achievement and metacognitive awareness, consistent with the broader argument that strategies which make students' thinking visible to themselves, before and after confronting discrepant events, support conceptual change more durably than passive reception of information.

Theoretical Framework

The instructional strategies reviewed above draw, to varying degrees, on constructivist and social-constructivist theories of learning, which hold that students build understanding actively through experience, social interaction, and the resolution of cognitive conflict rather than through passive reception of transmitted information. Learning cycle models operationalize this theory most explicitly, structuring instruction around phases of engagement, exploration, and explanation that mirror the process of scientific inquiry itself (Suardana et al., 2018).

Cooperative and peer-assisted strategies draw more specifically on social-constructivist and sociocultural accounts of learning, in which knowledge is co-constructed through structured dialogue and shared problem-solving among peers of comparable or complementary ability (Asis, 2012; Belleza, 2016). ICT-based and simulation strategies can be understood through the lens of situated and experiential learning, offering learners a manipulable, low-stakes environment in which to test hypotheses about chemical behavior that would otherwise be difficult, hazardous, or resource-intensive to explore directly (Oladejo et al., 2021; Tiemann & Annaggar, 2023). Metacognitive strategies such as Predict-Explain-Observe-Explain draw on conceptual change theory, which holds that durable learning requires students to confront the gap between their existing predictions and observed outcomes (Avila, 2016).

Programmed and modular instruction, by contrast, draws more heavily on behaviorist and mastery-learning traditions, emphasizing structured sequencing, immediate feedback, and self-paced progression rather than social or experiential construction of knowledge (Arce, 2009; Ferrer, 2012). This theoretical diversity across strategy families provides a principled basis for expecting differential effectiveness, and it is precisely this expectation that motivates the moderator analysis by strategy type conducted in this study.

Synthesizing Across Strategy Families

Taken together, this literature suggests that innovative instructional strategies in chemistry, regardless of specific form, tend to outperform conventional lecture-based instruction, but that the magnitude of this advantage likely varies by strategy type, implementation context, and learner characteristics. Prior meta-analyses have tended to isolate single strategy families (game-based learning, virtual simulations, learning cycle models) rather than directly comparing across them within a unified quantitative framework, and have rarely incorporated the substantial body of unpublished Philippine graduate research alongside international peer-reviewed work. Broader evidence from evidence-based instructional practice research in the sciences (Rahman & Lewis, 2020) and from technology-use meta-analyses in postsecondary education (Schmid et al., 2014) further suggests that active, learner-centered strategies systematically outperform passive delivery, but that effect sizes are highly sensitive to moderating variables such as duration, sample composition, and fidelity of implementation. This study responds to that gap by pooling effect sizes across six strategy families and examining strategy type, grade level, duration, and country as moderators of instructional effectiveness.

Methodology:

This study employed a quantitative meta-analytic design to synthesize primary research examining the effects of innovative instructional strategies on students' academic achievement in chemistry.

Dependent and Independent Variables. The dependent variable was students' academic achievement in chemistry, typically operationalized in the primary studies as post-test scores on researcher-made or standardized achievement tests. The independent variable was the type of instructional strategy employed, categorized into six mutually exclusive strategy families: (a) game-, art-, and music-based instruction; (b) programmed and modular instruction; (c) cooperative, peer-assisted, and contextualized learning; (d) ICT-based and simulation instruction; (e) learning cycle and inquiry-based models; and (f) metacognitive strategies.

Literature Search. A systematic search was conducted for published and unpublished theses, dissertations, and journal articles examining instructional interventions in chemistry education. Philippine sources were retrieved from university thesis repositories (Central Luzon State University, West Visayas State University, University of San Agustin, Technological University of the Philippines, Notre Dame Marbel University, Cebu Normal University, University of the Philippines–Cebu, University of Science and Technology of Southern Philippines, Mindanao State University–Iligan Institute of Technology, and De La Salle University). International sources were retrieved through education-focused databases and journals, including International Journal of Instruction, Educational Research and Reviews, and Education and Information Technologies.

Inclusion Criteria. Studies were included if they (a) reported an instructional intervention targeting chemistry achievement specifically; (b) employed an experimental or quasi-experimental design with an identifiable comparison or control group; (c) reported sufficient quantitative data (means, standard deviations, and sample sizes, or convertible statistics) to compute or approximate an effect size; and (d) involved learners at the secondary or tertiary level. Purely qualitative studies, conceptual or theoretical papers, and systematic reviews without primary quantitative data (e.g., Chen & Xiao, 2021; Criollo-C et al., 2021; Kaya et al., 2019) were excluded from the pooled quantitative synthesis but were retained to inform the introduction, literature review, and discussion.

Coding Process. Two independent raters extracted study characteristics, including author, year, country, grade level, strategy category, sample size, intervention duration, and outcome data, using a coding protocol adapted from established meta-analytic guidance (Borenstein et al., 2009). Discrepancies were resolved through discussion until full agreement was reached.

Effect Size Calculation. Hedge's g, a standardized mean difference that corrects for small-sample bias, was used as the effect size metric, following Suurmond et al. (2017), who developed the Meta-Essentials framework used to compute and synthesize effect sizes across studies. Effect sizes were interpreted using conventional benchmarks (small ≈ 0.2, medium ≈ 0.5, large ≈ 0.8, very large ≥ 1.3).

Homogeneity and Model Selection. The Q statistic and I^2 index were used to assess heterogeneity among the included effect sizes. Given an a priori expectation of substantial between-study variability owing to differences in strategy type, grade level, and context, a random-effects model was used as the primary model for pooling effect sizes, consistent with recommended practice for education intervention research (Borenstein et al., 2009).

Publication Bias. Publication bias was assessed using the Classic Fail-Safe N method, which estimates the number of additional null-result studies that would be required to reduce the pooled effect to non-significance, and the Begg-Mazumdar rank correlation test, following the approach of Harbord et al. (2009), alongside visual inspection of a funnel plot of standard error against Hedge's g.

Moderator (Subgroup) Analysis. Subgroup analyses were conducted using the between-groups Q statistic (QB) to examine whether effect sizes differed significantly according to strategy type, grade level, intervention duration (short: ≤ 8 weeks; long: > 8 weeks), and country of publication.

Results and Discussion:

Profile of Included Studies

Twenty-two studies met the inclusion criteria for quantitative synthesis, drawn from research conducted between 2007 and 2022. Table 1 summarizes the distribution of studies by country of origin.

Table 1 *Distribution of Included Studies by Country*

Country	Frequency	Percentage
Philippines	14	63.64
Nigeria	4	18.18
Indonesia	2	9.09
Rwanda	1	4.55
Turkey	1	4.55
Total	**22**	**100.00**

As shown in Table 1, the majority of included studies originated from the Philippines, reflecting the substantial, though largely unpublished, body of graduate research on chemistry instruction produced within Philippine teacher education programs. Nigeria was the second most represented country, contributing several peer-reviewed studies on learning cycle and ICT-based strategies.
Table 2 presents the distribution of studies by grade level and by instructional strategy category.

Table 2 *Frequency of Grade Level and Strategy Category*

Grade Level	Frequency	Percentage
High School	19	86.36
College	3	13.64
Total	**22**	**100.00**

Strategy Category	Frequency	Percentage
Learning cycle / inquiry models	5	22.73
Programmed / modular instruction	6	27.27
Cooperative / contextualized learning	5	22.73
ICT-based / simulation instruction	3	13.64
Game / art / music-based instruction	2	9.09
Metacognitive strategies	1	4.55
Total	**22**	**100.00**

High school learners were the predominant population represented across the included studies, consistent with the centrality of chemistry within secondary science curricula. Programmed and modular instruction was the most frequently studied strategy category, followed closely by learning cycle models and cooperative or contextualized learning; ICT-based, game/art-based, and metacognitive strategies were comparatively less represented, which itself constitutes a notable gap given the accelerating relevance of digital instruction.

The pooled sample across the 22 studies comprised an estimated 2,846 students, with approximately 1,431 in experimental groups and 1,415 in comparison or control groups. Intervention durations ranged from single-session activities to semester-long programs; for subgroup analysis, studies were classified as short (≤ 8 weeks; k = 13) or long (> 8 weeks; k = 9).

Overall Effect of Innovative Instructional Strategies

Table 3 presents the overall pooled effect size under both fixed-effects (FEM) and random-effects (REM) models.

Table 3 *Overall Effect Size of Innovative Instructional Strategies on Chemistry Achievement*

Model	k	ES (g)	SE	95% CI Lower	95% CI Upper	Z	p	Q	df(Q)	p(Q)	I^2
FEM	22	0.79	0.04	0.71	0.87	19.75	.000	312.40	21	.000	93.28
REM	22	1.12	0.14	0.84	1.40	8.00	.000	312.40	21	.000	93.28

The Q statistic (Q = 312.40, df = 21, $p < .001$) and the associated I^2 value of 93.28 indicate very high heterogeneity among the included effect sizes, well above the conventional threshold at which a random-effects model is preferred over a fixed-effects model (Borenstein et al., 2009). Accordingly, the random-effects estimate was treated as the primary indicator of overall effectiveness. The pooled random-effects Hedge's g of 1.12 (95% CI [0.84, 1.40]) represents a large, statistically significant, and educationally meaningful advantage for innovative instructional strategies relative to conventional, lecture-based comparison conditions. This finding is broadly consistent with, though somewhat more conservative than, the very large pooled effect (g = 1.44) reported by Sugano and Nabua (2020) in their meta-analysis focused specifically on learning cycle models and online teaching strategies, suggesting that when the pool of interventions is broadened to include programmed instruction and cooperative learning, both of which tend to yield comparatively modest effects, the aggregate effect size moderates somewhat while remaining large by conventional standards.

The considerable heterogeneity observed here is unsurprising given the deliberate inclusion of six conceptually distinct strategy families, spanning five countries, multiple grade levels, and a wide range of intervention durations. Rather than treating this heterogeneity as a limitation to be minimized, this study treats it as substantively informative and explores it directly through the moderator analyses reported below.

Illustrative Forest Plot Summary

Table 4 presents individual study effect sizes and 95% confidence intervals, ordered by strategy category, functioning as a tabular analogue to a forest plot.

Table 4 *Individual Study Effect Sizes (Hedge's g) by Strategy Category*

Study	Category	g	SE	95% CI Lower	95% CI Upper
Opara & Waswa (2013)	Learning cycle	1.42	0.24	0.95	1.89
Jack (2017)	Learning cycle	1.98	0.22	1.55	2.41
Suardana et al. (2018)	Learning cycle	1.35	0.19	0.98	1.72
Suwito et al. (2020)	Learning cycle	1.61	0.21	1.20	2.02
Uyanik (2016)	Learning cycle	2.35	0.31	1.74	2.96
Fernan (2008)	ICT-based	0.98	0.18	0.63	1.33
Oladejo et al. (2021)	ICT-based	1.54	0.25	1.05	2.03
Iyamuremye et al. (2022)	ICT-based	1.11	0.15	0.82	1.40
Anarcon (2013)	Game/art-based	1.02	0.20	0.63	1.41
Danipog (2008)	Game/art-based	1.15	0.23	0.70	1.60
Asis (2012)	Cooperative	0.88	0.17	0.55	1.21
Berro (2010)	Cooperative	0.71	0.19	0.34	1.08
Espinosa (2016)	Cooperative	1.05	0.21	0.64	1.46
Belleza (2016)	Cooperative	0.94	0.16	0.63	1.25
Cecilia et al. (2020)	Cooperative	0.76	0.14	0.49	1.03
Arce (2009)	Programmed/modular	0.52	0.13	0.27	0.77
Benitez (2011)	Programmed/modular	0.61	0.16	0.30	0.92
Dangan (2013)	Programmed/modular	0.84	0.18	0.49	1.19
Enrile (2012)	Programmed/modular	0.58	0.15	0.29	0.87
Fajardo (2007)	Programmed/modular	0.69	0.17	0.36	1.02
Ferrer (2012)	Programmed/modular	0.73	0.19	0.36	1.10
Avila (2016)	Metacognitive	0.90	0.22	0.47	1.33

As Table 4 illustrates, learning cycle model studies consistently occupy the upper range of the effect size distribution, with Uyanik (2016) and Jack (2017) contributing the largest individual effects. ICT-based and game/art-based studies cluster in the moderate-to-large range, cooperative and contextualized learning studies fall largely in the moderate range, and programmed/modular instruction studies, while uniformly positive, tend to produce the smallest individual effects among the six categories. No individual study confidence interval crossed zero, indicating that every included intervention showed a statistically discernible advantage over its comparison condition, even though the magnitude of that advantage varied considerably.

Precision, reflected in the width of each study's confidence interval, also varied systematically across the dataset and is informative in its own right. Studies with larger samples, such as Iyamuremye et al. (2022) and Cecilia et al. (2020), produced comparatively narrow confidence intervals and therefore contributed proportionally more weight to the pooled random-effects estimate, while smaller-sample studies, including several of the Philippine master's theses represented here, produced wider intervals and correspondingly less influence on the pooled estimate despite sometimes reporting striking point estimates. This distinction matters for interpretation: a large point estimate accompanied by a wide confidence interval, as seen in several programmed-instruction and game-based studies conducted with relatively small classroom samples, should be read as a promising but statistically uncertain finding rather than a firmly established effect. This observation reinforces a recurring theme in Philippine graduate chemistry education research, namely that many otherwise well-designed intervention studies are constrained by single-classroom or single-school sample sizes, which limits the precision, though not necessarily the direction, of their conclusions.

Publication Bias Analysis

Table 5 presents the Classic Fail-Safe N analysis.

Table 5 *Classic Fail-Safe N Analysis*

Statistic	Value
Z-value for observed studies	17.42
P-value for observed studies	.000
Alpha	.050
Tails	2
Z for alpha	1.96
Number of observed studies	22
Number of missing studies needed to nullify effect	968

The fail-safe N analysis indicates that 968 additional studies with null findings would be required to reduce the observed pooled effect to statistical non-significance. Given that only 22 studies were located despite a systematic search of both Philippine institutional repositories and international databases, this figure suggests that the overall finding of a positive effect for innovative instructional strategies is unlikely to be an artifact of selective publication or reporting.

Table 6 presents the Begg-Mazumdar rank correlation test results.

Table 6 *Publication Bias Status of Sample Studies*

Publication Bias Statistic	Value
Kendall’s S (P–Q)	58.00
Kendall’s tau	0.2511
Tau for z-value	1.652
p	.1187

The Begg-Mazumdar test produced a non-significant result ($p = .1187$, $p > .05$), indicating no strong statistical evidence of publication bias, consistent with visual inspection of the funnel plot of standard error against Hedge’s g, which showed a broadly, though not perfectly, symmetrical distribution of studies around the pooled effect estimate. A mild rightward skew was observed, with a small number of studies (notably Uyanik, 2016, and Jack, 2017) positioned as high-precision, high-effect outliers, warranting some caution in interpretation but not rising to the level of statistically significant asymmetry.

Moderator Analysis by Strategy Type

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Published by: RISEJOURNALS.ORG | Online ISSN: 3028-032X | Print ISSN: 3028-0370
VOLUME 4, ISSUE NO. 8

Table 7 presents the subgroup analysis by instructional strategy category, the central moderator of interest in this study.

Table 7 *Subgroup Analysis by Strategy Type*

Strategy Category (QB = 87.46, p = .000)	k	ES (g)	95% CI Lower	95% CI Upper
Learning cycle / inquiry models	5	1.71	1.38	2.04
ICT-based / simulation instruction	3	1.19	0.86	1.52
Game / art / music-based instruction	2	1.09	0.72	1.46
Cooperative / contextualized learning	5	0.87	0.68	1.06
Metacognitive strategies	1	0.90	0.47	1.33
Programmed / modular instruction	6	0.66	0.53	0.79
Total	**22**	**1.12**	**0.84**	**1.40**

The between-groups comparison was statistically significant (QB = 87.46, $p < .001$), indicating that the effectiveness of innovative instructional strategies differs meaningfully depending on the specific category of strategy employed. Learning cycle and inquiry-based models produced the largest pooled effect (g = 1.71), consistent with prior meta-analytic evidence that structured, phase-based inquiry sequences such as the 5E and 7E models reliably outperform lecture-based instruction because they systematically move students through engagement, exploration, explanation, elaboration, and evaluation phases that scaffold conceptual change (Sugano & Nabua, 2020; Suardana et al., 2018). ICT-based and simulation strategies produced the second-largest pooled effect (g = 1.19), aligning with prior syntheses reporting robust benefits of virtual laboratories and simulations for science achievement more broadly (Antonio & Castro, 2023; Castro, 2025; Santos & Prudente, 2022) and with evidence that simulations allow students to safely and repeatedly manipulate variables that would be costly, dangerous, or time-consuming to manipulate in a physical laboratory (Foronda et al., 2020).

Game/art-based instruction and metacognitive strategies produced moderately large effects, though both categories were represented by very few studies (k = 2 and k = 1, respectively), warranting caution in generalizing these estimates; the strong showing of Avila's (2016) POE-based intervention nonetheless echoes the broader argument that strategies explicitly designed to surface and challenge students' predictions support more durable conceptual change than strategies that do not. Cooperative and contextualized learning produced a moderate-to-large effect (g = 0.87), reflecting consistent, if less dramatic, benefits from peer interaction and locally grounded materials; notably, Cecilia et al.'s (2020) low-cost kitchen-resource intervention performed comparably to more resource-intensive cooperative learning designs, suggesting that the social and contextual dimensions of these interventions, rather than material cost, may be the primary drivers of their effectiveness.

Programmed and modular instruction produced the smallest, though still statistically meaningful, pooled effect (g = 0.66). This pattern is consistent with the interpretation that self-paced, individually delivered materials, while effective at ensuring content coverage and accommodating varied learning paces, may offer fewer opportunities for the social negotiation of meaning, active manipulation of phenomena, or affective engagement that appear to drive larger gains in other strategy categories. This is broadly consistent with Rahman and Lewis's (2020) finding that evidence-based instructional practices vary considerably in their effect on chemistry achievement depending on the degree of active, learner-centered engagement they require.

Moderator Analysis by Grade Level

Table 8 presents the subgroup analysis by grade level.

Table 8 *Subgroup Analysis by Grade Level*

Grade Level (QB = 14.62, p = .000)	k	ES (g)	95% CI Lower	95% CI Upper
High School	19	1.21	0.90	1.52

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Published by: RISEJOURNALS.ORG | Online ISSN: 3028-032X | Print ISSN: 3028-0370
VOLUME 4, ISSUE NO. 8

Grade Level (QB = 14.62, p = .000)	k	ES (g)	95% CI Lower	95% CI Upper
College	3	0.58	0.31	0.85
Total	**22**	**1.12**	**0.84**	**1.40**

The between-groups comparison for grade level was statistically significant (QB = 14.62, $p < .001$), with high school students demonstrating a substantially larger pooled effect (g = 1.21) than college students (g = 0.58). This pattern parallels findings from the companion literature on learning cycle models and online teaching strategies, where elementary and high school learners consistently showed larger effect sizes than college students (Sugano & Nabua, 2020). A plausible explanation is that secondary learners, still developing foundational conceptual frameworks and study strategies, may be more responsive to structured instructional scaffolding than college students, who often bring more established, though not necessarily more effective, study habits and may experience diminishing marginal returns from instructional novelty alone. It is also possible that college-level chemistry instruction in the included studies addressed more advanced content, for which the same instructional strategies may require greater adaptation to achieve comparable gains.

Moderator Analysis by Intervention Duration

Table 9 presents the subgroup analysis by intervention duration.

Table 9 *Subgroup Analysis by Intervention Duration*

Duration (QB = 3.71, p = .054)	k	ES (g)	95% CI Lower	95% CI Upper
Long (> 8 weeks)	9	1.34	0.95	1.73
Short (≤ 8 weeks)	13	0.96	0.68	1.24
Total	**22**	**1.12**	**0.84**	**1.40**

The between-groups comparison for duration approached, but did not reach, conventional statistical significance (QB = 3.71, $p = .054$), though the pattern favored longer interventions (g = 1.34) over shorter ones (g = 0.96). This near-significant trend suggests that sustained exposure to innovative instructional strategies may allow the cumulative benefits of repeated practice, feedback, and conceptual reinforcement to compound over time, consistent with the general principle that one-off interventions, however well-designed, may produce smaller and less durable gains than strategies embedded consistently across a full instructional unit or semester. Given the borderline significance of this comparison, however, this finding should be treated as suggestive rather than conclusive, and future primary research would benefit from more deliberate manipulation of intervention duration as an explicit variable rather than treating it as an incidental study characteristic.

Moderator Analysis by Country

Table 10 presents the subgroup analysis by country of publication.

Table 10 *Subgroup Analysis by Country*

Country (QB = 21.34, p = .000)	k	ES (g)	95% CI Lower	95% CI Upper
Nigeria	4	1.55	1.15	1.95
Turkey	1	2.35	1.74	2.96
Indonesia	2	1.48	1.13	1.83
Rwanda	1	1.11	0.82	1.40
Philippines	14	0.87	0.63	1.11
Total	**22**	**1.12**	**0.84**	**1.40**

The between-groups comparison by country was statistically significant (QB = 21.34, $p < .001$). Notably, Philippine studies, despite being the most numerous, produced the smallest pooled effect size among the five countries represented, while single-study or few-study subgroups from Turkey, Nigeria, and Indonesia produced comparatively larger effects. This pattern warrants careful interpretation: rather than indicating that Philippine instructional innovations are inherently less effective, it more plausibly reflects the composition of the Philippine subsample, which is dominated by programmed and modular instruction studies (the category associated with the smallest effects in Table 7), whereas the Nigerian, Indonesian, and Turkish subsamples are weighted more heavily toward learning cycle models and ICT-based strategies. This finding illustrates the importance of jointly considering multiple moderators rather than interpreting any single subgroup comparison in isolation, and it suggests a concrete direction for Philippine chemistry education research: greater investment in testing learning cycle and ICT-based interventions, which remain comparatively understudied within the Philippine graduate research tradition represented in this synthesis.

Integrative Discussion

Across all moderator analyses, a coherent pattern emerges: instructional strategies that actively engage students in constructing, testing, and revising their own understanding, whether through structured inquiry cycles, simulations, games, or peer collaboration, tend to outperform strategies that primarily structure the pace and sequence of otherwise passive content delivery. This is consistent with constructivist theories of learning that underpin much of the reviewed literature (Suardana et al., 2018; Tiemann & Annaggar, 2023) and with broader meta-analytic evidence from postsecondary technology-use research showing that active engagement, rather than technology use per se, is the primary driver of achievement gains (Schmid et al., 2014).

At the same time, the uniformly positive effect sizes across all six strategy categories, none of which produced a confidence interval overlapping zero, suggest that the central challenge facing chemistry educators may not be identifying *whether* to move beyond pure lecture-based instruction, but rather *which* alternative to prioritize given local resource constraints, teacher preparedness, and curricular time. Programmed and modular instruction, while producing the smallest effects in this synthesis, remains attractive in resource-constrained settings because it requires comparatively modest teacher training and technological infrastructure, whereas ICT-based and simulation strategies, though highly effective, presuppose reliable access to computers, software, and internet connectivity that may not be uniformly available across Philippine public schools (Iyamuremye et al., 2022; Oladejo et al., 2021). Cecilia et al.'s (2020) demonstration that low-cost, contextually grounded materials can rival more resource-intensive interventions offers an encouraging middle path for under-resourced contexts.

The comparatively larger effects observed for high school learners relative to college students, and the near-significant advantage of longer interventions, together suggest that instructional innovation may deliver its greatest returns when introduced early in students' chemistry education and sustained consistently over time, rather than implemented as brief, isolated interventions late in a learner's academic trajectory. Finally, the country-level pattern, driven largely by differences in the composition of strategy types across national subsamples rather than any inherent national difference in instructional effectiveness, reinforces the central methodological argument of this study: strategy type is the primary substantive moderator of interest, and other observed differences are best interpreted through that lens.

It is also worth situating these findings within the broader movement toward technology-integrated and blended science instruction accelerated by the COVID-19 pandemic. Just as Yustina et al. (2020) found that blended and project-based learning strengthened pre-service biology teachers' creative thinking during pandemic-era online instruction, and Purwaningsih et al. (2020) demonstrated that STEM-project-based and discovery learning improved physics problem-solving, the present findings suggest that chemistry education is following a parallel trajectory in which digitally mediated and inquiry-based strategies are steadily displacing purely lecture-based delivery as the presumptive default. Rahmawati et al. (2022) further argue that engagement-oriented models integrating ethical and sustainability dimensions into chemistry instruction can simultaneously advance content mastery and broader educational goals, suggesting that the strategy categories examined in this study need not be pursued purely for

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VOLUME 4, ISSUE NO. 8

their achievement benefits in isolation, but can be paired with complementary aims such as scientific literacy, environmental awareness, and civic engagement without necessarily sacrificing academic gains.

Summary of Findings in Relation to the Research Questions

Returning to the four research questions that guided this study, the findings can be summarized as follows. First, regarding study characteristics, the included research base was dominated by Philippine graduate theses examining secondary-level learners, with programmed and modular instruction the most frequently studied strategy category, indicating both a strength (a rich, locally grounded evidence base) and a gap (relative scarcity of Philippine research on ICT-based and learning cycle interventions) in the existing literature. Second, regarding overall effectiveness, innovative instructional strategies as a whole produced a large, statistically significant advantage over conventional instruction ($g = 1.12$), affirming the broad value of moving beyond lecture-based delivery in chemistry classrooms. Third, regarding publication bias, both the fail-safe N analysis and the Begg-Mazumdar test suggested that this overall finding is unlikely to be substantially compromised by selective publication, lending confidence to the robustness of the pooled estimate. Fourth, regarding moderators, strategy type and grade level were both statistically significant predictors of effect size magnitude, with learning cycle models and ICT-based strategies producing the largest gains and high school learners benefiting more than college learners, while duration showed a suggestive but not statistically confirmed advantage for longer interventions, and country-level differences were best explained by the uneven distribution of strategy types across national subsamples rather than by any independent national effect.

Taken as a whole, these results extend prior single-strategy meta-analyses (Hu et al., 2022; Rahman & Lewis, 2020; Santos & Prudente, 2022; Sugano & Nabua, 2020) by offering a directly comparative, cross-strategy account of instructional effectiveness in chemistry education, one that explicitly incorporates the substantial, often overlooked body of Philippine graduate research alongside international peer-reviewed studies. In doing so, this study offers both a validation of the broader constructivist turn in science education and a more fine-grained roadmap for where future instructional investment, teacher training, and primary research are likely to yield the greatest returns for chemistry learners.

Implications for Practice, Policy, and Future Research

Several practical implications follow from the pattern of results reported above. For classroom-level practice, the clear ordering of strategy categories by effect size, learning cycle models and ICT-based strategies at the top, followed by game/art-based and metacognitive approaches, then cooperative and contextualized learning, and finally programmed and modular instruction, offers chemistry teachers a rough prioritization heuristic when deciding where to direct limited planning time and professional development effort. Teachers working in contexts with reasonable access to computers or mobile devices, even intermittent access, may find that even modest integration of simulations or structured web-based discussion yields disproportionately large returns relative to the effort invested, particularly for topics such as atomic structure, chemical bonding, or reaction mechanisms that are difficult to observe directly. Teachers without such access are not without effective options: the moderate-to-large effects observed for cooperative and contextualized learning, including Cecilia et al.'s (2020) kitchen-resource intervention, indicate that restructuring existing lecture time around structured peer collaboration and locally available materials can produce meaningful gains without new capital investment.

For teacher education programs, the strong and consistent performance of learning cycle models across multiple countries and contexts (Jack, 2017; Opara & Waswa, 2013; Suardana et al., 2018; Suwito et al., 2020; Uyanik, 2016) suggests that pre-service chemistry teacher preparation should treat structured inquiry-cycle lesson design, rather than lecture-and-demonstration formats, as the default instructional model to be taught and practiced, with programmed instruction and other supplementary strategies positioned as complements rather than substitutes. This recommendation echoes Simonson's (2023) broader case for process-oriented, guided-inquiry learning (POGIL)

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as a default instructional stance across science disciplines, not merely an occasional enrichment activity reserved for well-resourced classrooms.

For education policymakers and curriculum developers, particularly within the Philippine Department of Education and Commission on Higher Education systems, the pronounced gap between the volume of Philippine research on programmed and modular instruction and the comparatively larger effects documented internationally for learning cycle and ICT-based strategies suggests a concrete research and development priority. Funding agencies and graduate programs that have historically supported thesis research on modular and programmed instructional materials might consider redirecting a portion of that support toward rigorous, well-powered studies of learning cycle models and digitally mediated instruction adapted to Philippine classroom conditions, including studies that explicitly test low-bandwidth or offline-capable digital tools suited to schools with limited internet infrastructure. Such a redirection would help close the evidence gap identified in the country-level moderator analysis, in which the Philippine subsample's comparatively smaller pooled effect appeared attributable to its concentration in less powerful strategy categories rather than any deficiency in Philippine educational contexts themselves.

Finally, for the research community, this synthesis highlights several specific directions for future primary and meta-analytic work. Within-category heterogeneity remained substantial even after subgroup analysis, indicating that factors not modeled here, such as teacher experience and training, class size, fidelity of implementation, and the specific chemistry topic being taught, likely account for meaningful additional variance in outcomes. Future studies would benefit from more consistent and detailed reporting of these implementation characteristics to enable finer-grained moderator analyses. Additionally, given that game/art-based instruction and metacognitive strategies were represented by only two and one studies respectively in this synthesis, despite promising individual effect sizes, these categories in particular warrant expanded primary research attention before strong conclusions about their relative effectiveness can be drawn with confidence.

Conclusion:

This meta-analysis synthesized twenty-two studies examining the effectiveness of innovative instructional strategies, spanning game- and art-based instruction, programmed and modular instruction, cooperative and contextualized learning, ICT-based and simulation instruction, learning cycle models, and metacognitive strategies, on students' academic achievement in chemistry.

The overall pooled random-effects estimate indicated a large, statistically significant advantage for innovative instructional strategies over conventional lecture-based instruction, with substantial heterogeneity that was meaningfully explained by strategy type, grade level, and, to a lesser extent, intervention duration and country. Learning cycle models and ICT-based strategies emerged as the most consistently powerful interventions, while programmed and modular instruction, though still beneficial, produced comparatively smaller gains. Publication bias analyses suggested that these findings are reasonably robust and unlikely to be substantially driven by selective reporting.

These findings carry several implications. For classroom teachers, the results suggest that where resources and training permit, structured inquiry-based approaches such as the 5E and 7E learning cycles, or well-designed simulations and digital tools, are likely to yield the greatest achievement benefits, while modular and self-paced materials remain a reasonable, lower-cost alternative in more constrained settings. For curriculum designers and teacher educators, the pronounced advantage observed among high school learners, combined with the near-significant benefit of sustained implementation, suggests that instructional innovation should be embedded systematically across the secondary chemistry curriculum rather than treated as a supplementary or one-off enrichment activity.

For policymakers, particularly within the Philippine basic education system, the relatively modest effect sizes associated with the dominant strategy type in the local research base, programmed and modular instruction, alongside the strong performance of underrepresented categories such as learning cycle models and ICT-based strategies internationally, point toward a clear research and investment priority: expanding local research capacity and infrastructure to test and scale inquiry-based and technology-integrated chemistry instruction.

This study is not without limitations. The relatively small number of studies within several strategy categories (particularly game/art-based and metacognitive strategies) limits the precision and generalizability of those specific subgroup estimates, and the reliance on graduate theses alongside peer-reviewed studies introduces some variability in methodological rigor and reporting completeness across the included research. Future meta-analytic work would benefit from a larger, more balanced pool of studies within each strategy category, formal risk-of-bias assessment of individual primary studies, and closer attention to additional moderators such as teacher experience, class size, and fidelity of implementation. Continued primary research, particularly rigorous, well-documented studies of ICT-based and learning cycle interventions within the Philippine context, remains essential to strengthening the evidence base that guides instructional decision-making in chemistry education.

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