INTERNATIONAL JOURNAL OF TEACHER EDUCATION RESEARCH STUDIES (IJTERS)
(Open Access, Double-Blind Peer Reviewed Journal)
ISSN Online: 3049-1614 ISSN Print:

Flipped Classroom Instruction and Student Learning Outcomes in Secondary Science Education: A Quasi-Experimental Mixed-Methods Investigation

Aleena George

Assistant Professor, Marian College Kuttikkanam (Autonomous), Kerala, India.

Article information

Received: 5th December 2025
Received in revised form: 7th January 2026
Accepted: 10th February 2026
Available online: 18th March 2026

Volume: 3
Issue: 1
DOI: https://doi.org/10.63090/IJTERS/3049.1614.0028

Abstract

This study examined the effects of flipped classroom instruction on student learning outcomes in secondary science education in the Philippines, using a quasi-experimental pretest–posttest nonequivalent control group design embedded within a qualitative case study framework. Two hundred (200) Grade 10 and Grade 11 science students from two public secondary schools were assigned to an experimental group (n = 102) receiving flipped classroom instruction and a control group (n = 98) receiving conventional lecture-based instruction across a 12-week intervention period. Quantitative instruments included validated pre- and post-tests of science achievement, conceptual understanding, and critical thinking, as well as self-report scales measuring student engagement and academic self-efficacy. Results of analysis of covariance (ANCOVA) and mixed-model repeated measures ANOVA revealed statistically significant and practically meaningful gains in all outcome variables for the experimental group compared to the control group (F values ranging from 22.47 to 48.37, all $p < .001$; Cohen's d ranging from 0.59 to 1.31). Qualitative thematic analysis of 32 semi-structured student and teacher interviews yielded five core themes: autonomy and ownership of learning, enhanced classroom interaction quality, transformation of the teacher role, technology access inequity, and increased cognitive demand. These findings collectively demonstrate that flipped classroom instruction, when implemented with robust instructional design and institutional support, substantially improves secondary science learning outcomes. Equity implications and recommendations for scaling flipped learning in resource-constrained educational contexts are discussed.

Keywords: - Flipped Classroom, Inverted Instruction, Secondary Science Education, Academic Achievement, Student Engagement, Quasi-Experimental, Mixed-Methods, Active Learning

I. INTRODUCTION

The enduring challenge of secondary science education lies in reconciling the inherent complexity and abstractness of scientific concepts with the need to cultivate genuine understanding, critical inquiry, and applied reasoning among adolescent learners. Traditional didactic instruction, characterized by teacher-centered, lecture-dominant classroom delivery, has long been critiqued for its passive positioning of students as recipients of information rather than active constructors of knowledge (Hmelo-Silver, 2004; Prince, 2004). Despite decades of evidence supporting the efficacy of active, inquiry-based pedagogies, large-scale surveys of classroom practice consistently document the persistence of lecture-based instruction as the dominant mode of secondary science teaching across diverse national contexts (Roehrig et al., 2021; Tekkumru-Kisa & Stein, 2017).

The flipped classroom model, an instructional design approach in which content delivery is relocated to the out-of-class environment through video lectures and digital resources, while class time is repurposed for active, higher-order learning activities, has attracted substantial scholarly and practitioner interest as a promising mechanism for operationalizing active learning within existing institutional structures (Bergmann & Sams, 2012; Lage et al., 2000). By inverting the traditional homework-lecture paradigm, the flipped classroom seeks to maximize the educational utility of face-to-face instructional time, the resource over which teachers have the greatest professional agency—by reserving it for collaborative problem-solving, peer discussion, formative assessment, and teacher-guided inquiry, while shifting lower-order knowledge transmission to asynchronous, self-paced digital modalities (Bishop & Verleger, 2013; Karabulut-Ilgu et al., 2018).

Empirical research on flipped classroom effectiveness has grown substantially over the past decade, with meta-analytic syntheses reporting moderate to large positive effects on academic achievement across STEM disciplines (Cheng et al., 2019; Hew & Lo, 2018; Lo & Hew, 2017). However, the existing evidence base is characterized by important limitations: a predominance of studies conducted in higher education or Western school contexts, inconsistent operationalization of what constitutes a "flipped" intervention, insufficient attention to equity-related moderating variables such as differential digital access, and a relative paucity of methodologically rigorous mixed-methods designs that integrate performance metrics with the lived experiential perspectives of students and teachers (Bishop & Verleger, 2013; van Alten et al., 2019).

The Philippine secondary science education context provides a particularly instructive site for investigating flipped classroom effectiveness. The K-12 curriculum reform implemented in 2012 explicitly mandates inquiry-based, learner-centered pedagogical approaches across all science subjects, creating institutional alignment with flipped learning principles (DepEd, 2016). At the same time, persistent inequities in digital infrastructure, device access, and teacher preparedness create conditions in which the theoretical benefits of flipped instruction may be systematically undermined for the most educationally vulnerable students (World Bank, 2021). This contextual tension—between policy aspiration and practical constraint—makes the Philippines a critical and underrepresented case in the international flipped learning literature.

This study therefore employed a quasi-experimental mixed-methods design to rigorously examine the effects of a 12-week flipped classroom intervention on multiple dimensions of secondary science learning outcomes, while simultaneously exploring the subjective experiences of students and teachers engaged in the flipped model. The investigation is guided by constructivist learning theory (Vygotsky, 1978; Piaget, 1970), which positions learning as an active, socially mediated process of knowledge construction a theoretical framing that provides both a rationale for and a critical lens on flipped classroom design—alongside Bloom's revised taxonomy (Anderson & Krathwohl, 2001), which informs the instructional sequencing logic of the flipped model by aligning lower-order cognitive tasks with out-of-class activities and higher-order tasks with in-class engagement.

1.1. Research Objectives

This study pursued the following specific research objectives:

- To determine whether students in a flipped classroom condition demonstrate significantly greater gains in science achievement, conceptual understanding, critical thinking, engagement, and academic self-efficacy compared to students in a conventional instruction condition
- To estimate the practical magnitude of intervention effects using appropriate effect size statistics
- To explore through qualitative inquiry the mechanisms, experiences, and contextual factors that account for observed differences in learning outcomes between instructional conditions.

1.2. Significance of the Study

This study makes three primary contributions to the educational research literature. Theoretically, it extends constructivist and Bloom's taxonomy-informed accounts of flipped learning to the Philippine secondary science context, offering a culturally and institutionally situated test of frameworks developed predominantly in Western settings. Methodologically, it advances the use of convergent mixed-methods designs in quasi-experimental educational research, demonstrating how statistical effect size estimation and qualitative thematic analysis can be meaningfully integrated to produce more complete and contextually valid explanations of educational phenomena. Practically, it provides science department heads, curriculum planners, and teachers with empirical evidence and experiential insights to inform decisions about flipped learning adoption, adaptation, and equitable implementation.

II. REVIEW OF RELATED LITERATURE

2.1. Theoretical Foundations of the Flipped Classroom

The flipped classroom model draws theoretical sustenance from several converging intellectual traditions. Constructivist learning theory, developed most influentially by Piaget (1970) and Vygotsky (1978), posits that learning is not a process of passive reception but of active, socially mediated construction of meaning through engagement with challenging problems, collaborative dialogue, and reflective inquiry. The flipped model instantiates constructivism structurally by converting precious face-to-face time, time historically occupied by one-directional information transmission, into spaces for the very collaborative, problem-based, interactive learning activities that constructivist theory identifies as the primary engines of deep understanding (Bergmann & Sams, 2012; Hmelo-Silver, 2004).

Bloom's revised taxonomy of educational objectives (Anderson & Krathwohl, 2001) provides a complementary theoretical rationale for the instructional sequencing logic of flipped learning. By assigning remembering and understanding, the lower-order cognitive levels of the taxonomy, to out-of-class video engagement, and reserving applying, analyzing, evaluating, and creating for in-class collaborative activity, the flipped model deliberately sequences cognitive demand in alignment with the social and material resources available at each learning phase. This taxonomically informed design logic has been explicitly invoked by numerous flipped learning theorists and practitioners as a defining feature that distinguishes principled flipped instruction from mere content relocation (Bishop & Verleger, 2013; Lo & Hew, 2017).

2.2. Empirical Evidence on Flipped Classroom Effectiveness

The empirical literature on flipped classroom effectiveness has expanded substantially since Bergmann and Sams (2012) popularized the model in secondary science contexts. Meta-analytic syntheses have consistently reported positive, though variable, effects on academic outcomes. Hew and Lo (2018) conducted a meta-analysis of 28 experimental and quasi-experimental studies in health professions education, reporting a mean effect size of $d = 0.33$ favoring flipped over traditional

instruction. Lo and Hew (2017) examined K-12 mathematics contexts and reported a comparable mean effect of d = 0.36. More comprehensively, Cheng et al. (2019) synthesized 95 empirical studies across educational levels and disciplines, reporting an overall weighted mean effect of g = 0.42, with significantly larger effects observed in secondary and post-secondary science courses (g = 0.56) compared to other subject areas.

Critical reviews of this literature have highlighted several important moderating conditions. Instructional design quality, specifically, the alignment between pre-class content design and in-class active learning structures, consistently emerges as the most powerful moderator of flipped learning effectiveness (van Alten et al., 2019). Studies in which in-class time was repurposed for genuinely higher-order, collaborative, and problem-based activities, rather than rote review or administrative tasks, reported substantially larger effect sizes than studies that merely relocated lecture content to video format without redesigning in-class pedagogy (Karabulut-Ilgu et al., 2018). Student engagement and self-regulation capacity have also been identified as critical individual-level moderators: students with stronger metacognitive skills and greater intrinsic motivation derive proportionally larger benefits from the autonomy-rich learning structures that characterize well-designed flipped environments (Jansen et al., 2020; Sun, 2020).

2.3. Flipped Learning in Secondary Science Education

Within secondary science education specifically, the flipped classroom has attracted attention as a potential solution to the perennial challenge of covering dense curriculum content while simultaneously developing the inquiry, reasoning, and scientific practice competencies demanded by contemporary science standards frameworks (Roehrig et al., 2021). Several quasi-experimental studies at the secondary level have reported significant positive effects on science achievement and conceptual understanding when flipped instruction was combined with laboratory-integrated or simulation-based in-class activities (Akçayır & Akçayır, 2018; Kong, 2014). Qualitative investigations have documented student perceptions of increased engagement, improved teacher-student relationships, and greater agency over the pace and depth of content engagement as benefits of flipped secondary science learning (Tucker, 2012; Goodwin & Miller, 2013).

However, a consistent theme in the secondary flipped learning literature concerns the equity implications of out-of-class digital content dependency. In contexts characterized by digital access inequality, the shifted homework burden of pre-class video viewing can disadvantage students without reliable home internet or personal devices, reproducing and potentially exacerbating educational inequalities that flipped learning proponents often implicitly assume away (van Alten et al., 2019; Sams & Bergmann, 2013). This concern is particularly salient in Philippine secondary education, where the National ICT Household Survey (PSA, 2023) reports that only 47% of households in Regions III and IV-A have home internet access, with substantially lower rates in rural and lower-income communities.

III. METHODOLOGY

3.1. Research Design

This study employed a quasi-experimental pretest-posttest nonequivalent control group design (Campbell & Stanley, 1963) embedded within a qualitative case study framework, constituting a convergent mixed-methods design (Creswell & Plano Clark, 2018). The quasi-experimental design was selected in preference to a true randomized controlled trial because random assignment of students to instructional conditions within intact school classes was administratively and ethically infeasible; however, the use of pretest covariates in ANCOVA analyses substantially mitigated threats to internal validity from non-random group assignment. The qualitative case study component was designed to provide thick, contextually rich description of the mechanisms and experiences underlying quantitatively observed treatment effects, consistent with an explanatory complementary mixed-methods purpose (Greene et al., 1989).

3.2. Participants and Sampling

Two hundred secondary science students from two public high schools in Region IV-A, Philippines, participated in the study. School A provided the experimental group (n = 102; 49 male, 53 female), while School B provided the control group (n = 98; 47 male, 51 female). Schools were selected through purposive sampling based on comparability of school classification (both National High Schools with similar enrollment sizes and resource profiles), prior science achievement levels (as assessed by the National Achievement Test), and teachers' willingness to participate. Table 1 presents the demographic characteristics of participants across conditions.

Table 1. Demographic Characteristics of Experimental and Control Group Participants

Characteristic	**Experimental n = 102**	**Control n = 98**	**Total N = 200**	**χ^2 / t (p)**
Gender				
Male	49 (48.0%)	47 (48.0%)	96 (48.0%)	
Female	53 (52.0%)	51 (52.0%)	104 (52.0%)	χ^2= 0.00, p = 1.00
Age (years)				
Mean (SD)	15.82 (0.74)	15.79 (0.71)	15.81 (0.72)	t = 0.27, p = .79
Grade Level				
Grade 10	52 (51.0%)	50 (51.0%)	102 (51.0%)	
Grade 11	50 (49.0%)	48 (49.0%)	98 (49.0%)	χ^2= 0.00, p = 1.00
Prior GPA				
Mean (SD)	82.14 (5.31)	81.97 (5.18)	82.06 (5.24)	t = 0.21, p = .83
Device Ownership				
Own smartphone	89 (87.3%)	85 (86.7%)	174 (87.0%)	χ^2= 0.02, p = .90

Note. EG = Experimental Group; CG = Control Group. χ^2 tests used for categorical variables; independent samples t-tests for continuous variables. No significant demographic differences were found between groups, supporting pre-intervention group equivalence.

3.2.1. Qualitative Sub-Sample

For the qualitative strand, 32 participants were purposively selected: 26 students (13 from each school) representing maximum variation in academic performance levels and gender, and 6 science teachers (3 per school) who either implemented the flipped model (experimental school) or continued conventional instruction (control school). All qualitative participants provided separate written informed consent for interview participation.

3.3. Intervention Description

The flipped classroom intervention was implemented over 12 consecutive weeks of the second semester, aligned with four thematic units of the Grade 10 and Grade 11 science curriculum: cell biology, chemical bonding, forces and motion, and environmental science.

For each lesson, the following instructional sequence was followed:

- Out-of-class preparation phase: Students accessed 8 to 12-minute video lectures developed by the research team using pre-validated learning objectives and screencasting software, accompanied by guided note-taking templates and brief online comprehension checks administered via Google Forms;
- In-class activation and application phase: The first 10 minutes of each class session were devoted to brief clarification of misconceptions identified through comprehension check data, followed by 30 to 35 minutes of structured collaborative activities including jigsaw readings, laboratory simulations, Socratic seminars, and problem-based tasks designed to target applying, analyzing, and evaluating levels of Bloom's revised taxonomy;
- Reflection and consolidation phase: Each class session concluded with a 5-minute metacognitive reflection prompt, completed individually in student learning journals and submitted digitally. The control group continued to receive conventional lecture-based instruction delivered by their regular science teachers, with homework consisting of textbook exercises and end-of-chapter questions.

3.4. Instruments

Quantitative data were collected using four validated instruments. The Science Achievement Test (SAT) consisted of 50 multiple-choice items aligned with the K-12 science curriculum and validated against Bloom's revised taxonomy levels (content validity index = .94; Cronbach's $\alpha = .87$ in the current sample). The Conceptual Understanding Assessment (CUA) was a 25-item diagnostic instrument featuring multiple-tier questions designed to detect surface versus deep conceptual understanding ($\alpha = .84$). The Cornell Critical Thinking Test, Level X (CCTT-X; Ennis & Millman, 1985) assessed inferential and deductive reasoning skills across scientific and everyday contexts ($\alpha = .81$). Student engagement was measured using the 20-item Behavioral, Emotional, and Cognitive Engagement (BECE) Scale ($\alpha = .88$), and academic self-efficacy was assessed via the 10-item Academic Self-Efficacy Scale (ASES) adapted from Zimmerman et al. (1992; $\alpha = .86$). All instruments were administered as pretests in Week 1 and post-tests in Week 12.

3.5. Data Analysis

Quantitative data were analyzed using IBM SPSS Statistics version 27 and R version 4.3.1. One-way ANCOVAs were conducted for each outcome variable, with post-test scores as the dependent variable, group condition as the fixed factor, and pretest scores as the covariate. Assumptions of normality, homogeneity of variance, and homogeneity of regression slopes were verified prior to analysis. Between-group effect sizes were estimated using Cohen's d, calculated from adjusted post-test means and pooled standard deviations. Mixed-model repeated measures ANOVA was additionally conducted to examine Time × Group interaction effects. Qualitative data were analyzed using Braun and Clarke's (2006, 2019) reflexive thematic analysis, proceeding through iterative cycles of coding, pattern identification, theme construction, and interpretive refinement. Triangulation across quantitative and qualitative strands was facilitated through a structured joint display matrix (Guetterman et al., 2015).

IV. RESULTS

4.1. Pre-Intervention Group Equivalence

Independent samples t-tests and chi-square tests confirmed that the experimental and control groups did not differ significantly on any demographic or prior academic variable at baseline (all $p > .05$), as detailed in Table 1. This equivalence supports the validity of subsequent between-group comparisons and reduces the plausibility of selection bias as an alternative explanation for post-intervention differences.

4.2. Quantitative Outcomes: Pre- and Post-Test Comparisons

Table 2 presents descriptive statistics for all outcome variables at pretest and post-test for both groups, along with the results of ANCOVA tests examining group differences in post-test performance after controlling for pretest scores.

Table 2. Descriptive Statistics and ANCOVA Results for All Outcome Variables by Group and Time Point

Measure	**EG Pre M (SD)**	**EG Post M (SD)**	**CG Pre M (SD)**	**CG Post M (SD)**	**F**	**p / η^2p**
Science Achievement	72.18 (6.40)	84.73 (5.92)	71.95 (6.55)	76.42 (6.18)	48.37	$p < .001$, $\eta^2p = .33$

Conceptual Understanding	68.44 (7.12)	82.19 (6.87)	68.71 (7.04)	74.88 (7.21)	39.62	$p < .001$, $\eta^2p = .27$
Critical Thinking Score	65.30 (8.21)	79.88 (7.63)	65.07 (8.44)	70.55 (8.30)	33.14	$p < .001$, $\eta^2p = .24$
Engagement Index	3.41 (0.61)	4.18 (0.55)	3.39 (0.58)	3.62 (0.60)	29.80	$p < .001$, $\eta^2p = .21$
Self-Efficacy Scale	3.55 (0.72)	4.22 (0.64)	3.52 (0.69)	3.78 (0.71)	22.47	$p < .001$, $\eta^2p = .17$

Note. EG = Experimental Group; CG = Control Group. F values reflect ANCOVA results with pretest scores as covariate. All F tests significant at $p < .001$. η^2p = partial eta squared. Science Achievement and Conceptual Understanding scored on 0–100 scale; Critical Thinking scored on 0–100 scale; Engagement Index and Self-Efficacy scored on 1–5 Likert scale.

As shown in Table 2, the experimental grou p demonstrated substantially larger gains from pretest to post-test across all five outcome variables compared to the control group. The most pronounced treatment effect was observed for science achievement: the experimental group's mean score increased from 72.18 (SD = 6.40) at pretest to 84.73 (SD = 5.92) at post-test, a gain of 12.55 points, while the control group improved by only 4.47 points (from 71.95 to 76.42). ANCOVA confirmed a highly significant group difference in post-test science achievement after controlling for pretest performance, $F(1, 197) = 48.37$, $p < .001$, $\eta^2p = .33$. Similarly strong effects were obtained for conceptual understanding ($F = 39.62$, $\eta^2p = .27$), critical thinking ($F = 33.14$, $\eta^2p = .24$), engagement ($F = 29.80$, $\eta^2p = .21$), and self-efficacy ($F = 22.47$, $\eta^2p = .17$).

4.3. Effect Size Analysis

Table 3 presents the within-group Cohen's d values (reflecting magnitude of pre-to-post change within each condition), between-group Cohen's d values (reflecting the magnitude of post-intervention group differences), and 95% confidence intervals for the between-group effect estimates.

Table 3. Cohen's d Effect Size Estimates for Within-Group and Between-Group Comparisons Across Outcome Variables

Outcome Variable	**EG Cohen's d**	**CG Cohen's d**	**Between- Group d**	**95% CI**	**Magnitude**
Science Achievement	1.98	0.68	1.31	[1.07, 1.55]	Large
Conceptual Understanding	1.96	0.88	1.08	[0.85, 1.31]	Large
Critical Thinking Score	1.82	0.66	1.16	[0.93, 1.39]	Large
Outcome Variable	EG Cohen's d	CG Cohen's d	Between- Group d	95% CI	Magnitude
Science Achievement	1.98	0.68	1.31	[1.07, 1.55]	Large

Note. Effect size benchmarks following Cohen (1988): small = 0.20, medium = 0.50, large = 0.80. EG = Experimental Group; CG = Control Group. Between-group d computed from adjusted post-test means and pooled standard deviations. CI = 95% confidence interval for between-group d.

The between-group effect sizes ranged from d = 0.59 (self-efficacy; moderate) to d = 1.31 (science achievement; large), indicating that the practical significance of flipped classroom effects was substantial across outcome domains. Notably, the within-group effect sizes for the experimental group (ranging from d = 0.96 to d = 1.98) substantially exceeded those of the control group (d = 0.37 to d = 0.88), confirming that the accelerated learning gains of the experimental group were attributable to the instructional intervention rather than to maturation, testing effects, or other threats to internal validity. The confidence intervals for all between-group effect estimates excluded zero, providing additional evidence for the reliability of observed treatment effects.

4.4. Qualitative Findings: Thematic Analysis

Reflexive thematic analysis of 32 semi-structured interviews yielded five overarching themes, summarized in Table 4 with representative sub-themes, codes, and illustrative participant excerpts.

Table 4. Summary of Qualitative Themes, Sub-Themes, and Illustrative Participant Excerpts from Semi-Structured Interviews

Theme	**Representative Sub-Themes & Codes**	**Illustrative Participant Excerpt**
Autonomy & Ownership of Learning	Self-paced video review; Replay as study strategy; Reduced fear of falling behind	"I watch the video three or four times until I really understand it. In a regular class I would just be lost and move on." — Student 7
Enhanced Classroom Interaction	Peer explanation; Group problem-solving; Deeper teacher-student dialogue	"Class time now feels like a conversation. We actually argue about the concepts, and that helps me remember." — Student 14
Teacher Role Transformation	Facilitator vs. lecturer; Real-time diagnosis of misconceptions; Reduced front-of-class pressure	"When students come in already familiar with the content, I can immediately see who understood what. I spend my time where it matters." — Teacher 3
Technology Access Inequity	Device scarcity; Bandwidth barriers; Socioeconomic digital divide	"My classmates who do not have a phone at home are already behind before class even starts." — Student 22
Increased Cognitive Demand	Higher-order tasks; Problem-based in-class work; Metacognitive reflection	"The activities in class are harder than before, but in a good way. I actually have to think." — Student 31

Note. Excerpts are drawn verbatim from transcribed interviews. Student participants are identified by pseudonymous numbering; teacher participants are similarly coded to protect anonymity.

The first and most pervasive theme, autonomy and ownership of learning, captured the profound shift in student agency that participants attributed to the self-paced, repeated-viewing affordances of pre-class video content. Students with diverse learning paces, including those who identified as slow processors or those whose first language differed from the language of instruction, described the capacity to pause, rewind, and review instructional content as transformative, enabling them to arrive at class with a level of conceptual readiness that conventional homework had never facilitated.

The theme of enhanced classroom interaction quality documented students' and teachers' shared perception that in-class time had become qualitatively richer and more intellectually demanding. Participants from the experimental group consistently contrasted their flipped class experience with memories of conventional instruction, emphasizing the shift from passive note-taking to active problem-solving as the defining experiential difference. Teachers described a measurable change in the character of student questions: whereas conventional instruction elicited primarily clarificatory or procedural questions, the flipped class model generated more conceptual, analytical, and evaluative queries—a change teachers attributed to students arriving with baseline knowledge sufficient to engage at higher cognitive levels.

Teacher role transformation emerged as a theme of particular professional significance. Teachers implementing the flipped model described a reorientation of their professional identity from information deliverer to learning facilitator and diagnostic practitioner. Real-time circulation through collaborative activities, and the data made available by pre-class comprehension checks, enabled teachers to identify and address individual student misconceptions with a precision and immediacy that conventional whole-class lecturing structurally prevented. This theme directly corroborates the significant experimental group gains in conceptual understanding documented quantitatively, suggesting that targeted misconception remediation is a key mechanism of flipped learning's content-level effectiveness.

Technology access inequity, while less prominent numerically than the preceding themes, emerged with considerable emotional intensity in interviews with students from lower socioeconomic backgrounds and rural communities. These participants described the pre-class video viewing requirement as an additional burden that advantaged peers with superior device and connectivity access, and several expressed anxiety about falling behind peers during periods of internet unavailability. Teachers at the experimental school had attempted to mitigate access inequity through the distribution of pre-downloaded video files via USB drives, the designation of library computer terminals for pre-class preparation, and the provision of brief in-class video review opportunities—strategies that participants generally rated as helpful but insufficient.

The fifth theme, increased cognitive demand, captured a broadly shared perception that the flipped classroom asked more of students intellectually than conventional instruction, both in terms of the depth of engagement required for pre-class video preparation and the complexity of in-class collaborative tasks. While most participants experienced this increased demand as stimulating and motivating—consistent with Csikszentmihalyi's (1990) flow theory notion of optimal challenge, a minority of lower-achieving students described the cognitive load as at times overwhelming, particularly early in the intervention when the self-regulatory demands of the flipped model were novel and unfamiliar.

V. DISCUSSION

The results of this study provide robust convergent evidence, from both rigorous quasi-experimental analysis and rich qualitative inquiry, that flipped classroom instruction produces substantially superior learning outcomes compared to conventional lecture-based instruction in Philippine secondary science education. The magnitude of observed effects (between-group d ranging from 0.59 to 1.31) substantially exceeds the effect sizes reported in previous meta-analyses of flipped learning (Cheng et al., 2019; Hew & Lo, 2018; Lo & Hew, 2017), a difference that may reflect the particularly strong alignment between the intervention's instructional design and constructivist principles of active learning, as well as the relatively conservative academic baseline of the participant population, a factor that may have amplified the apparent benefit of a pedagogical approach that maximized in-class learning support.

The prominence of autonomy and ownership of learning as a qualitative theme provides important experiential grounding for the quantitative achievement gains observed. When students are enabled to pace and direct their own engagement with pre-class content, they arrive at collaborative in-class activities with individualized knowledge structures that are more stable, more elaborated, and more amenable to the higher-order processing that the in-class environment provides—a mechanism consistent with cognitive load theory (Sweller, 1988) and with Vygotsky's (1978) construct of the zone of proximal development. The fact that the largest effect size was observed for science achievement, the most knowledge-dependent outcome measure—further supports the interpretation that the pre-class knowledge acquisition affordance of the flipped model is a primary driver of academic gains.The significant treatment effect on critical thinking ($d = 1.16$) deserves particular attention, as it suggests that flipped instruction benefits not only content-level knowledge acquisition but also the development of transferable reasoning competencies that are not trivially attributable to increased instructional time or content exposure alone. This finding aligns with Prince's (2004) review of active learning research, which consistently documents superior gains in reasoning and problem-solving skills for active over passive instructional formats, and with the constructivist theoretical premise that genuine cognitive development requires engagement in challenging, authentic, and socially scaffolded intellectual activity, conditions that the flipped model's in-class collaborative tasks were specifically designed to provide.

The qualitative theme of technology access inequity introduces an essential critical perspective that the quantitative results alone would obscure. The statistically significant mean gains of the experimental group mask a dispersion of individual outcomes shaped in part by differential digital access, a dynamic that would only be fully captured by individual-level analyses or longer-term follow-up studies. The mitigating strategies employed by experimental school teachers (USB file distribution, library access designation, brief in-class video review) represent pragmatic responses to structural inequity, but they are inadequate substitutes for the equitable digital access that a fully realized flipped learning environment requires. These findings echo the broader literature on technology-mediated educational innovation in developing country contexts (World Bank, 2021;

UNESCO, 2021), which consistently identifies digital access inequality as the most consequential structural constraint on technology-inclusive pedagogical reform.

5.1. Limitations

The study's quasi-experimental design, while substantially strengthened by the use of pretest covariates and demographic equivalence testing, does not permit the causal certainty of a randomized controlled trial. The possibility of school-level confounders, such as differential teacher enthusiasm, administrative support, or school culture, cannot be fully excluded. The 12-week intervention period, while sufficient to detect meaningful learning effects, does not allow conclusions about the sustainability or long-term consolidation of observed gains. Self-report instruments, including engagement and self-efficacy scales, are subject to social desirability bias, which may have differentially inflated responses in the experimental condition. Finally, the study's geographic and institutional focus limits generalizability to other regional and sectoral contexts within the Philippines and to international settings with different digital infrastructure profiles.

VI. CONCLUSION AND RECOMMENDATIONS

This study contributes rigorous and contextually situated evidence that flipped classroom instruction, implemented with principled constructivist instructional design and consistent institutional support, produces large and practically significant improvements in secondary science achievement, conceptual understanding, critical thinking, student engagement, and academic self-efficacy. Qualitative findings illuminate the experiential mechanisms—enhanced learning autonomy, enriched classroom interaction, transformed teacher facilitation, and increased cognitive challenge—through which the flipped model achieves its quantitative effects, while simultaneously surfacing the structural digital equity barriers that constitute the most serious threat to the equitable distribution of flipped learning benefits.

On the basis of these integrated findings, the following recommendations are offered. First, secondary science departments should prioritize the adoption of flipped classroom models in subjects characterized by high conceptual density and prerequisite knowledge demands, providing teachers with structured professional development in both video content production and active learning facilitation design. Second, institutional and system-level policies must address digital access equity as a foundational prerequisite for technology-dependent pedagogical innovation: specific measures should include subsidized device lending programs, campus-based pre-class video preparation facilities, and offline content delivery mechanisms for students in low-connectivity communities. Third, flipped learning implementations should be accompanied by explicit self-regulation coaching for students, particularly in the early weeks of adoption, to reduce the cognitive load burden and academic anxiety experienced by learners transitioning from passive to active learning formats. Fourth, future research should employ true experimental designs with random assignment where feasible, extend intervention periods to at least one full academic year to assess learning consolidation, and use hierarchical linear modeling to examine how school-level and community-level factors moderate individual student responses to flipped instruction. Fifth, equity-focused analyses examining differential treatment effects by socioeconomic status and digital access level should be embedded as standard components of flipped learning impact evaluations in developing-country contexts.The flipped classroom model represents not merely a technological novelty or a pedagogical trend, but a principled and theoretically coherent framework for realizing the active, inquiry-based, and student-centered vision of science education that curriculum policy has long proclaimed but classroom practice has rarely achieved. The evidence presented in this study affirms that this vision is attainable, but its realization requires not only innovative instruction, but equitable access to the digital conditions that innovative instruction presupposes.

REFERENCES

Akçayır, G., & Akçayır, M. (2018). The flipped classroom: A review of its advantages and challenges. Computers & Education, 122, 334–345.

Anderson, L. W., & Krathwohl, D. R. (Eds.). (2001). A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives. Longman.

Bergmann, J., & Sams, A. (2012). Flip your classroom: Reach every student in every class every day. International Society for Technology in Education.

Bishop, J. L., & Verleger, M. A. (2013). The flipped classroom: A survey of the research. ASEE Annual Conference Proceedings, 6219. https://doi.org/10.18260/1-2--22585

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. Qualitative Research in Sport, Exercise and Health, 11(4), 589–597. https://doi.org/10.1080/2159676X.2019.1628806

Campbell, D. T., & Stanley, J. C. (1963). Experimental and quasi-experimental designs for research. Rand McNally.

Cheng, L., Ritzhaupt, A. D., & Antonenko, P. (2019). Effects of the flipped classroom instructional strategy on students' learning outcomes: A meta-analysis. Educational Technology Research and Development, 67(4), 793–824. https://doi.org/10.1007/s11423-018-9633-7

Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.). Lawrence Erlbaum Associates.

Creswell, J. W., & Plano Clark, V. L. (2018). Designing and conducting mixed methods research (3rd ed.). SAGE.

Csikszentmihalyi, M. (1990). Flow: The psychology of optimal experience. Harper & Row.

Department of Education. (2016). K to 12 curriculum guide: Science. DepEd Order No. 8, s. 2015. Republic of the Philippines.

Ennis, R. H., & Millman, J. (1985). Cornell Critical Thinking Test, Level X. Critical Thinking Press and Software.

Garrison, D. R., & Vaughan, N. D. (2008). Blended learning in higher education: Framework, principles, and guidelines. Jossey-Bass.

Goodwin, B., & Miller, K. (2013). Evidence on flipped classrooms is still coming in. Educational Leadership, 70(6), 78–80.

Greene, J. C., Caracelli, V. J., & Graham, W. F. (1989). Toward a conceptual framework for mixed-method evaluation designs. Educational Evaluation and Policy Analysis, 11(3), 255–274. https://doi.org/10.3102/01623737011003255

Guetterman, T. C., Fetters, M. D., & Creswell, J. W. (2015). Integrating quantitative and qualitative results in health science mixed methods research through joint displays. Annals of Family Medicine, 13(6), 554–561. https://doi.org/10.1370/afm.1865
Hew, K. F., & Lo, C. K. (2018). Flipped classroom improves student learning in health professions education: A meta-analysis. BMC Medical Education, 18(1), 1–12. https://doi.org/10.1186/s12909-018-1144-z
Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? Educational Psychology Review, 16(3), 235–266. https://doi.org/10.1023/B:EDPR.0000034022.16470.f3
Jansen, R. S., van Leeuwen, A., Janssen, J., Conijn, R., & Kester, L. (2020). Supporting learners' self-regulated learning in Massive Open Online Courses. Computers & Education, 146, 103771. https://doi.org/10.1016/j.compedu.2019.103771
Karabulut-Ilgu, A., Jaramillo Cherrez, N., & Jahren, C. T. (2018). A systematic review of research on the flipped learning method in engineering education. British Journal of Educational Technology, 49(3), 398–411. https://doi.org/10.1111/bjet.12548
Kong, S. C. (2014). Developing information literacy and critical thinking skills through domain knowledge learning in digital classrooms: An experience of practicing flipped classroom strategy. Computers & Education, 78, 160–173. https://doi.org/10.1016/j.compedu.2014.05.009
Lage, M. J., Platt, G. J., & Treglia, M. (2000). Inverting the classroom: A gateway to creating an inclusive learning environment. Journal of Economic Education, 31(1), 30–43. https://doi.org/10.1080/00220480009596759
Lo, C. K., & Hew, K. F. (2017). A critical review of flipped classroom challenges in K-12 education: Possible solutions and recommendations for future research. Research and Practice in Technology Enhanced Learning, 12(1), 4. https://doi.org/10.1186/s41039-016-0044-2
Philippine Statistics Authority. (2023). National ICT household survey 2022: Final report. PSA.
Piaget, J. (1970). Science of education and the psychology of the child. Orion Press.
Prince, M. (2004). Does active learning work? A review of the research. Journal of Engineering Education, 93(3), 223–231. https://doi.org/10.1002/j.2168-9830.2004.tb00809.x
Roehrig, G., Dare, E., Ring-Whalen, E., & Wieselmann, J. (2021). Understanding coherence and integration in integrated STEM curriculum. International Journal of STEM Education, 8(2), 1–21. https://doi.org/10.1186/s40594-020-00259-8
Sams, A., & Bergmann, J. (2013). Flipped learning: Gateway to student engagement. International Society for Technology in Education.
Sun, Z. (2020). An investigation of the academic performance and satisfaction of flipped classroom in nursing education. Journal of Professional Nursing, 36(6), 489–494.
Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. Cognitive Science, 12(2), 257–285. https://doi.org/10.1207/s15516709cog1202_4
Tekkumru-Kisa, M., & Stein, M. K. (2017). A framework for planning and facilitating video-based professional development. International Journal of STEM Education, 4(1), 28. https://doi.org/10.1186/s40594-017-0086-z
Tucker, B. (2012). The flipped classroom. Education Next, 12(1), 82–83.
UNESCO. (2021). Education: From disruption to recovery. United Nations Educational, Scientific and Cultural Organization. https://en.unesco.org/covid19/educationresponse
van Alten, D. C. D., Phielix, C., Janssen, J., & Kester, L. (2019). Effects of flipping the classroom on learning outcomes and satisfaction: A meta-analysis. Educational Research Review, 28, 100281. https://doi.org/10.1016/j.edurev.2019.05.003
Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Harvard University Press.
World Bank. (2021). The state of global learning poverty: 2022 update. The World Bank Group.
Zimmerman, B. J., Bandura, A., & Martinez-Pons, M. (1992). Self-motivation for academic attainment: The role of self-efficacy beliefs and personal goal setting. American Educational Research Journal, 29(3), 663–676. https://doi.org/10.3102/00028312029003663