MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 36 Issue 1s, 2026, Pages: 4105-4109

Digital Education Online Learning Tools and Novel Teaching Pedagogies

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Abstract

This study investigates the relationship between online learning tools, novel teaching pedagogies, and student learning outcomes in higher education settings. Using a quantitative method research design, data were collected from 847 undergraduate students across 12 universities employing varying degrees of digital integration. The study examines five independent variables, Learning Management System (LMS) engagement, synchronous video conferencing participation, gamified learning elements, adaptive learning technology usage, and flipped classroom implementation against dependent variables measuring academic performance, student engagement, self-regulated learning, and perceived learning satisfaction. Structural equation modeling (SEM) and hierarchical multiple regression analyses reveal that adaptive learning technologies ($\beta = 0.42$, $p < 0.001$) and flipped classroom pedagogies ($\beta = 0.38$, $p < 0.001$) demonstrate the strongest predictive relationships with academic performance, while gamification significantly enhances engagement metrics ($\beta = 0.51$, $p < 0.001$). The interaction between technological tools and pedagogical approaches explains 67.3% of variance in overall learning outcomes. These findings contribute to theoretical frameworks on technology-enhanced learning and provide evidence-based recommendations for institutional digital transformation strategies.

Keywords: online learning, digital pedagogy, adaptive learning, flipped classroom, educational technology, student engagement, higher education

1. Introduction

The landscape of higher education has undergone unprecedented transformation in the twenty-first century, catalyzed by rapid technological advancement and accelerated by global disruptions to traditional educational delivery models. Digital education, once considered supplementary to face-to-face instruction, has emerged as a fundamental component of contemporary pedagogical practice [1]. The integration of online learning tools with innovative teaching methodologies represents a paradigm shift in how knowledge is constructed, transmitted, and assessed within academic institutions. The proliferation of Learning Management Systems, video conferencing platforms, artificial intelligence-driven adaptive technologies, and gamified learning environments has created an educational ecosystem markedly different from traditional classroom-based instruction [2]. However, the mere availability of technological tools does not guarantee enhanced learning outcomes. The pedagogical frameworks within which these tools are deployed including constructivist approaches, connectivism learning theories, and active learning methodologies fundamentally shape their educational impact [3]. Despite substantial institutional investment in educational technology infrastructure, empirical evidence regarding the optimal integration of digital tools with teaching pedagogies remains fragmented and often contradictory. Meta-analyses have reported effect sizes ranging from negligible to substantial for technology-enhanced learning interventions, suggesting significant variability attributable to implementation factors rather than technological capabilities alone [4]. This heterogeneity in outcomes presents a critical challenge for educational policymakers, institutional leaders, and instructional designers seeking evidence-based guidance for digital transformation initiatives. Furthermore, existing research frequently examines individual technologies or pedagogical approaches in isolation, failing to capture the synergistic or potentially antagonistic interactions between multiple simultaneous interventions [5]. The COVID-19 pandemic necessitated rapid, often unplanned transitions to online instruction, generating both opportunities for natural experimentation and methodological challenges related to confounding variables and selection effects. This study contributes to educational scholarship and practice in several dimensions. Theoretically, it extends the Self-Determination Theory and the Community of Inquiry framework by incorporating pedagogical moderators previously underexamined in digital learning contexts. Practically, findings inform institutional decision-making regarding educational technology investments, faculty development priorities, and curriculum design. The identification of optimal technology-pedagogy combinations for different learning contexts enables more efficient resource allocation and targeted intervention strategies. Based on this research objectives stated

1.1. Research Objectives

This study addresses the following primary research objectives:

- To quantify the independent and combined effects of five categories of online learning tools on measurable student learning outcomes
- To examine how novel teaching pedagogies moderate the relationship between technology use and learning effectiveness
- To identify interaction effects between technological tools and pedagogical approaches
- To develop a predictive model for optimizing digital education implementations based on institutional and learner characteristics

1.2. Research Questions

RQ1: To what extent do online learning tools (LMS engagement, synchronous video conferencing, gamification, adaptive learning technology, and digital collaboration platforms) predict student academic performance when controlling for prior achievement and demographic variables?

RQ2: How do novel teaching pedagogies (flipped classroom, problem-based learning, peer instruction, and inquiry-based learning) moderate the relationship between technology utilization and student learning outcomes?

RQ3: What interaction effects exist between specific technological tools and pedagogical approaches in predicting student engagement and self-regulated learning?

RQ4: How do students and instructors perceive the effectiveness of integrated technology-pedagogy approaches, and what factors facilitate or impede successful implementation?

2. Literature Review

The trajectory of digital education spans approximately five decades, progressing through distinct phases characterized by dominant technologies and pedagogical assumptions. Early computer-assisted emphasizing drill-and-practice activities and programmed instruction sequences [6]. The emergence of the World Wide Web enabled asynchronous communication and content distribution, giving rise to first-generation Learning Management Systems. The Web introduced participatory technologies wikis, blogs, social networks that aligned with constructivist and social constructivist learning theories emphasizing knowledge co-construction [7]. Contemporary developments in artificial intelligence, learning analytics, and immersive technologies virtual and augmented reality represent a new phase characterized by personalization, adaptivity, and multimodal learning experiences [8]. Learning Management Systems serve as the foundational infrastructure for digital education, providing centralized platforms for content delivery, assessment, communication, and administrative functions [9]. Research examining LMS effectiveness has produced mixed results, with a comprehensive meta-analysis reporting a small positive effect on student achievement compared to non-LMS conditions [10]. Critical variables moderating LMS effectiveness include usage intensity, interaction features employed, and alignment with course design. Studies have distinguished between passive LMS use content repository function and active engagement discussion forums, collaborative tools, finding that the latter demonstrates substantially stronger relationships with learning outcomes [11]. The rapid adoption of video conferencing platforms Zoom, Microsoft Teams, Google Meet for synchronous instruction during the pandemic generated extensive research on this modality. Systematic reviews indicate that synchronous online instruction achieves learning outcomes comparable to face-to-face instruction when incorporating active learning strategies, but produces inferior results when employing lecture-dominant approaches [12]. Key factors influencing synchronous session effectiveness include session duration, interaction frequency engagement activities per hour, and technical quality (bandwidth stability, audio clarity, Student perceptions of social presence in synchronous environments correlate moderately with satisfaction and perceived learning [13]. Gamification the application of game design elements points, badges, leaderboards, progress indicators to non-game contexts has generated considerable interest in educational technology research. A meta-analysis of empirical studies reported a moderate positive effect on learning outcomes and a larger effect on engagement and motivation [14]. However, effect sizes demonstrate significant heterogeneity, with studies employing full game-based learning environments showing larger effects than those utilizing isolated gamification elements [15]. The theoretical mechanism underlying gamification effects involves enhanced intrinsic motivation through competence feedback and autonomy support, consistent with Self-Determination Theory predictions [16]. Adaptive learning systems utilize algorithms to personalize content delivery, pacing, and assessment based on individual learner performance and characteristics. These systems represent a technological instantiation of mastery learning principles, ensuring prerequisite knowledge before advancing to more complex material [17]. Research evidence supports the effectiveness of adaptive systems, with a meta-analysis of studies reporting a moderate-to-large effect compared to non-adaptive instruction. Effects are particularly pronounced for mathematics and science subjects, where prerequisite knowledge hierarchies are well-defined [18]. However, implementation quality varies substantially, and poorly designed adaptive systems may produce no benefit or even negative effects. The flipped classroom inverts traditional instructional sequences by delivering direct instruction typically via video lectures outside class time, reserving synchronous sessions for active learning, problem-solving, and application activities [19]. A comprehensive meta-analysis including studies reported a significant positive effect on learning outcomes and an even larger effect on student engagement. Moderator analyses reveal that flipped classroom effectiveness depends critically on the quality of out-of-class materials, student compliance with pre-class preparation, and the nature of in-class activities [20]. Interactive, application-focused in-class sessions produce larger effects than sessions devoted to clarifying pre-class content. Problem-Based Learning presents students with complex, authentic problems as the starting point for learning, with knowledge acquisition occurring through collaborative investigation and solution development [21]. Meta-analytic evidence indicates that PBL produces superior outcomes for knowledge application and problem-solving skills compared to traditional instruction, though effects on factual knowledge acquisition are smaller. Digital technologies support PBL implementation through access to information resources, collaboration tools, and simulation environments [22]. Online PBL adaptations have shown comparable effectiveness to face-to-face implementations when incorporating structured scaffolding and regular facilitator feedback. Peer instruction, developed by [23] for physics education, combines brief direct instruction segments with conceptual questions that students discuss in pairs or small groups before responding. Research demonstrates substantial learning gains compared to traditional lecture [24]. Digital tools enhance peer instruction through polling systems enabling rapid response collection, breakout room functionality for small group discussions, and collaborative annotation platforms. Technology-mediated peer instruction has shown effects comparable to face-to-face implementations [25]. Limited research has examined how technological tools and pedagogical approaches interact to influence learning outcomes. A study examining the flipped classroom with adaptive learning technology found synergistic effects, with the combination producing larger gains than either approach alone [26]. Similarly, gamification elements within problem-based learning environments enhanced motivation and persistence without detracting from deep learning outcomes. These findings suggest that the relationship between technology and learning outcomes is not direct but mediated and moderated by pedagogical design decisions [27]. This study contributes to this emerging literature by systematically examining multiple technology-pedagogy combinations. This study is grounded in an integrated theoretical framework drawing from perspectives, Self-Determination Theory Deci and Ryan's motivational framework posits that learning environments supporting autonomy, competence, and relatedness enhance intrinsic motivation and engagement [28]. Online learning tools are examined for their capacity to fulfill these psychological needs. Community of Inquiry, Garrison, Anderson, and Archer's model identifies three interdependent presences cognitive, social, and teaching as essential for meaningful online learning experiences [29]. This framework guides the selection of variables and interpretation of results regarding engagement and perceived learning.

2.1. Research Gaps

The review identifies gaps addressed by this research:

- Most studies examine single technologies or pedagogies in isolation; few employ factorial designs examining interactions
- Sample sizes are frequently insufficient for detecting moderate effect sizes or examining moderator effects
- Instructor-level variables, particularly digital competency, are underexamined as moderators

3. Methodology

3.1. Research Design: This study employs an explanatory sequential mixed-methods design, combining quantitative survey and assessment data with qualitative interview data. The quantitative phase establishes relationships between variables and tests hypothesized models, while the qualitative phase provides interpretive context and explores mechanisms underlying observed relationships. The design addresses threats to internal validity through statistical control of confounding variables, and threats to external validity through multi-institutional sampling across diverse institutional types and geographic regions.

3.2. Population and Sampling: The target population comprised undergraduate students enrolled in blended or fully online courses at accredited higher education institutions. Stratified random sampling ensured representation across institution types, geographic regions, and academic disciplines. Eligible courses were randomly selected based on enrollment size, documented digital tool usage, and instructor consent. Survey invitations were sent to all enrolled students, resulting in a final sample of 847 students.

Table 1: Sample Characteristics

Characteristic	n	%
Gender		
Female	456	53.8
Male	371	43.8
Non-binary/Other	20	2.4
Year of Study		
First year	198	23.4
Second year	224	26.4
Third year	237	28.0
Fourth year+	188	22.2
Age (M = 21.3, SD = 3.7)		
18-20	412	48.6
21-24	298	35.2
25+	137	16.2

Power analysis indicated that a sample of 800 participants would provide power > 0.95 to detect medium effect sizes ($f^2 = 0.15$) in multiple regression analyses with 15 predictors at $\alpha = 0.05$.

3.2. Qualitative Sample: Purposive sampling identified 48 participants (36 students, 12 instructors) for semi-structured interviews. Selection criteria ensured variation in:

Table 2: Online Learning Tool Variables

Variable	Operationalization	Measurement	Scale
LMS Engagement	Composite of login frequency, time-on-platform, interaction count	LMS analytics extraction	Continuous (z-standardized)
Synchronous Participation	Attendance rate × active engagement index	Attendance logs + engagement survey	Continuous (0-100)
Gamification Exposure	Points/badges earned + gamified activities completed	Platform analytics	Continuous (z-standardized)
Adaptive Learning Usage	Time in adaptive system + mastery units completed	System analytics	Continuous (z-standardized)
Digital Collaboration	Frequency and quality of collaborative tool usage	Self-report + peer ratings	Continuous (1-7 Likert)

Table 3: Pedagogical Approach Variables

Variable	Operationalization	Measurement
Flipped Classroom Implementation	Percentage of content delivered asynchronously + active learning time ratio	Instructor survey + observation
Problem-Based Learning	Number and duration of PBL activities	Syllabus coding + instructor report
Peer Instruction	Frequency of peer discussion activities + polling usage	Observation protocol
Inquiry-Based Learning	Student-directed investigation opportunities	Syllabus coding rubric

Table 4: Variables and Operationalization

Category	Variable	Measurement	Interpretation
Online Learning Tools	LMS Engagement	LMS analytics	Higher use of LMS platform
	Synchronous Participation	Attendance + survey	Better live class participation
	Gamification Exposure	Platform analytics	More involvement in gamified tasks
	Adaptive Learning Usage	System analytics	Greater use of personalized learning tools
	Digital Collaboration	Self-report + peer ratings	Better teamwork and collaboration
Teaching Pedagogies	Flipped Classroom	Survey + observation	Stronger use of flipped learning
	Problem-Based Learning	Syllabus + instructor report	More problem-solving activities
	Peer Instruction	Observation	Greater peer interaction
	Inquiry-Based Learning	Syllabus rubric	More student-led inquiry
Dependent Variables	Academic Performance	Grades + tests	Better learning achievement
	Student Engagement	Surveys + LMS data	Higher participation and motivation
	Self-Regulated Learning	MSLQ scale	Stronger independent learning skills
	Learning Satisfaction	Satisfaction scale	Greater student satisfaction
Moderators	Digital Competency	Standardized scale	Influences effectiveness of tools
	Discipline / Modality	Classification	Compares subject and delivery mode
Controls	GPA, Demographics, Tech Access, Experience	Records + survey	Controls background differences

The table 4, summarizes the study variables. Independent variables include online learning tools and teaching methods, while dependent variables measure student outcomes such as performance, engagement, self-regulation, and satisfaction. Moderating and control variables help explain contextual differences and improve accuracy of results.

MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 36 Issue 1s, 2026, Pages: 4105-4109

Table 5: Student Survey Battery Instruments

Instrument	Items	Purpose	Reliability (α)
Technology Usage Survey (TUS)	28	Measures frequency and quality of engagement with digital learning tools	0.88
Revised Study Process Questionnaire (R-SPQ-2F)	20	Assesses deep and surface learning approaches	0.82
Motivated Strategies for Learning Questionnaire (MSLQ)	44	Measures motivation and learning strategies	0.86
Student Engagement Scale	24	Measures behavioral, cognitive, and emotional engagement	0.91
Perceived Learning Satisfaction Scale	12	Measures course satisfaction and perceived learning	0.89
Confirmatory Factor Analysis (CFA)	—	Tests overall measurement model fit	CFI=0.94, TLI=0.93, RMSEA=0.048, SRMR=0.052

The table 5, shows that all survey instruments demonstrate strong internal consistency, with Cronbach's alpha values ranging from 0.82 to 0.91, indicating reliable measurement across constructs. The highest reliability was observed for the Student Engagement Scale (α = 0.91), while the R-SPQ-2F also maintained acceptable consistency (α = 0.82). Further, the Confirmatory Factor Analysis results indicate a good overall model fit, as reflected by high CFI and TLI values and low RMSEA and SRMR values. This confirms the validity and suitability of the survey battery for assessing student technology usage, learning behavior, engagement, and satisfaction in the study.

4. Results

4.1. Descriptive Statistics

Table 6: Descriptive Statistics for Key Variables

Variable	M	SD	Min	Max	Skewness	Kurtosis
Independent Variables						
LMS Engagement (z)	0.00	1.00	-2.87	2.94	-0.12	-0.23
Synchronous Participation	72.34	18.67	12.00	100.00	-0.54	-0.41
Gamification Exposure (z)	0.00	1.00	-1.98	3.21	0.34	0.18
Adaptive Learning Usage (z)	0.00	1.00	-2.45	2.78	0.08	-0.31
Digital Collaboration	4.52	1.23	1.00	7.00	-0.28	-0.19
Flipped Implementation	0.48	0.31	0.00	1.00	0.12	-0.87
PBL Activities	3.21	2.14	0.00	9.00	0.67	0.24
Peer Instruction Frequency	2.87	1.56	0.00	7.00	0.43	-0.12
Dependent Variables						
Academic Performance (z)	0.00	1.00	-3.12	2.45	-0.34	0.21
Normalized Learning Gain	0.41	0.19	-0.12	0.89	0.08	-0.34
Engagement Composite	4.89	1.08	1.56	7.00	-0.23	-0.28
Self-Regulated Learning	4.67	0.98	1.78	6.89	-0.18	-0.15
Learning Satisfaction	5.12	1.21	1.25	7.00	-0.45	-0.12

The descriptive statistics indicate that most variables are well distributed with moderate variation among respondents. Standardized variables have means near zero and standard deviations of one, confirming correct normalization. Among independent variables, students showed relatively high Synchronous Participation (M = 72.34) and moderate to high Digital Collaboration (M = 4.52). Flipped Implementation, PBL Activities, and Peer Instruction reflect moderate use of innovative teaching methods. For dependent variables, Normalized Learning Gain (M = 0.41), Engagement Composite (M = 4.89), Self-Regulated Learning (M = 4.67), and Learning Satisfaction (M = 5.12) indicate generally positive learning outcomes and student perceptions. Skewness and kurtosis values fall within acceptable limits, confirming approximate normality and suitability for further parametric analysis.

4.2. Correlation Analysis

Table 7: Correlation Matrix for Primary Variables

	1	2	3	4	5	6	7	8	9	10
1. LMS Engagement	—									
2. Synch. Participation	.34***	—								
3. Gamification	.28***	.21***	—							
4. Adaptive Learning	.41***	.19***	.32***	—						
5. Flipped Implementation	.23***	.18***	.15**	.27***	—					
6. PBL Activities	.19***	.24***	.29***	.18***	.31***	—				
7. Academic Performance	.38***	.29***	.31***	.52***	.44***	.27***	—			
8. Learning Gain	.31***	.24***	.28***	.48***	.41***	.29***	.78***	—		
9. Engagement	.42***	.34***	.54***	.39***	.37***	.35***	.51***	.47***	—	
10. Self-Reg. Learning	.35***	.22***	.31***	.44***	.38***	.28***	.56***	.52***	.62***	—

The correlation matrix shows positive and statistically significant relationships among all major variables, indicating that online learning tools and pedagogical practices are associated with better student outcomes. Among the independent variables, **LMS Engagement** is moderately related to **Adaptive Learning (**r = .41) and **Synchronous Participation** (r = .34), suggesting that students active on one platform tend to engage in others. **Gamification** also has a strong relationship with **Engagement** (r = .54), indicating that game-based elements may enhance student involvement. Regarding dependent variables, **Academic Performance** is strongly correlated with **Adaptive Learning** (r = .52), **Engagement** (r = .51), and **Self-Regulated Learning** (r = .56). **Learning Gain** is highly associated with **Academic Performance** (r = .78), showing that students who improve more also achieve higher grades. Further, **Engagement** has a strong positive relationship with **Self-Regulated Learning** (r = .62), suggesting that motivated and engaged students are more likely to manage their own learning effectively. Overall, the findings indicate that greater use of digital learning tools and active pedagogical methods are linked with stronger academic outcomes, engagement, and self-regulated learning.

4.3. Hierarchical Regression Analysis

Table 8: Hierarchical Regression Results for Academic Performance

Model/Predictor	B	SE	β	t	p	95% CI
Model 1: Controls						
Prior GPA	0.52	0.04	0.41	13.45	<.001	[0.45, 0.59]
Age	-0.02	0.01	-0.06	-1.89	.059	[-0.04, 0.001]
Female (vs. Male)	0.08	0.06	0.04	1.34	.181	[-0.04, 0.20]
First-generation	-0.14	0.07	-0.06	-2.01	.045	[-0.28, -0.003]
R^2 = .198						
Model 2: +Technology						
LMS Engagement	0.09	0.03	0.09	2.78	.006	[0.03, 0.15]
Synch. Participation	0.08	0.03	0.08	2.45	.015	[0.02, 0.14]
Gamification	0.11	0.03	0.11	3.52	<.001	[0.05, 0.17]
Adaptive Learning	0.42	0.03	0.42	13.21	<.001	[0.36, 0.48]
Digital Collaboration	0.07	0.03	0.07	2.12	.034	[0.005, 0.13]
ΔR^2 = .284***						
Model 3: +Pedagogy						
Flipped Implementation	0.38	0.04	0.29	9.12	<.001	[0.30, 0.46]
PBL Activities	0.06	0.02	0.09	2.87	.004	[0.02, 0.10]
Peer Instruction	0.05	0.02	0.07	2.14	.033	[0.004, 0.09]
Inquiry-Based Learning	0.04	0.02	0.05	1.78	.076	[-0.004, 0.08]

ΔR^2 = .141***						
Model 4: +Interactions						
Adaptive × Flipped	0.12	0.03	0.11	3.87	<.001	[0.06, 0.18]
Gamification × PBL	0.09	0.03	0.08	2.94	.003	[0.03, 0.15]
ΔR^2 = .050***						
Final Model R^2 = .673*						

The full model explained 67.3% of variance in academic performance. Adaptive learning technology (β = 0.42, p < 0.001) and flipped classroom implementation (β = 0.38, p < 0.001) emerged as the strongest predictors after controlling for prior achievement.

4.4. Predicting Student Engagement

Table 9: Regression Results for Student Engagement

Predictor	β	p
LMS Engagement	0.18***	<.001
Synchronous Participation	0.14**	.002
Gamification Exposure	0.51***	<.001
Adaptive Learning	0.21***	<.001
Digital Collaboration	0.23***	<.001
Flipped Implementation	0.19***	<.001
PBL Activities	0.24***	<.001
R^2 = .587*		

Gamification demonstrated the strongest relationship with engagement (β = 0.51, p < 0.001), followed by PBL activities (β = 0.24) and digital collaboration tools (β = 0.23).

Table 10: Key Findings from SEM Analysis

Relationship	Effect Size	Significance
Adaptive Learning → Academic Performance	β = 0.39	p < 0.001
Flipped Classroom → Academic Performance	β = 0.34	p < 0.001
Gamification → Engagement → Academic Performance	Indirect effect = 0.16	95% CI [0.11, 0.22]
Adaptive Learning → Self-Regulated Learning → Academic Performance	Indirect effect = 0.09	95% CI [0.05, 0.14]

The SEM results indicate that adaptive learning and flipped classroom pedagogy are the strongest direct predictors of academic performance. Adaptive learning showed the highest positive effect, followed closely by flipped classroom implementation. The mediation analysis further reveals that gamification improves academic performance indirectly through higher student engagement. Similarly, adaptive learning enhances performance not only directly but also indirectly by improving self-regulated learning skills. Overall, the findings suggest that both instructional design and learner motivation mechanisms play a significant role in improving student outcomes.

4.5. Moderation Analysis

Table 11: Moderation Effects of Instructor Digital Competency

Interaction	B	SE	t	p	95% CI
Adaptive × IDC	0.18	0.04	4.52	<.001	[0.10, 0.26]
Flipped × IDC	0.21	0.04	5.14	<.001	[0.13, 0.29]
Gamification × IDC	0.09	0.04	2.23	.026	[0.01, 0.17]
LMS × IDC	0.05	0.04	1.24	.215	[-0.03, 0.13]

The moderation analysis indicates that instructor digital competency significantly strengthens the impact of adaptive learning, flipped classroom, and gamification on student outcomes. Specifically, the positive effect of adaptive learning was strongest when instructor digital competency was high (+1 SD; β = 0.57, p < 0.001), moderate at the mean level (β = 0.39, p < 0.001), and weaker when competency was low (-1 SD; β = 0.21, p < 0.001). This demonstrates that students benefit more from adaptive learning systems when instructors possess stronger digital skills. Further, the Johnson-Neyman analysis showed that the adaptive learning effect becomes statistically significant once instructor digital competency exceeds the 23rd percentile, suggesting that even moderate digital competency among instructors is sufficient to generate meaningful learning benefits.

Table 12: Measurement Model Fit Indices by Construct

Construct	χ^2	df	CFI	RMSEA	SRMR
LMS Engagement	12.34	8	0.98	0.026	0.021
Engagement	34.56	18	0.97	0.033	0.028
Self-Regulated Learning	89.12	42	0.96	0.037	0.031
Learning Satisfaction	18.45	12	0.99	0.025	0.019

The confirmatory factor analysis results indicate that all constructs achieved a good to excellent model fit. LMS Engagement showed excellent fit indices (CFI = 0.98, RMSEA = 0.026, SRMR = 0.021), confirming strong construct validity. Engagement also demonstrated very good fit (CFI = 0.97, RMSEA = 0.033, SRMR = 0.028), indicating that the measurement items reliably captured student engagement dimensions. Self-Regulated Learning presented an acceptable to strong fit (CFI = 0.96, RMSEA = 0.037, SRMR = 0.031), supporting the adequacy of the scale despite its relatively larger number of indicators. Learning Satisfaction achieved the best fit among all constructs (CFI = 0.99, RMSEA = 0.025, SRMR = 0.019), indicating highly consistent measurement. Overall, all CFI values exceeded the recommended threshold of 0.90, while RMSEA and SRMR values remained well below 0.08, confirming strong convergent validity and reliability of the measurement model.

5. Finding

Instructor digital competency significantly moderated the relationship between adaptive learning, flipped classroom, gamification, and student outcomes. The positive effect of adaptive learning increased as instructor digital competency improved. Under high instructor digital competency (+1 SD), the adaptive learning effect was strongest (β = 0.57, p < 0.001), followed by mean competency levels (β = 0.39, p < 0.001), and low competency levels (-1 SD; β = 0.21, p < 0.001). Johnson-Neyman analysis further indicated that the adaptive learning effect became statistically significant when instructor digital competency exceeded the 23rd percentile. These findings highlight that higher instructor digital skills enhance the effectiveness of technology-enabled learning tools.

6. Discussion

The findings indicate that adaptive learning was the strongest predictor of academic performance, highlighting the value of personalized instruction, mastery progression, and metacognitive feedback that helps students regulate their learning. Flipped classroom pedagogy also showed a substantial positive effect, particularly when combined with adaptive learning, as personalized pre-class preparation improved readiness for active in-class engagement. Gamification had the greatest impact on student engagement but a smaller direct effect on academic performance, suggesting that it mainly works through motivational pathways such as persistence and time-on-task, especially when integrated with meaningful problem-based activities. Most importantly, instructor digital competency significantly enhanced the effectiveness of all technologies, demonstrating that successful technology adoption depends not only on tools themselves but also on faculty capability to implement them effectively.

7. Contributions to the Study

This study contributes theoretically by extending the TPACK framework, showing that technological and pedagogical knowledge interact jointly to improve learning outcomes rather than functioning independently. It also refines Self-Determination Theory by explaining how adaptive learning builds competence,

MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 36 Issue 1s, 2026, Pages: 4105-4109

gamification increases motivation, and collaborative tools enhance relatedness, while reinforcing the Community of Inquiry framework by highlighting the importance of instructor competency in digital learning success. Practically, the findings suggest that institutions should prioritize adaptive learning investments, especially in foundational courses, combine technology adoption with faculty training focused on pedagogical integration, and avoid one-size-fits-all strategies since effective technology use varies across disciplines and course objectives.

8. Conclusion

This study provides robust empirical evidence that the effectiveness of digital education depends fundamentally on the interaction between technological tools and pedagogical approaches. Neither technology alone nor pedagogy alone accounts for observed variation in learning outcomes; rather, their combination—mediated by instructor competency—explains substantial variance in academic performance (67.3%), engagement, self-regulated learning, and satisfaction. Adaptive learning technologies and flipped classroom pedagogies emerged as particularly powerful interventions, especially in combination. Gamification demonstrates substantial engagement benefits when integrated with cognitively demanding activities. Critically, all technology effects are moderated by instructor digital competency, underscoring the continuing centrality of human expertise in educational practice. These findings argue against technological determinism—the assumption that deploying new tools will automatically improve education—while also rejecting technophobic resistance to digital transformation. Instead, they support a nuanced view in which technology serves as a powerful amplifier of pedagogical intent. When wielded by competent instructors within well-designed learning environments, digital tools can substantially enhance educational outcomes. When deployed without pedagogical thoughtfulness, they add cost without benefit. The imperative for educational institutions is clear: invest strategically in technologies with demonstrated effectiveness, couple these investments with robust faculty development, and maintain focus on the pedagogical purposes that technology should serve. The future of effective digital education lies not in choosing between technology and pedagogy but in their thoughtful integration.

9. References

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