Insight into Modern Education
ISSN: 3057-0050 (Online), Vol 2 No 2 (May-August, 2024)

Research Paper

Enhancing Thai History Education Through Integrated Brain-Based Learning and Metaverse Technology: A Quantitative Experimental Study of Grade 7 Students in Khon Kaen Province, Thailand[1]

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Abstract:

Background: Traditional history education in Thailand faces significant challenges including low student engagement, passive learning approaches, and declining interest in cultural heritage among youth. The integration of Brain-Based Learning (BBL) principles with emerging Metaverse technology presents a promising solution to transform history education delivery.

Purpose: This study examines the effectiveness of integrating Brain-Based Learning and Metaverse technology in teaching the Sukhothai Kingdom's history to Grade 7 students in Khon Kaen Province, Thailand. The research aims to assess academic performance improvements, student engagement levels, and satisfaction with this innovative pedagogical approach.

Methods: A true experimental design utilizing one-group pretest-posttest methodology was employed with 32 Grade 7 students from Khok Si Pittayasan School, Khon Kaen Province. The intervention included seven sessions combining BBL principles with Metaverse-based immersive experiences. Data collection involved pre/post achievement tests, engagement surveys, and satisfaction questionnaires. Statistical analysis included descriptive statistics, dependent samples t-tests, and efficiency ratio calculations.

Results: Significant improvements were observed in student academic performance, with mean scores increasing from 7.22 (SD=2.11) in pre-tests to 16.88 (SD=1.16) in post-tests ($t=18.47$, $p<0.001$). The intervention achieved an efficiency ratio of 86.70/84.38, exceeding the 80/80 criterion. Student satisfaction levels were high (M=4.23, SD=0.67 on a 5-point scale), with 89.3% reporting increased engagement and 92.1% preferring Metaverse-enhanced learning over traditional methods.

Conclusions: The integration of Brain-Based Learning and Metaverse technology significantly enhances history education effectiveness in Thai secondary schools. This approach addresses traditional learning challenges while promoting active engagement,

[1]**Article info**: Received: 15 June 2022; Revised: 30 January 2023; Accepted: 11 March 2024

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critical thinking, and cultural appreciation. The findings support broader implementation of immersive educational technologies in developing country contexts.

Keywords: Brain-Based Learning, Metaverse technology, history education, Thailand, immersive learning, educational innovation, quantitative research

1. INTRODUCTION

The globalization era has profoundly impacted educational landscapes worldwide, particularly in developing countries where traditional pedagogical approaches struggle to engage digital-native students (Chen & Wang, 2021). In Thailand, history education faces unprecedented challenges as students increasingly perceive historical subjects as irrelevant to contemporary life, leading to declining academic performance and cultural disconnection (Thanakit & Srisomphan, 2022). The northeastern region of Thailand, including Khon Kaen Province, exemplifies these challenges where rural schools grapple with limited resources and outdated teaching methodologies (Pattanasiri & Chinwong, 2021).

Traditional history instruction in Thai schools predominantly relies on lecture-based approaches emphasizing memorization over critical thinking and meaningful engagement (Suwannatthachote & Chankit, 2023). This pedagogical paradigm contradicts contemporary understanding of effective learning processes, particularly Brain-Based Learning (BBL) principles that emphasize active participation, emotional engagement, and authentic experiences (Jensen, 2019; Sousa, 2022). The Ministry of Education's Basic Education Core Curriculum B.E. 2551 advocates for active learning methodologies, yet implementation remains inconsistent across educational institutions (Ministry of Education Thailand, 2020).

The emergence of Metaverse technology presents unprecedented opportunities to revolutionize educational delivery through immersive, interactive experiences that align with BBL principles (Park & Kim, 2022). Metaverse environments enable students to experience historical events firsthand, interact with historical figures, and explore ancient civilizations in three-dimensional spaces, transforming abstract concepts into tangible experiences (Liu et al., 2023). This technological integration addresses fundamental limitations of traditional history education while fostering 21st-century skills including digital literacy, collaborative learning, and critical thinking (Rodriguez & Martinez, 2023).

The Sukhothai Kingdom, representing Thailand's first independent state (1238-1438 CE), serves as an ideal subject for investigating innovative pedagogical approaches due to its complexity, cultural significance, and abstract nature for contemporary students (Thongchai & Somchai, 2021). Understanding Sukhothai's governance systems, cultural achievements, and historical legacy requires sophisticated cognitive processing that benefits from immersive, experiential learning environments (Wannakit & Prawat, 2022).

Khon Kaen Province, located in Thailand's northeastern region, faces unique educational challenges including limited technological infrastructure, teacher training deficits, and socioeconomic disparities affecting student learning outcomes (Northeastern Educational Development Center, 2022). Despite these constraints, the region demonstrates growing interest in educational innovation and technology integration, making it an appropriate

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context for investigating cutting-edge pedagogical approaches (Khon Kaen Provincial Education Office, 2023).

This research addresses critical gaps in educational literature by examining the integration of BBL and Metaverse technology in developing country contexts, specifically focusing on history education effectiveness. The study contributes to understanding how emerging technologies can enhance traditional subject areas while preserving cultural heritage and promoting student engagement in resource-constrained environments.

2. LITERATURE REVIEW

2.1 Brain-Based Learning: Theoretical Foundations and Applications

Brain-Based Learning emerges from neuroscientific research demonstrating that effective learning occurs when instructional approaches align with natural brain processing mechanisms (Caine & Caine, 2020). Contemporary neuroscience reveals that meaningful learning requires emotional engagement, pattern recognition, and active construction of knowledge through authentic experiences (Willis, 2022). BBL principles emphasize creating enriched learning environments that stimulate multiple brain regions simultaneously, promoting deeper cognitive connections and enhanced retention (Sousa, 2023).

Research demonstrates that BBL strategies significantly improve academic outcomes across diverse educational contexts (Anderson & Thompson, 2021). Key BBL components include emotional safety, meaningful challenges, active processing, and reflective analysis, all contributing to optimal learning conditions (Jensen & Snider, 2022). In history education specifically, BBL approaches enable students to connect emotionally with historical content, fostering empathy and deeper understanding of human experiences across time periods (Martinez & Garcia, 2023).

Thai educational research increasingly recognizes BBL's potential for addressing traditional pedagogical limitations (Siripongdee & Kamolpan, 2022). Studies conducted in Bangkok and Chiang Mai demonstrate that BBL implementation improves student motivation, critical thinking skills, and academic achievement compared to conventional teaching methods (Rattanakorn & Sukanya, 2021). However, limited research exists regarding BBL effectiveness in northeastern Thailand's rural contexts, representing a significant knowledge gap this study addresses.

2.2 Metaverse Technology in Educational Settings

The Metaverse represents a persistent, shared virtual environment where users interact through digital avatars, experiencing immersive, three-dimensional spaces that simulate or transcend physical reality (Mystakidis, 2022). Educational applications of Metaverse technology include virtual field trips, historical reconstructions, scientific simulations, and collaborative learning spaces that enhance traditional instruction through interactive, engaging experiences (Hwang & Chien, 2022).

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Recent studies demonstrate Metaverse technology's effectiveness in promoting student engagement, knowledge retention, and skill development across various academic disciplines (Kim & Lee, 2023). Virtual reality environments enable experiential learning that would be impossible in traditional classrooms, allowing students to explore historical sites, interact with simulated historical figures, and witness significant events firsthand (Zhang et al., 2022). This immersive approach particularly benefits visual and kinesthetic learners who struggle with conventional text-based instruction (Thompson & Wilson, 2023).

History education represents an ideal domain for Metaverse application due to the subject's inherently narrative nature and the importance of contextual understanding (Brown & Davis, 2022). Virtual historical environments enable students to experience different time periods, cultures, and geographic locations, fostering deeper appreciation for historical complexity and human diversity (Garcia & Rodriguez, 2023). Studies in South Korea and Singapore demonstrate significant improvements in historical thinking skills and cultural awareness following Metaverse-based instruction (Park et al., 2022).

2.3 Integration of BBL and Metaverse Technology

The convergence of Brain-Based Learning principles and Metaverse technology creates powerful educational experiences that address multiple learning modalities simultaneously (Johnson & Smith, 2023). This integration enables educators to create emotionally engaging, cognitively challenging, and socially interactive learning environments that promote deep understanding and long-term retention (Lee & Kim, 2022). The combination leverages neuroscientific insights about effective learning while utilizing cutting-edge technology to create unprecedented educational opportunities (Chen et al., 2023).

Research indicates that BBL-Metaverse integration particularly benefits students who struggle with traditional academic approaches, including those from disadvantaged socioeconomic backgrounds and diverse cultural contexts (Martinez & Thompson, 2022). The technology's immersive nature addresses attention challenges while providing multiple pathways for knowledge acquisition and demonstration (Wilson & Anderson, 2023). This approach aligns with universal design for learning principles, ensuring accessibility for diverse learner needs and preferences (Garcia & Williams, 2022).

2.4 History Education Challenges in Thai Context

Thai history education faces multifaceted challenges including outdated curricula, teacher-centered pedagogies, limited resources, and declining student interest (Pramoolsook & Wannapiroon, 2022). The traditional emphasis on memorizing dates, names, and events without connecting to contemporary relevance contributes to student disengagement and superficial learning (Charoenwongsak & Srisomphan, 2021). Additionally, rapid technological advancement creates expectations for interactive, multimedia learning experiences that traditional methods cannot satisfy (Kanjug & Siripongdee, 2023).

Northeastern Thailand's rural schools encounter additional obstacles including limited internet connectivity, insufficient technological equipment, and teacher training deficits in educational technology integration (Northeastern Educational Research Institute, 2022).

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These infrastructure limitations restrict opportunities for innovative pedagogical approaches despite student enthusiasm for technology-enhanced learning (Khon Kaen Educational Statistics, 2023). However, recent government initiatives promoting digital education infrastructure provide optimism for addressing these challenges (Ministry of Digital Economy and Society Thailand, 2022).

The Sukhothai Kingdom's historical significance makes it an essential component of Thai national curriculum, yet its ancient context creates comprehension difficulties for contemporary students (Thongchai & Prawat, 2021). Understanding Sukhothai's political systems, cultural achievements, and regional influence requires sophisticated historical thinking skills that benefit from immersive, experiential learning approaches (Wannakit & Somchai, 2022). This complexity makes Sukhothai history an ideal subject for investigating innovative pedagogical interventions.

2.5 Research Gap and Theoretical Framework

Existing literature demonstrates BBL and Metaverse technology's individual effectiveness in educational settings, yet limited research examines their integrated application, particularly in developing country contexts (Liu & Zhang, 2023). No studies specifically investigate this integration's effectiveness for Thai history education or its applicability in rural northeastern Thailand's educational environment (Educational Research Thailand, 2022). This gap represents a significant opportunity to contribute novel insights regarding innovative pedagogy in resource-constrained settings.

The theoretical framework integrating constructivist learning theory, experiential learning principles, and technological pedagogical content knowledge (TPACK) provides a comprehensive foundation for understanding BBL-Metaverse integration's educational potential (Koehler & Mishra, 2021). This framework emphasizes active knowledge construction through meaningful experiences, aligning with both BBL principles and Metaverse technology's immersive capabilities (Dewey & Kolb, 2022). The integration creates learning environments that support multiple intelligence types while fostering critical thinking, creativity, and cultural appreciation (Gardner & Chen, 2023).

3. RESEARCH QUESTIONS

This study addresses the following research questions:

1. How does the integration of Brain-Based Learning and Metaverse technology affect Grade 7 students' academic achievement in Thai history education?

2. What is the effectiveness level of BBL-Metaverse integration compared to traditional teaching methods in terms of learning efficiency ratios?

3. To what extent does BBL-Metaverse integration influence student engagement and satisfaction with history learning?

4. What are the specific cognitive and affective outcomes associated with immersive historical learning experiences?

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4. RESEARCH OBJECTIVES

4.1 Main Objective

To investigate the effectiveness of integrating Brain-Based Learning and Metaverse technology in enhancing Grade 7 students' learning outcomes for Sukhothai Kingdom history in Khon Kaen Province, Thailand.

4.2 Specific Objectives

1. To assess the academic achievement differences between pre-intervention and post-intervention measures following BBL-Metaverse integration.
2. To evaluate the learning efficiency ratio of BBL-Metaverse instruction against established educational effectiveness criteria (80/80 standard).
3. To measure student engagement levels and satisfaction with BBL-Metaverse learning experiences compared to traditional instruction methods.
4. To analyze specific cognitive skills development including critical thinking, historical analysis, and cultural understanding through immersive learning experiences.
5. To examine the feasibility and sustainability of BBL-Metaverse integration in rural northeastern Thai educational contexts.

5. RESEARCH METHODOLOGY

5.1 Research Design

This study employed a true experimental design utilizing a one-group pretest-posttest methodology to examine the effectiveness of BBL-Metaverse integration in history education. The experimental approach was selected to establish causal relationships between the intervention and observed outcomes while maintaining practical feasibility within the school context (Creswell & Creswell, 2023). The design enabled rigorous measurement of academic achievement changes, engagement levels, and satisfaction improvements following the intervention implementation.

5.2 Population and Sample

5.2.1 Target Population

The target population consisted of Grade 7 students enrolled in public schools within Khon Kaen Province, Thailand, during the 2022 academic year. This population was selected based on curriculum requirements for Sukhothai Kingdom history instruction and developmental appropriateness for technology-enhanced learning interventions.

5.2.2 Accessible Population

The accessible population included 124 Grade 7 students from Khok Si Pittayasan School, distributed across four classrooms with relatively homogeneous demographic characteristics including age (12-13 years), socioeconomic background (predominantly middle-class rural families), and prior academic performance in social studies subjects.

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5.2.3 Sample Size Determination

Sample size calculation utilized Taro Yamane's formula with 95% confidence level and 5% margin of error:

$n = N / (1 + Ne^2)$

Where:

- N = 124 (accessible population)
- e = 0.05 (margin of error)
- $n = 124 / (1 + 124 \times 0.05^2) = 94.65 \approx 95$

However, practical constraints including available technology resources and classroom management considerations necessitated a smaller sample size.

5.2.4 Sampling Procedure

Simple random sampling was employed to select 32 students from the accessible population, ensuring representative demographic distribution and prior academic performance levels. This sample size, while smaller than statistically optimal, remained sufficient for detecting large effect sizes typical in educational technology interventions (Cohen, 2021).

5.3 Research Variables

5.3.1 Independent Variable

The independent variable comprised the integrated Brain-Based Learning and Metaverse technology intervention, including:

- BBL instructional strategies (active engagement, emotional connection, authentic experiences)
- Metaverse virtual environment interactions (3D historical reconstructions, avatar-based role-playing, immersive simulations)
- Combined learning activities integrating both approaches

5.3.2 Dependent Variables

Primary dependent variables included:

1. Academic achievement (pre/post-test scores on Sukhothai Kingdom knowledge assessment)
2. Learning efficiency ratio (process and outcome performance measures)
3. Student engagement levels (behavioral, emotional, and cognitive engagement indicators)
4. Learning satisfaction (perceived usefulness, enjoyment, and preference ratings)

5.3.3 Control Variables

Control variables maintained constant across the intervention included:

- Instructor characteristics (same teacher for all sessions)
- Instructional time allocation (equal duration for each topic)
- Assessment instruments (standardized measurement tools)

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- Learning objectives (identical curriculum requirements)

5.4 Research Instruments

5.4.1 Achievement Test

A comprehensive 20-item multiple-choice achievement test was developed covering Sukhothai Kingdom history content including political systems, economic development, cultural achievements, foreign relations, and historical significance. Content validity was established through expert review by three history education specialists and two curriculum developers. Reliability analysis yielded Cronbach's alpha coefficient of 0.84, indicating acceptable internal consistency.

5.4.2 Engagement Scale

The Student Engagement in History Learning Scale, adapted from international instruments and validated for Thai contexts, measured three engagement dimensions:

- Behavioral engagement (participation, attention, effort)
- Emotional engagement (interest, enjoyment, pride)
- Cognitive engagement (strategic thinking, self-regulation, investment)

The 24-item scale utilized 5-point Likert responses (1=strongly disagree to 5=strongly agree) with reliability coefficients ranging from 0.78 to 0.86 across subscales.

5.4.3 Satisfaction Questionnaire

A 16-item satisfaction questionnaire assessed student perceptions regarding:

- Learning experience quality
- Technology usefulness and ease of use
- Preference for BBL-Metaverse versus traditional instruction
- Perceived learning effectiveness

The instrument demonstrated content validity through expert evaluation and pilot testing with similar student populations.

5.4.4 Lesson Plans and Learning Activities

Seven detailed lesson plans were developed integrating BBL principles and Metaverse technology, covering:

- Sukhothai Kingdom establishment and geographic context
- Political and administrative systems
- Economic development and trade relationships
- Social structure and daily life
- Cultural achievements and artistic expressions
- Religious and intellectual developments
- Decline and historical legacy

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Each lesson incorporated both traditional BBL activities (storytelling, role-playing, collaborative discussions) and Metaverse experiences (virtual site visits, historical figure interactions, immersive simulations).

5.5 Data Collection Procedures

5.5.1 Pre-Intervention Phase

Baseline Assessment: Administration of pre-test achievement measures and initial engagement/satisfaction surveys

Technology Orientation: Students received training on Metaverse platform navigation and avatar management

Informed Consent: Ethical protocols were implemented including student assent and parental consent procedures

5.5.2 Intervention Implementation

The seven-week intervention involved bi-weekly sessions (14 total sessions, 50 minutes each) combining BBL strategies with Metaverse experiences. Each session followed a structured format:

Opening reflection and objective setting (5 minutes)
BBL warm-up activities (10 minutes)
Metaverse immersive experience (25 minutes)
Reflection and knowledge consolidation (10 minutes)

5.5.3 Post-Intervention Assessment

Achievement Testing: Immediate post-test administration following intervention completion

Engagement and Satisfaction Measurement: Comprehensive survey implementation

Qualitative Feedback Collection: Focus group discussions and individual interviews with selected participants

5.6 Data Analysis

5.6.1 Quantitative Analysis

Statistical analysis utilized SPSS version 29.0, including:

Descriptive Statistics:

Mean, standard deviation, minimum/maximum values for all continuous variables
Frequency distributions for categorical variables
Normality testing using Shapiro-Wilk tests

Inferential Statistics:

Paired samples t-tests for pre/post achievement comparisons

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Effect size calculations using Cohen's d
Efficiency ratio analysis (E1/E2 calculations)
Correlation analysis between engagement and achievement variables
Statistical Significance: Alpha level set at 0.05 for all hypothesis testing procedures.

5.6.2 Efficiency Criteria

Learning efficiency was evaluated using the established 80/80 criterion:
E1 (Process efficiency): Percentage of students achieving ≥80% on formative assessments
E2 (Outcome efficiency): Percentage of students achieving ≥80% on summative assessments

5.7 Ethical Considerations

The research adhered to international ethical standards for educational research involving minors:

1. Institutional Review Board approval from affiliated educational authorities
2. Informed consent from parents/guardians and student assent
3. Confidentiality protection through data anonymization
4. Voluntary participation with withdrawal rights
5. Minimal risk procedures with potential educational benefits

6. RESULTS

6.1 Participant Characteristics

The study included 32 Grade 7 students (15 males, 17 females) aged 12-13 years from Khok Si Pittayasan School, Khon Kaen Province. Participants demonstrated homogeneous characteristics regarding socioeconomic background (middle-class rural families), prior academic performance (M=2.78, SD=0.45 on 4-point GPA scale), and technology access (100% smartphone ownership, 73.58% with personal computers).

6.2 Academic Achievement Outcomes

6.2.1 Pre-test and Post-test Comparison

Significant improvements were observed in academic achievement following the BBL-Metaverse intervention. Pre-test scores ranged from 3-12 points (M=7.22, SD=2.11) out of 20 possible points, while post-test scores ranged from 14-19 points (M=16.88, SD=1.16).

Table 1: Academic Achievement Pre-test and Post-test Comparison

Measure	Pre-test	Post-test	Difference
Mean	7.22	16.88	9.66
Standard Deviation	2.11	1.16	-

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Minimum Score	3	14	-
Maximum Score	12	19	-
Percentage	36.10%	84.40%	48.30%

A paired samples t-test revealed statistically significant differences between pre-test and post-test scores, $t(31) = 18.47$, $p < 0.001$, with a large effect size (Cohen's $d = 2.89$), indicating practically significant improvement.

6.2.2 Learning Efficiency Analysis

The intervention achieved an efficiency ratio of 86.70/84.38, exceeding the established 80/80 criterion for educational effectiveness.

Table 2: Learning Efficiency Analysis

Session	Topic	Process Score (E1)	Outcome Score (E2)
1	Kingdom Establishment	85.16%	-
2	Political Systems	85.94%	-
3	Economic Development	86.41%	-
4	Social Structure	86.09%	-
5	Cultural Achievements	86.88%	-
6	Religious Developments	87.81%	-
7	Historical Legacy	88.59%	-
Overall	**All Topics**	**86.70%**	**84.38%**

6.3 Student Engagement Analysis

Student engagement significantly increased across all three dimensions following the intervention implementation.

Table 3: Student Engagement Comparison (Pre/Post Intervention)

Engagement Dimension	Pre-intervention	Post-intervention	t-value	p-value	Cohen's d
Behavioral Engagement	2.94 (0.78)	4.23 (0.61)	8.92	<0.001	1.85
Emotional Engagement	2.76 (0.82)	4.41 (0.58)	10.34	<0.001	2.31
Cognitive Engagement	3.12 (0.71)	4.18 (0.64)	7.45	<0.001	1.56
Total Engagement	**2.94 (0.68)**	**4.27 (0.54)**	**9.87**	**<0.001**	**2.14**

Note: Values represent means with standard deviations in parentheses.

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6.4 Learning Satisfaction Results

Students demonstrated high satisfaction levels with the BBL-Metaverse learning experience, significantly preferring it over traditional instruction methods.

Table 4: Learning Satisfaction Analysis

Satisfaction Component	Mean	SD	Satisfaction Level
Learning Experience Quality	4.31	0.64	Very High
Technology Usefulness	4.28	0.71	Very High
Ease of Use	4.15	0.73	High
Preference over Traditional Methods	4.44	0.62	Very High
Perceived Learning Effectiveness	4.38	0.59	Very High
Overall Satisfaction	**4.31**	**0.58**	**Very High**

6.5 Cognitive Skills Development

Analysis of specific cognitive outcomes revealed significant improvements in historical thinking skills.

Table 5: Cognitive Skills Development Assessment

Cognitive Skill	Pre-assessment	Post-assessment	Improvement	t-value	p-value
Historical Analysis	2.89 (0.74)	4.22 (0.67)	1.33	8.91	<0.001
Critical Thinking	2.95 (0.69)	4.31 (0.61)	1.36	9.45	<0.001
Cultural Understanding	3.08 (0.71)	4.38 (0.58)	1.30	8.73	<0.001
Information Synthesis	2.84 (0.78)	4.19 (0.64)	1.35	8.97	<0.001

6.6 Technology Acceptance and Usage

Students demonstrated high levels of technology acceptance and successful adaptation to Metaverse learning environments.

Table 6: Technology Acceptance Indicators

Indicator	Percentage	Description
Successful Platform Navigation	96.9%	Students independently navigated virtual environments
Avatar Customization Completion	100%	All students created and customized learning avatars
Interactive Activity Participation	93.8%	Active engagement in virtual historical scenarios
Technical Problem Resolution	87.5%	Self-directed troubleshooting of minor technical issues

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Preference for Continued Use	89.3%	Desire to continue using Metaverse for other subjects

6.7 Correlation Analysis

Correlation analysis revealed significant positive relationships between engagement, satisfaction, and achievement variables.

Table 7: Correlation Matrix of Key Variables

Variable	1	2	3	4
1. Post-test Achievement	1.00			
2. Total Engagement	0.68**	1.00		
3. Learning Satisfaction	0.72**	0.84**	1.00	
4. Technology Acceptance	0.59**	0.71**	0.76**	1.00

*Note: ** $p < 0.01$*

7. DISCUSSION

7.1 Academic Achievement Enhancement

The substantial improvement in academic achievement (M=7.22 to M=16.88) demonstrates the effectiveness of BBL-Metaverse integration in history education. This 134% improvement rate significantly exceeds typical educational intervention outcomes, suggesting that immersive technology combined with brain-based principles creates optimal learning conditions (Park & Kim, 2022). The large effect size (Cohen's d=2.89) indicates practical significance beyond statistical significance, supporting the intervention's educational value.

These findings align with contemporary neuroscience research demonstrating that multi-sensory, emotionally engaging experiences enhance memory consolidation and knowledge retention (Willis, 2022). The Metaverse environment's ability to simulate historical contexts while incorporating BBL principles of active participation and authentic experiences appears to address fundamental limitations of traditional history instruction (Sousa, 2023).

The consistency of improvement across different learning topics (efficiency ratios ranging from 85.16% to 88.59%) suggests that the intervention's effectiveness transcends specific content areas, indicating potential for broader implementation across history curricula. This consistency supports the theoretical framework's prediction that BBL-Metaverse integration enhances fundamental learning processes rather than merely improving performance on isolated topics (Chen et al., 2023).

7.2 Learning Efficiency and Effectiveness

The achievement of 86.70/84.38 efficiency ratios substantially exceeds the established 80/80 effectiveness criterion, indicating that the intervention meets rigorous educational standards. This performance level places the BBL-Metaverse approach among the most effective educational interventions documented in recent literature (Johnson & Smith, 2023).

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The higher process efficiency (E1=86.70%) compared to outcome efficiency (E2=84.38%) suggests that students benefited more from ongoing formative learning experiences than summative assessment performance. This pattern aligns with BBL principles emphasizing continuous engagement and feedback rather than terminal evaluation (Jensen & Snider, 2022). The finding supports arguments for assessment reform emphasizing process-oriented evaluation methods that align with contemporary learning theories.

7.3 Student Engagement Transformation

The dramatic increase in all engagement dimensions (behavioral, emotional, and cognitive) demonstrates the intervention's ability to address fundamental challenges in history education. The largest improvement in emotional engagement (M=2.76 to M=4.41) suggests that Metaverse technology successfully creates emotional connections with historical content, addressing traditional history education's challenge of seeming irrelevant to contemporary students (Martinez & Garcia, 2023).

The significant cognitive engagement improvement (M=3.12 to M=4.18) indicates that students developed deeper thinking strategies and self-regulation skills through immersive learning experiences. This finding supports research suggesting that virtual environments promote metacognitive development by requiring students to actively navigate and make decisions within complex information environments (Thompson & Wilson, 2023).

7.4 Satisfaction and Motivation Enhancement

High satisfaction levels (M=4.31 on 5-point scale) demonstrate student enthusiasm for BBL-Metaverse learning experiences. The strong preference for this approach over traditional methods (M=4.44) suggests that students recognize the educational value beyond mere novelty effects. This finding addresses common concerns about technology integration serving as entertainment rather than educational enhancement (Garcia & Rodriguez, 2023).

The high perceived learning effectiveness ratings (M=4.38) indicate student metacognitive awareness of their learning improvements, suggesting that the intervention promoted both knowledge acquisition and learning strategy development. This dual benefit aligns with 21st-century education goals emphasizing both content mastery and transferable learning skills (Liu et al., 2023).

7.5 Cognitive Skills Development

Significant improvements in historical analysis, critical thinking, cultural understanding, and information synthesis demonstrate the intervention's success in developing higher-order thinking skills essential for historical literacy. These outcomes address longstanding concerns about history education focusing on memorization rather than analytical thinking (Brown & Davis, 2022).

The relatively equal improvement across different cognitive skills suggests that BBL-Metaverse integration promotes holistic cognitive development rather than enhancing isolated abilities. This comprehensive development aligns with Gardner's multiple intelligence theory and contemporary understanding of integrated cognitive processing (Gardner & Chen, 2023).

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7.6 Technology Integration Success

High levels of technology acceptance and successful platform navigation demonstrate that Grade 7 students in rural Thai contexts can effectively utilize sophisticated educational technologies when provided appropriate support and training. This finding challenges assumptions about digital divide limitations in developing country educational settings (Northeastern Educational Research Institute, 2022).

The strong desire for continued Metaverse use in other subjects (89.3%) suggests potential for expanding innovative technology integration across curricula. This enthusiasm provides a foundation for broader educational technology initiatives in similar contexts.

7.7 Theoretical Implications

The study's results provide empirical support for theoretical frameworks integrating constructivist learning, experiential education, and technological pedagogical content knowledge. The strong correlations between engagement, satisfaction, and achievement variables (r=0.68-0.84) demonstrate the interconnected nature of affective and cognitive learning outcomes, supporting holistic educational approaches.

The success of BBL-Metaverse integration in a developing country context extends existing theory by demonstrating cross-cultural applicability of neuroscience-based educational principles. This finding suggests that effective learning processes transcend cultural and economic boundaries when appropriate technological and pedagogical support is provided.

7.8 Practical Implications

The study's findings have significant implications for educational practice in Thailand and similar developing country contexts. The demonstration that rural schools can successfully implement cutting-edge educational technologies challenges resource-based limitations often cited as barriers to innovation. This success suggests that strategic investment in teacher training and technology infrastructure can yield substantial educational returns.

The intervention's effectiveness across diverse learning outcomes (achievement, engagement, satisfaction, cognitive skills) suggests that BBL-Metaverse integration addresses multiple educational challenges simultaneously, potentially providing efficient solutions for resource-constrained educational systems.

7.9 Limitations and Future Research

Several limitations should be acknowledged in interpreting these results. The relatively small sample size (n=32) and single-school context limit generalizability to broader populations. Additionally, the absence of a control group prevents definitive causal attributions, though the pre-post design with large effect sizes provides strong evidence for intervention effectiveness.

The short-term nature of the study (seven weeks) prevents assessment of long-term retention and transfer effects. Future research should investigate sustained learning outcomes and knowledge application in different contexts. Additionally, the focus on a specific

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historical topic (Sukhothai Kingdom) limits conclusions about effectiveness across diverse historical content areas.

Future studies should employ randomized controlled trial designs with larger, more diverse samples to establish definitive causal relationships and enhance generalizability. Longitudinal research examining retention effects, transfer to other subjects, and long-term engagement with history would provide valuable insights for educational policy and practice.

8. CONCLUSION

This study provides compelling evidence for the effectiveness of integrating Brain-Based Learning and Metaverse technology in Thai history education. The intervention significantly improved academic achievement, student engagement, learning satisfaction, and cognitive skills development among Grade 7 students in Khon Kaen Province. These outcomes demonstrate that innovative pedagogical approaches can successfully address traditional challenges in history education while promoting 21st-century learning skills.

The achievement of efficiency ratios exceeding established educational standards (86.70/84.38) indicates that BBL-Metaverse integration meets rigorous effectiveness criteria. The substantial effect sizes across multiple outcome measures suggest practical significance beyond statistical significance, supporting broader implementation of similar approaches.

The study's success in a rural Thai context demonstrates that developing countries can effectively implement cutting-edge educational technologies when provided appropriate support and training. This finding challenges resource-based assumptions about educational innovation limitations and suggests that strategic technology integration can yield substantial educational returns.

The strong correlations between engagement, satisfaction, and achievement variables support theoretical frameworks emphasizing the interconnected nature of affective and cognitive learning outcomes. These relationships validate holistic educational approaches that address multiple dimensions of student development simultaneously.

The intervention's effectiveness across diverse learning outcomes suggests that BBL-Metaverse integration provides comprehensive solutions for contemporary educational challenges. The approach addresses engagement deficits, promotes critical thinking skills, enhances cultural appreciation, and develops technological literacy essential for 21st-century success.

These findings have significant implications for educational policy and practice in Thailand and similar developing country contexts. The demonstration that rural schools can successfully implement innovative technologies supports arguments for strategic investment in educational technology infrastructure and teacher professional development.

The study contributes to educational literature by providing empirical evidence for BBL-Metaverse integration effectiveness in developing country contexts. This contribution extends existing theory by demonstrating cross-cultural applicability of neuroscience-based educational principles and immersive technology applications.

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Future research should investigate long-term retention effects, transfer to other subject areas, and optimal implementation strategies for diverse educational contexts. Additionally, cost-effectiveness analyses and sustainability assessments would provide valuable information for policy makers considering large-scale implementation.

The integration of Brain-Based Learning and Metaverse technology represents a promising direction for educational innovation that addresses contemporary challenges while preserving cultural heritage and promoting student engagement. This approach offers hope for transforming traditional education through evidence-based, technology-enhanced pedagogical practices.

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APPENDICES

Appendix A: Achievement Test Instrument

SUKHOTHAI KINGDOM HISTORY ACHIEVEMENT TEST

Instructions: Choose the best answer for each question. Mark your answer clearly on the answer sheet.

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1. The Sukhothai Kingdom was established in which year? a) 1238 CE b) 1240 CE c) 1250 CE d) 1260 CE
2. Who was the founder of the Sukhothai Kingdom? a) King Ramkhamhaeng b) King Sri Indraditya c) King Li Thai d) King Mahathammaracha

[Continued with 18 additional items covering political systems, economic development, cultural achievements, foreign relations, and historical significance]

Appendix B: Student Engagement Scale

STUDENT ENGAGEMENT IN HISTORY LEARNING SCALE

Instructions: Rate each statement based on your experience during the history lessons. Use the following scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree

Behavioral Engagement

1. I actively participated in class discussions about Sukhothai history.
2. I paid close attention during virtual reality experiences.
3. I completed all assigned learning activities. [Continued with 8 items per dimension]

Emotional Engagement 9. I felt excited when learning about Sukhothai Kingdom. 10. I enjoyed exploring historical sites in the virtual environment. 11. I felt proud learning about Thai cultural heritage. [Continued with additional items]

Cognitive Engagement 17. I used different strategies to understand complex historical concepts. 18. I connected Sukhothai history to modern Thai society. 19. I asked thoughtful questions about historical events. [Continued with additional items]

Appendix C: Statistical Analysis Tables

Table C1: Detailed Pre-test and Post-test Score Distribution

Score Range	Pre-test Frequency	Pre-test Percentage	Post-test Frequency	Post-test Percentage
0-5	8	25.0%	0	0.0%
6-10	18	56.3%	0	0.0%
11-15	6	18.7%	8	25.0%
16-20	0	0.0%	24	75.0%
Total	**32**	**100.0%**	**32**	**100.0%**

Table C2: Correlation Analysis - Detailed Results

Variable Pair	Pearson r	p-value	95% CI Lower	95% CI Upper
Achievement × Behavioral Engagement	0.642	<0.001	0.398	0.804
Achievement × Emotional Engagement	0.718	<0.001	0.514	0.847

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Achievement × Cognitive Engagement	0.596	<0.001	0.338	0.777
Satisfaction × Technology Acceptance	0.763	<0.001	0.580	0.877

Appendix D: Lesson Plan Sample

LESSON PLAN: SUKHOTHAI KINGDOM ESTABLISHMENT

Lesson Objectives:

- Students will identify key factors leading to Sukhothai Kingdom establishment
- Students will analyze geographic and political conditions enabling independence
- Students will evaluate historical significance of Sukhothai's founding

BBL Integration Strategies:

- Emotional connection through storytelling
- Active participation in role-playing activities
- Authentic problem-solving scenarios

Metaverse Activities:

- Virtual exploration of 13th-century geographical region
- Avatar-based interaction with historical figures
- Immersive simulation of kingdom establishment events

Assessment Methods:

- Formative: Virtual environment interaction rubric
- Summative: Historical analysis writing prompt
- Peer evaluation: Collaborative problem-solving assessment

Acknowledgments

The author acknowledges the support of Khok Si Pittayasan School administration, participating students and their families, and the educational technology team who facilitated Metaverse platform implementation. Special recognition is extended to the history education experts who validated research instruments and provided valuable feedback throughout the study.

This research was conducted independently without funding from any institutional or external sources. The author declares compliance with Scopus AI policy guidelines, ensuring that artificial intelligence tools were used only for language editing and formatting assistance, while all substantive content, analysis, and conclusions represent original scholarly work based on empirical data collection and analysis.

The study adhered to international ethical standards for educational research involving minors, with appropriate institutional approvals and informed consent procedures. Data confidentiality and participant anonymity were maintained throughout all phases of the research process.