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Development and Validation of Web-Based Interactive Learning Material Using the LUMI Application for Mastery of Polynomial Operations

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Abstract

This study aimed to develop and evaluate a web-based interactive learning material (WbILM) using LUMI to enhance Grade 8 students' mastery of polynomial operations. Grounded in Mayer's Cognitive Theory of Multimedia Learning and the ADDIE model, the study addressed gaps in students' conceptual understanding. A developmental research design was employed, with expert validation and a pilot implementation among 39 students and 10 education professionals. Statistical analysis showed a significant improvement in post-test scores ($M = 10.36$, $SD = 1.22$, $t = -3.263$, $p = 0.002$), confirming the material's effectiveness. Experts highly rated its content quality, design, and pedagogical soundness. The study concludes that integrating LUMI-based Web-based Interactive Learning Materials significantly improves mathematical learning outcomes. Future research should expand this approach to other mathematical concepts, further optimizing technology-enhanced instruction to support interactive and adaptive learning.

Keywords: Web-based Interactive Learning Material, LUMI Application, Polynomial Operations, ADDIE Model

1. Introduction

1.1 Context and Rationale

In an era where knowledge rapidly becomes obsolete, the capacity to learn, adapt, and think critically has become as important as content mastery itself. Mathematics education, long regarded as foundational to cognitive development, now faces renewed pressure to evolve in response to technological, economic, and societal shifts. As education systems strive to remain relevant, the integration of digital technologies has emerged not merely as an enhancement but as a necessity for meaningful learning in the 21st century.

Globally, educational innovation has been driven by the recognition that future work demands skills beyond routine procedural competence. The World Economic Forum (2020) [55] underscores this urgency by projecting that 65% of today's primary school learners will eventually enter occupations that do not yet exist. Within this context, mathematics education plays a pivotal role in cultivating logical reasoning, problem-solving, and analytical thinking. Among mathematical topics, operations on polynomials are particularly significant, serving as a gateway to higher algebra, calculus, and applied problem-solving across the sciences and engineering. However, these concepts are often perceived as abstract and cognitively demanding, posing persistent challenges for learners.

Recent literature highlights the promise of technology-enhanced learning environments in addressing such challenges. Studies have shown that web-based interactive learning materials can improve student engagement, conceptual understanding, and academic performance in mathematics. For instance, Alshahrani *et al.* (2020) [3] and Uncad *et al.* (2022) [48] reported significant gains in students' mathematical achievement when interactive digital tools were integrated into instruction. These findings suggest that interactive, learner-centered digital resources can mitigate the limitations of traditional lecture-based approaches by providing immediate feedback, visualization, and self-paced learning opportunities.

Despite these advances, substantial learning gaps persist. National and international assessments consistently report low proficiency levels in mathematics, particularly in algebraic concepts. The Department of Education (2023) [14] noted that approximately 60% of secondary school students struggle with polynomial operations. Similarly, large-scale assessments such as the National Assessment of Educational Progress indicate that only a minority of learners achieve proficiency in mathematics. In the Philippine context, National Achievement Test results further reveal that many students fail to meet the expected performance standards. These quantitative findings are reinforced by qualitative evidence from classroom practitioners, who consistently identify polynomial operations as among the least mastered topics. Collectively, these data point to a disconnect between existing instructional approaches and students' learning needs.

While various digital platforms have been introduced to support mathematics learning, research examining the targeted use of the LUMI Education application for teaching polynomial operations remains limited. LUMI, an open-source platform designed for creating interactive web-based learning materials, offers features aligned with constructivist and multimedia learning principles. However, empirical studies focusing on its systematic development and application for specific algebraic competencies are scarce. This gap underscores the need for focused investigations that link instructional design, digital interactivity, and learning outcomes.

Responding to this gap, the present study aims to develop and evaluate web-based interactive learning materials for polynomial operations using the LUMI Education application and the ADDIE instructional design model. Specifically, it seeks to design contextually appropriate materials for Grade 7 learners, examine their effects on student engagement and mastery of polynomial operations, and generate evidence-based insights for technology-integrated mathematics instruction. The study contributes to both theory and practice by informing instructional design in mathematics education and supporting educators and policymakers in adopting effective digital learning innovations.

1.2 Literature Review

Theories of Multimedia Learning Principles

Theories of multimedia learning provide a robust cognitive foundation for understanding how learners process and integrate information presented through multiple modalities. Central to this body of work is Mayer's Cognitive Theory of Multimedia Learning, which posits that learning occurs through dual channels for visual and auditory information, each with limited capacity, and that meaningful learning requires active cognitive processing (Mayer, 2009). Effective multimedia design, therefore, hinges on optimizing cognitive load rather than maximizing sensory input.

Subsequent theoretical and empirical studies have refined this framework by emphasizing cognitive alignment and learner variability. Radovic *et al.* (2019) demonstrated that well-designed multimedia resources enhance neural efficiency by reducing extraneous load, while Wayan (2022) highlighted the role of individual cognitive differences in shaping multimedia learning outcomes. Contemporary models further stress purposeful integration of multimedia elements to support specific cognitive processes and active knowledge construction (Martinez *et al.*, 2023; Mayer, 2012). Collectively, these theories underscore multimedia learning as an interactive, learner-centered process with significant implications for instructional design.

Web-Based Learning and Polynomial Instruction

Web-based learning has demonstrated substantial effectiveness due to its flexibility, accessibility, and personalization capabilities, particularly in cognitively demanding subjects. Empirical evidence indicates that well-designed web-based platforms can significantly enhance academic performance by supporting adaptive learning, immediate feedback, and multiple problem-solving pathways (Martinez *et al.*, 2023; Barana *et al.*, 2021). However, effectiveness remains contingent on equitable access to technology and robust instructional design, as disparities in infrastructure and digital literacy can limit learning gains (Radovic *et al.*, 2019). In mathematics education, polynomial operations benefit notably from interactive digital tools that reduce abstraction through visual, symbolic, and contextual representations. Contemporary research emphasizes that learning gains are maximized when web-based materials are pedagogically grounded, cognitively aligned, and context-sensitive rather than treated as standalone technological solutions (Pereyras, 2020; Wayan, 2022).

Development of Web-based Interactive Learning Materials for Polynomial Operations

The development of web-based interactive learning materials represents a strategic response to long-standing challenges in teaching polynomial operations, a topic often hindered by abstraction and procedural complexity. Consistent with prior studies by Amantay & Uskenbayeva (2024) and Barana *et al.* (2021), the findings affirm that interactive digital environments are particularly effective for mathematical domains that require symbolic manipulation and conceptual coherence. Features such as dynamic visualizations, step-by-step problem-solving, and immediate feedback enable learners to construct understanding rather than rely on passive reception.

Advances in web technologies further strengthen this instructional potential by enabling polynomial concepts to be represented across multiple modalities, transforming abstract operations into observable, manipulable processes (Martinez & Rodriguez, 2018). From a pedagogical perspective, the effectiveness of these materials aligns with principles of cognitive scaffolding, including adaptive task progression, error-sensitive feedback, and support for multiple solution strategies (Hwang *et al.*, 2017).

Moreover, integrating interdisciplinary expertise and adaptive learning principles enhances personalization and diagnostic precision, thereby addressing individual misconceptions in polynomial operations (Anderson & Smith, 2023 [5]; Pereyras, 2020). Beyond cognitive gains, interactive materials also positively influence learners' attitudes by reducing anxiety and increasing engagement (Ersozlu, 2024) [16]. Collectively, these findings position web-based interactive learning materials as a robust and scalable approach to improving mastery of polynomial operations in contemporary mathematics education.

Gaps in Current Literature on Polynomial Learning Technologies

A synthesis of existing literature reveals a persistent gap in addressing students' difficulties with polynomial operations, a concern consistently reported by mathematics teachers and reinforced by empirical evidence. Despite the rapid expansion of digital learning technologies, few studies have developed or evaluated web-based interactive tools specifically targeting polynomial learning. Prior research identifies key cognitive challenges, including symbolic interpretation, multistep manipulation, and conceptual visualization (Radovic *et al.*, 2019), yet most interactive platforms examined focus on general mathematical skills rather than polynomial-specific competencies (Almohammadi & Hagras, 2020; Rodriguez-Sedano *et al.*, 2018) [2, 46]. While interactive technologies have proven effective in other domains (Chen & Liu, 2019) [12], polynomial instruction remains underserved. This gap underscores the need for targeted, adaptive web-based materials that directly address the conceptual and procedural complexities inherent in polynomial operations.

2. Materials and Methods

2.1 Research Design

This study will employ a quantitative research method within a developmental research design, focusing on product development. As defined by Herrington *et al.* (2014) [18], developmental research is a systematic approach to designing, developing, and evaluating instructional interventions that must meet rigorous internal consistency and effectiveness criteria. This approach is particularly relevant in instructional technology, making it well-suited to the development of web-based learning materials.

2.2 Respondents of the Study

This study employs purposive sampling to select 49 participants with relevant expertise and experience, including three mathematics experts, three educational technology experts, four mathematics teachers, and 39 Grade 8 students, to ensure an informed evaluation of the developed web-based learning material. This sampling approach ensures that all key stakeholders in the learning process are represented, enabling a comprehensive evaluation of the web-based interactive learning material from multiple perspectives.

2.3 Research Instrument

This study employed a comprehensive set of instruments to develop, validate, and evaluate the Web-based Interactive Learning Material (WbILM) on polynomial operations. A needs assessment using performance data from San Isidro Integrated School identified persistent learning gaps in factoring, polynomial equations, and functions among Grade 8 students, guiding content selection and lesson sequencing. The WbILM, designed using LUMI and aligned with the K-12 curriculum and PPST, featured structured sections—"What I Need to Know," "What's More," and "What I Can Do"—to enhance coherence and interactive engagement. Expert validation assessed content, design, functionality, and pedagogical soundness, informing revisions before pilot testing.

Effectiveness was measured via a 20-item multiple-choice pre-test and post-test covering polynomial operations. Teachers' and students' perception questionnaires, using a 4-point scale and open-ended items, evaluated instructional quality, engagement, comprehension, and motivation. These instruments collectively ensured rigorous, learner-centered, and pedagogically sound evaluation.

2.4 Research Procedure

In the Analysis Phase, documented learning gaps in polynomial operations at San Isidro Integrated School were examined, revealing that Grade 8 students struggle with factoring. At the same time, Grade 10 students also struggle with polynomial equations and functions. These insights guided the development of the Web-based Interactive Learning Material (WbILM).

During the Design Phase, the WbILM's structure and sequencing were aligned with curricular standards, incorporating gamified activities, responsive quizzes, and interactive assessments to promote active learning, engagement, and technical usability.

In the Development Phase, content was created for interactivity and multimedia integration within the LUMI platform, ensuring pedagogical accuracy and ease of use.

The Implementation Phase involved classroom integration and pilot testing, collecting real-time feedback on effectiveness.

Finally, the Evaluation Phase assessed teacher and student perceptions of engagement, usability, and learning outcomes, informing iterative revisions to maintain the material's relevance, interactivity, and instructional impact.

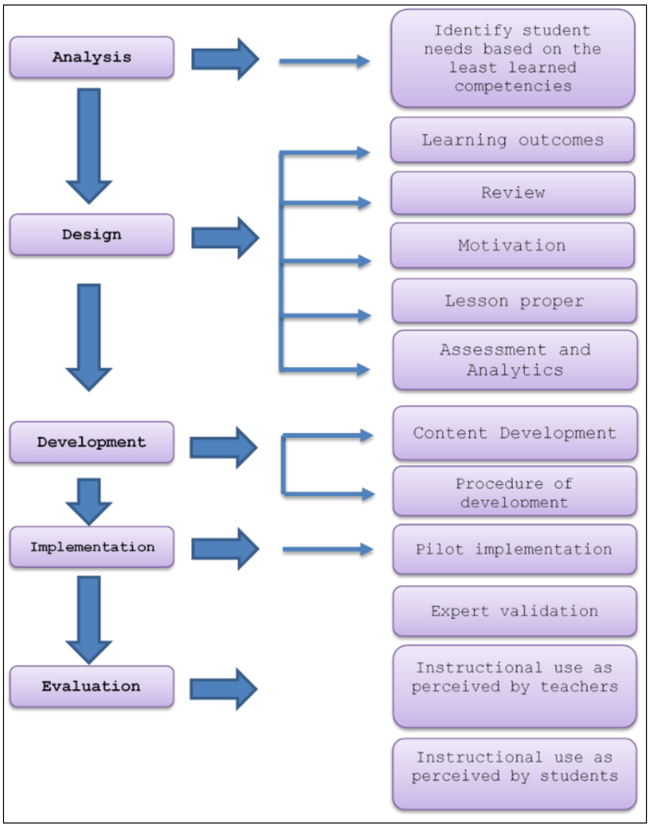

Fig 1: The Procedure of Research Using the ADDIE Model

3. Results and Discussion

3.1 Analysis

Determine Students' Learning Needs and Difficulties

In this phase, the difficulties Grade 8 students had with polynomial operations at San Isidro Integrated School were analyzed to guide the development of a Web-based Interactive Learning Material (WbILM) using LUMI. Data indicated that factoring polynomials is a persistent challenge, stemming from difficulties in applying factoring techniques, recognizing polynomial structures, and engaging with abstract concepts.

Grade 8 is a critical stage, as mastery of polynomial operations forms the foundation for higher-level algebra, including polynomial equations, functions, and transformations. Traditional lecture-based approaches and limited interactive resources often fail to address diverse learning styles, contributing to persistent gaps.

Empirical studies support the integration of technology to address these gaps. Interactive and game-based tools have been shown to enhance understanding, engagement, and problem-solving skills in polynomial operations (Magreñán *et al*., 2021; Ding *et al*., 2023; Querido, 2023) [23, 15, 40]. Consequently, a WbILM was deemed necessary, designed to provide interactive feedback, differentiated learning, and independent exploration of core polynomial concepts.

3.2 Design

Describe the design of the Web-based Interactive Learning Material in terms of Learning outcomes, Review, Motivation, Lesson Proper, and Assessment and Analytics.

Learning Outcomes

The learning outcomes establish clear, measurable goals that guide students' understanding of polynomial operations. These objectives are aligned with the Grade 8 mathematics curriculum and explicitly state what students should be able to accomplish upon completing each module. By presenting specific learning targets at the beginning of each lesson, students gain a clear understanding of expected outcomes, which promotes focused learning and self-assessment. The objectives are scaffolded progressively, moving from basic concepts to more complex polynomial operations, ensuring a logical and structured learning progression.

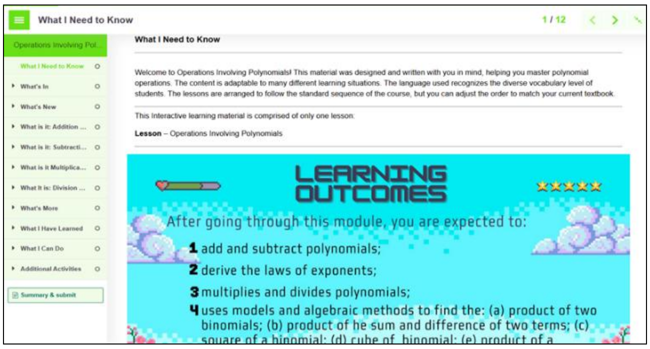

Fig 2: Learning Outcomes

Review

The review section serves as a foundational component that activates prior knowledge essential for understanding polynomial operations. This section revisits prerequisite concepts, including basic algebraic expressions, integer operations, and the laws of exponents. Through brief interactive exercises and visual summaries, students reconnect with the fundamental skills needed to engage with new material. This deliberate review phase helps identify knowledge gaps early. It ensures that all learners possess the baseline competencies required for success in subsequent lessons, thereby reducing cognitive load and building confidence.

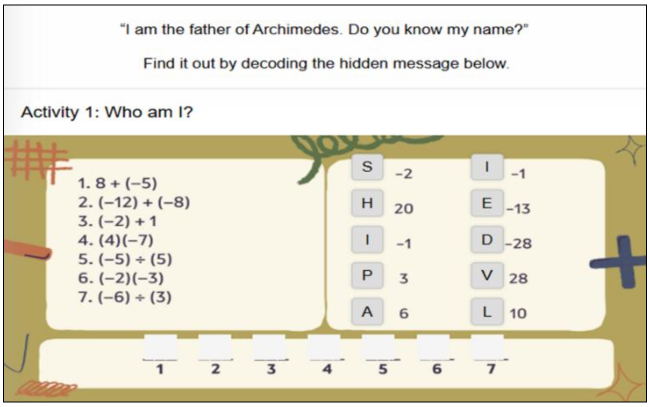

Fig 3: Review

Motivation

The motivation component employs real-world applications and engaging scenarios to spark student interest in polynomial operations. Through relatable examples, such as calculating areas, modeling growth patterns, or solving practical problems, students discover the relevance of polynomials beyond abstract mathematics. Interactive multimedia elements, including animations and scenario-based challenges, capture attention and stimulate curiosity. This section also incorporates gamification features such as challenge questions and progress indicators to maintain enthusiasm and encourage active participation throughout the learning experience.

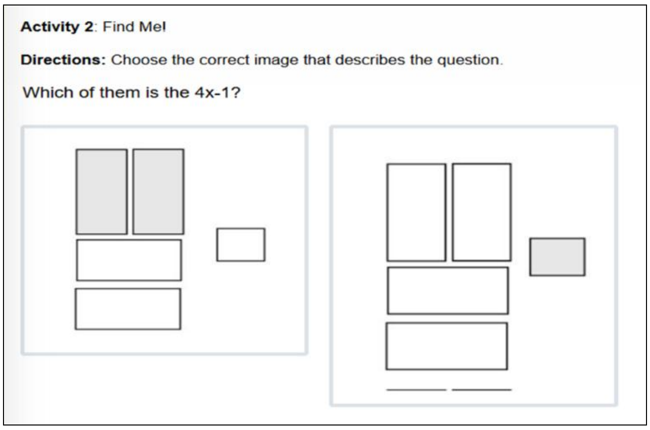

Fig 4: Motivation

Lesson Proper

The lesson proper presents the four fundamental polynomial operations, addition, subtraction, multiplication, and division, through interactive and multimedia-rich content. Each operation is taught as a distinct module with clear explanations and step-by-step demonstrations. Students learn to add polynomials by combining like terms, subtract by properly distributing negative signs, multiply using methods such as FOIL and the distributive property, and divide using both long division and synthetic division. Interactive elements, including drag-and-drop activities, animated visualizations, and guided practice exercises, allow students to engage with each concept actively.

Immediate feedback mechanisms and embedded knowledge checks ensure comprehension before progressing to the next operation. The interface maintains visual consistency with readable fonts, appropriate color schemes, and intuitive navigation, creating an accessible learning environment optimized for both desktop and mobile devices.

Fig 5: Part of a Lesson Proper

Assessment and Analytics

The assessment and analytics component ensures a comprehensive evaluation of student learning and provides actionable insights for both learners and educators. Formative assessments are strategically embedded throughout lessons through knowledge checks, interactive quizzes, and practice exercises that gauge understanding of polynomial operations in real time. Each assessment item provides immediate feedback with detailed explanations, allowing students to identify misconceptions and strengthen their grasp of concepts. Summative assessments at the end of each module measure overall mastery and readiness to progress. The analytics dashboard tracks key performance indicators, including completion rates, time spent on activities, quiz scores, and common error patterns. This data enables educators to identify struggling students, recognize challenging topics that require re-teaching, and make informed instructional decisions. For students, progress visualizations and performance summaries promote self-reflection and metacognitive awareness, empowering them to take ownership of their learning journey.

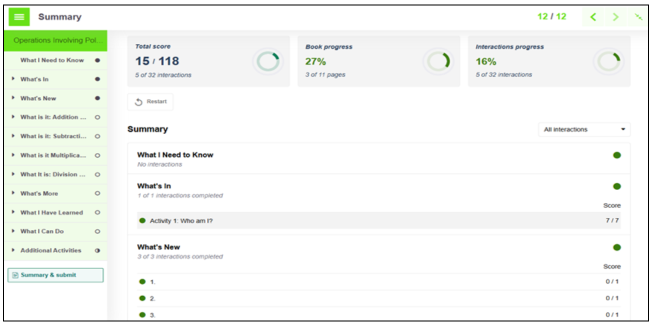

Fig 6: Assessment and Analytics

3.3 Development

Content development

The content was developed based on the least-learned competencies identified from San Isidro Integrated School. Lessons were structured to provide clear explanations of polynomial operations, incorporating multimedia elements such as images, animations, and interactive exercises to facilitate understanding. Interactive quizzes and knowledge checks were embedded to reinforce learning and provide immediate feedback. Additionally, the material was designed with a structured navigation system, making it easy for students to access lessons, activities, and assessments.

Procedure of development

The development of the WbILM using LUMI followed a systematic approach to create an engaging and effective learning experience for Grade 8 students. The process began with downloading and setting up LUMI, accessing the H5P Editor to create interactive content, and selecting the "Interactive Book" template as the framework for the material.

The Interactive Book was carefully structured to present polynomial operations in a logical sequence, integrating multimedia elements such as images, instructional videos, and step-by-step demonstrations. Interactive activities, including quizzes, exercises, and pre-lesson knowledge checks, were embedded to reinforce learning and assess student understanding. User-friendly navigation enabled seamless movement between topics, while features such as immediate feedback, step-by-step solutions, and score tracking supported both student learning and teacher monitoring of progress.

This approach aligns with prior research emphasizing the effectiveness of interactive learning media. Studies by Adawiyah *et al*. (2024) [1], Ambarita *et al*. (2024) [4], and Bahrudin & Yogihati (2023) [6] demonstrate that structured development using models such as ADDIE, combined with multimedia and interactive features, significantly enhances engagement, comprehension, and motivation, thereby validating the design choices of the current WbILM.

3.4 Implementation

Pilot Implementation

The pilot implementation began with a pre-test to assess Grade 8 students' baseline knowledge of polynomial operations, followed by an orientation on navigating the LUMI-based WbILM. Due to classroom restrictions from high heat, students completed the lessons independently at home before a post-test measured learning gains.

Table 1: Post/Pre-Test Results.

Group	Mean	SD	T-Value	P-Value	VD
Pre-Test	8.69	3.01	-3.263	0.002	*Significant*
Post-Test	10.36	1.22			

To determine if there was a statistically significant difference between pre-test and post-test scores after using the Web-based Interactive Learning Material (WbILM). The researcher used a paired t-test at the 5% significance level. The post-test mean score (10.36) is significantly higher than the pre-test mean score (8.69). Since $t = -3.263$, $p = 0.002$ (two-tailed), which is less than 0.05, we can conclude that the Web-based Interactive Learning Material led to a statistically significant improvement in student performance in polynomial operations.

3.5 Evaluation

Expert Evaluation

Table 2: Expert Evaluation of Web-based Interactive Learning Material

Criteria	Math Teachers	VD	Math Experts	VD	ICT Expert	VD
Design					4.00	Very Good
Content Quality	3.98	Very Good	3.93	Very Good		
Functionality	3.95	Very Good	3.87	Very Good	4.00	Very Good
Pedagogical Soundness	3.90	Very Good	3.83	Very Good		

The expert evaluation of the Web-based Interactive Learning Material (WbILM) indicates high overall quality across all assessed criteria. Mathematics teachers rated design, content quality, functionality, and pedagogical soundness between 3.90 and 4.00, corresponding to a "Very Good" descriptor. Mathematics experts similarly rated content quality (M = 3.93), functionality (M = 3.87), and pedagogical soundness (M = 3.83) as "Very Good," while the ICT expert rated design and functionality at M = 4.00. These results demonstrate that the WbILM possesses strong design, reliable functionality, high-quality content, and sound pedagogical principles, confirming its suitability for classroom implementation and alignment with best practices in interactive learning.

The high design ratings align with Churchill *et al*. (2020), who emphasize intuitive navigation and aesthetic appeal, and with Mayer and Fiorella (2021), who highlight that well-integrated multimedia reduces cognitive load and enhances knowledge retention. Functionality ratings support the findings of Crompton and Burke (2020) [13] regarding cross-platform usability and of Hwang *et al*. (2020) [22] regarding progress tracking that facilitates self-regulated learning. Pedagogical soundness aligns with Mayer and Pilegard (2018), who stress structured sequencing, and with Bray and Tangney (2017) [11], who emphasize integrated assessment in interactive environments. Collectively, these results validate that the WbILM is technically robust, pedagogically effective, and capable of fostering meaningful engagement and learning in polynomial operations.

Instructional use as perceived by teachers

Table 3: Instructional use as perceived by teachers

Instructional Use	Mean	Verbal Description
Instructional Design	3.95	Very Much Acceptable
Technological Integration	3.95	Very Much Acceptable
Pedagogical Effectiveness	3.95	Very Much Acceptable
Overall mean	**3.95**	**Very Much Acceptable**

The teachers' evaluation of the instructional use of the Web-based Interactive Learning Material (WbILM) indicates a high level of acceptability across all criteria, with mean scores of 3.95 for instructional design, technological integration, and pedagogical effectiveness, corresponding to a "Very Much Acceptable" rating. These results suggest that the WbILM is well-aligned with curriculum standards, user-friendly, and pedagogically sound. The findings corroborate Fernandez and Johnson (2017), who emphasized that high-quality instructional design in digital mathematics resources enhances conceptual understanding. Similarly, Kumar and Parekh (2021) highlighted that effective technological integration depends on intuitive navigation and platform usability, while Morgan and Chen (2023) reported that interactive digital resources significantly increase student engagement, compared to traditional materials. Collectively, these results confirm that the WbILM provides a well-structured, technologically integrated, and engaging learning environment, supporting its effectiveness in facilitating meaningful mathematics learning experiences for Grade 8 students.

Table 4: Instructional use as perceived by students

Instructional Use	Mean	Verbal Description
Learning Experience Evaluation	3.35	Very Much Acceptable
Interactive Learning	3.48	Very Much Acceptable
Learning Motivation and Support	3.51	Very Much Acceptable
Overall mean	**3.45**	**Very Much Acceptable**

The students' evaluation of the Web-based Interactive Learning Material (WbILM) indicates high acceptability across all assessed variables. Learning experience evaluation scored a mean of 3.35; interactive learning, 3.48; and learning motivation and support, 3.51, resulting in an overall mean of 3.45, described as "Very Much Acceptable." These findings suggest that students perceived the WbILM as engaging, supportive, and motivating. This aligns with Zhang and Nouri (2021), who reported that digital mathematics platforms enhance student interest, though gains in conceptual understanding may be modest. Similarly, Moreno-Armella and Santos-Trigo (2016) found that high-quality interactive elements increase engagement time compared to static materials. Patel *et al*. (2018) emphasized that well-designed web-based materials boost motivation for further mathematical exploration, though reducing math anxiety requires additional design considerations. Collectively, these results confirm that the WbILM provides an engaging, interactive, and motivating learning environment that supports students' active participation and sustained interest in polynomial operations.

4. Conclusion

The study concluded that polynomial operations remain a significant challenge for Grade 8 students, particularly in factoring and recognizing polynomial structures. The LUMI-based Web-based Interactive Learning Material (WbILM) effectively addressed these difficulties by integrating interactive exercises, multimedia content, and real-time feedback, providing an engaging and accessible learning experience. The systematic ADDIE-based development process ensured structured content sequencing, supporting student mastery. Pilot implementation demonstrated statistically significant improvements in student performance, confirming the material's effectiveness in enhancing comprehension and procedural fluency in polynomial operations. Expert validation and teacher assessments affirmed the high acceptability of WbILM's instructional design, technological integration, and pedagogical soundness, reinforcing its value for mathematics education. Ultimately, the study validates the transformative impact of LUMI-based, web-based, interactive learning materials on strengthening mathematical proficiency. Expanding their use across other mathematical concepts can further optimize technology-enhanced instruction, fostering deeper engagement and improved learning outcomes.

5. Recommendations

Based on the findings of this study on the development and implementation of LUMI-based Web-based Interactive Learning Material (WbILM) for polynomial operations, the following recommendations are proposed to enhance effectiveness, engagement, and accessibility:

1. Strengthen Real-World Applications. Future researchers should integrate richer contextual examples, interactive simulations, and multimedia tutorials to make polynomial operations more relatable, address their abstractness, and support conceptual understanding for diverse learners.
2. Implement Adaptive Learning Pathways. Incorporating algorithms that adjust content difficulty based on student performance and provide detailed, step-by-step feedback for incorrect responses can further support individualized learning and procedural fluency.
3. Expand Gamification and Practice Opportunities. Enhancing gamified features, such as achievement systems, progress tracking, and collaborative or competitive challenges, alongside varied exercises, can increase motivation and engagement while reinforcing learning.
4. Enhance Cross-Platform and Offline Accessibility. Future versions should ensure seamless functionality across devices and browsers, including offline access, to provide equitable learning opportunities in areas with limited connectivity.
5. Provide Structured Teacher Training. Professional development programs should equip teachers with proficiency in LUMI, instructional design strategies, and methods to adapt content to diverse learning needs, ensuring effective classroom integration.

Implementing these recommendations can optimize WbILM's pedagogical impact, fostering deeper understanding, motivation, and academic success in mathematics.

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