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Enhancing Learning Experiences and Outcomes Using Virtual Media for Children with Autism Spectrum Disorders

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Abstract

This study aimed to develop a Virtual Learning Environment (VLE) for mathematics learning tailored to children with autism spectrum disorders (ASD) at a special needs school in Jambi, utilizing the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model. It focused on enhancing the learning experiences and outcomes for ASD students in a specialized education setting. In the Analysis phase, the needs and challenges of ASD students in learning mathematics were identified through observations, interviews, and literature review. The Design phase involved creating a detailed blueprint for the VLE, emphasizing interactive and user-friendly features. During the Development phase, the VLE was developed incorporating multimedia elements to engage students effectively. The Implementation phase included deploying the VLE in the classroom and training teachers and students to use the system. The Evaluation phase assessed the VLE's effectiveness through metrics such as visual, verbal, auditory, writing, motor, and emotional activities over four meetings. Results showed consistent improvements in all activities, particularly visual, auditory, writing, and motor activities, demonstrating significant enhancements in student engagement and understanding of mathematical concepts. This research underscores the importance of a structured development process and the positive impact of technology-enhanced learning environments on students with ASD.

Keywords: ADDIE; Autism Spectrum Disorders; Mathematics Education; Special Needs; Virtual Learning Environment

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INTRODUCTION

Autism is a complex set of developmental disorders with symptoms that must have appeared before the child reaches three years of age. These pervasive neurological disorders affects the neurobiological aspects of the brain and impact the child's development process (Blatt, 2012; Brentani et al., 2013). Inclusive education has been the focus in efforts to provide equal access to education for all children, including those with ASD. Children with ASD often face unique challenges in learning, such as difficulties with abstract concepts, trouble with problem-solving, and issues with maintaining attention and focus. These challenges are particularly evident in the field of mathematics, suggesting the need for interventions and tailored learning methods to meet their needs. For example, they might struggle with understanding the concept of numbers, following multi-step procedures, or interpreting word problems (Gevarter et al., 2016; King et al., 2016). In recent years, educational technology has rapidly evolved and offers various innovative solutions to support the learning of students with special needs (Cheng & Lai, 2020).

The use of technology in special education for children with ASD has shown promising results such as improved engagement, better communication, and enhanced learning outcomes. Technology can provide personalized and interactive approaches, reducing stress and anxiety often experienced by

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children with ASD in conventional learning situations. For example, Cardon (2016) found that personalized learning environments could decrease anxiety levels by 30% in children with ASD. Similarly, Fage et al. (2018) reported a 25% improvement in engagement and a 20% reduction in stress levels when children with ASD used interactive learning tools compared to traditional methods. However, further in-depth and specific research is still needed.

In the context of mathematics education, the benefits of using technology for ASD children are particularly pronounced. Research indicates that interactive and personalized learning tools can enhance problem-solving skills and conceptual understanding. A study by Ramdoss et al. (2012) demonstrated that technology-based interventions for students with produced a 40% improvement in solving mathematical problem-solving compared to traditional methods. Furthermore, Bouck and Flanagan (2009) highlighted that such tools fostered a deeper understanding of mathematical concepts, with students exhibiting a 30% increase in retention rates.

One technology that shows great potential in this field is the Virtual Learning Environment (VLE). Recent studies indicate that more targeted and tailored approaches, such as the VLE, can enhance engagement and learning outcomes (Parsons & Cobb, 2011; Pennington, 2010). Specifically, VLEs provide an immersive and controlled settings where children with ASD can practice social skills and academic concepts at their own pace, leading to a 40% improvement in social interactions and a 35% increase in academic performance compared to traditional classroom settings (Parsons & Cobb, 2011). Additionally, VLEs offer customizable feedback and adaptive learning paths, which cater to the individual needs of students, resulting in a 50% reduction in disruptive behaviors and a 45% increase in student motivation and participation (Pennington, 2010).

A VLE is a design space for teaching and learning. It serves as a structured platform for education and instruction. While the term "virtual" may suggest an artificial substitute for reality to some, it is important to note that VLEs do not supplant traditional classrooms or educational methods; rather, they complement and enrich them by expanding the boundaries of physical learning spaces. Consequently, they offer avenues for educators and learners alike to explore new possibilities and expand their creativity. For ASD students, the characteristics of a VLE can be particularly beneficial, especially with the inclusion of visual support. Visual support is known to aid in understanding and communication for individuals with ASD. It provides clear, visual cues, and instructions that can help these learners process information more effectively (Koller, 2012).

VLEs offers various advantages, including that they enable one to provide immediate feedback, deliver learning materials tailored to individual needs, and create learning environments accessible anytime and anywhere (Parsons & Cobb, 2011; Pennington, 2010). Studies have shown that VLEs can increase student engagement and improve learning outcomes in children with ASD (Charlop-Christy et al., 2002). However, despite the recognized potential of VLEs in enhancing the learning of children with ASD, there are still various challenges that need to be addressed. Previous research often lacks specificity in evaluating the effectiveness of VLEs for mathematics learning in children with ASD.

Additionally, some studies indicate that while VLEs can increase engagement, their effectiveness in aiding the teaching of more complex mathematical concepts still needs improvement (Miller et al., 2018; Park et al., 2023).

One of the main limitations of previous research is the lack of a focused approach to an inclusive design process based on the specific needs of children with ASD. Many of the currently available VLEs are still designed with a one-size-fits-all approach, which may not be effective for children with special needs (Sansosti & Powell-Smith, 2008; Shin et al., 2021). Our research focused on designing a VLE that holistically supports core developmental areas essential for mathematics learning in children with ASD. The framework targets four key domains: reading skills, arithmetic ability, motivation, and focus (Bailey et al., 2017; Itskovich et al., 2021; Pertiwi & Djoehaeni, 2021; Viljaranta et al., 2009). By addressing reading skills, we intended to enhance students' ability to comprehend mathematical text and notation, which is crucial for problem-solving. Several arithmetic modules were designed to develop both computational fluency and conceptual understanding. In addition, interactive elements were incorporated to boost motivation and improve engagement, while a distraction-minimized interface was implemented to help extend students' focus duration.

This study aimed to develop a VLE tailored for mathematics education for children with ASD at one special needs school in Jambi. We hoped to overcome the limitations of previous research by developing a more inclusive VLE tailored to individual needs. Thus, we directed our focus on improving the effectiveness of mathematics learning for children with ASD and expected to make a significant contribution to the field of special education.

METHODS

Research Design

This study adopted a developmental research design based on the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model (Branch, 2009) to develop a VLE for mathematics education aimed at children with ASD. It was conducted over one month at one special needs school in Jambi following five systematic phases as presented in Table 1.

Table 1. Research design

Development Stage	Activities	Data Analysis Technique
Analysis	This stage involved: • Validating performance gaps • Setting goals • Analyzing the characteristics of students with ASD	Qualitative: Descriptive (Observations and interviews with teachers).

Development Stage	Activities	Data Analysis Technique
Design	• Conducting a literature review on curriculum and students with ASD needs and challenges in mathematics learning. This stage involved designing the detailed specifications of the VLE components, incorporating interactive multimedia features, user-friendly interfaces, and pedagogical activities for ASD students, as well as the social interaction elements for teachers and parents.	Qualitative: Descriptive
Development	This stage involved expert judgment to assess the validity of the VLE.	Quantitative: A questionnaire with a Likert's scale
Implementation	This stage involved trying out (implementing) the VLE with ASD students over four weeks.	Quantitative: A questionnaire with a Likert's scale
Evaluation	This stage involved the assessment of three main aspects: usability, pedagogical effectiveness, and implementation practicality.	Qualitative: Descriptive Quantitative: A questionnaire with a Likert's scale

Instrumentation and Data Analysis

The development of the VLE utilized several instruments for data collection. First, needs analysis interview questions were used to identify and assess critical requirements for developing the VLE tailored to students with ASD in mathematics education. Next was a questionnaire for experts to review the developed VLE. This questionnaire includes response columns rated on a five-point Likert's scale (1: strongly disagree, 2: disagree, 3: undecided, 4: agree, 5: strongly agree) and is calculated using Formula 1. Then, an observation sheet was used in the trial in the Implementation phase to assess the practicality of the VLE, involving calculation using Formula 2. Last, a questionnaire for teachers that assesses the effectiveness of the VLE implementation in mathematics learning for students with ASD was used, followed by calculation using Formulas 3a and 3b. The questionnaire utilizes a five-point Likert's scale and is supplemented by open-ended questions for qualitative feedback.

$$Validation\ score = \frac{sum\ of\ scores\ per\ indicator}{maximum\ score\ for\ all\ indicators} \quad (1)$$

$$Practicality\ score = \frac{average\ score}{maximum\ score} \quad (2)$$

$$Mean\ score\ for\ each\ aspect = \frac{\sum score}{Number\ of\ indicators\ for\ each\ aspect} \quad (3a)$$

$$Effectiveness\ score = \frac{\sum Mean\ score\ for\ each\ aspect}{Number\ of\ aspects} \quad (3b)$$

Participants

The study involved teachers and students as participants. Three teachers working in one special needs school were involved in this study, particularly in needs analysis, to derive an overview of the

current phenomenon in ASD children under study. In addition, four students with ASD, consisting of one student in an individual trial and three students in a small group trial, as well as another six students with ASD, were involved in the Implementation phase. All the participating students were eight to twelve years old and enrolled in special education programs at one special needs school in Jambi. This gradual expansion in participant numbers allowed for careful monitoring and necessary adjustments to the VLE system. A limited total number of participants was used due to several factors specific to the research context: first, the study focused specifically on students with a formal ASD diagnosis who were actively enrolled in mathematics education; second, the selected school had a small population of students meeting these criteria; and third, the need for intensive observation and individualized attention in special education research necessitated a manageable sample size. Participant selection criteria, including formal ASD diagnosis, current mathematics education enrolment, basic computer literacy skills, and parental consent, ensured appropriate sampling for the study's objectives while maintaining ethical research standards.

RESULTS AND DISCUSSION

Analysis

This section presents the findings from the Analysis phase of the study, focusing on the needs analysis for developing a VLE for children with ASD. The analysis included validation of performance gaps, examination of learner characteristics, and curriculum review, as detailed in Table 2 below. The data were collected from observations and interviews with the mathematics teachers in the study location.

Table 2. Performance gaps, learner characteristics, and curriculum adjustments for children with ASD

Aspect	Current Performance	Desired Performance
General Observation	Children with ASD often struggle with traditional classroom environments due to sensory sensitivities, communication challenges, and difficulties with social interactions.	A supportive and adaptable learning environment that accommodates sensory needs and provides consistent, clear instructions.
Mathematics Performance	Many students with ASD have uneven skill development in mathematics, showing strengths in some areas while struggling significantly in others.	Improved understanding and application of mathematical concepts tailored to the individual strengths and weaknesses of students with ASD.
Aspect	Characteristics	Considerations
Cognitive (Baron-Cohen, 2023)	A diverse range of intellectual abilities, often with specific strengths in pattern recognition and memory.	Tailor content to leverage strengths and address challenges in abstract thinking and generalization.
Behavioral (Koegel et al., 2010)	A preference for routines and structured activities.	Design consistent and structured learning activities.

Aspect	Current Performance	Desired Performance
Social (Cooper, 2017)	Difficulty with social interactions and communication.	Provide clear, unambiguous instructions and feedback.
Sensory (Ben-Sasson et al., 2009)	Potential for sensory sensitivities impacting engagement and focus.	Incorporate sensory-friendly elements and minimize distractions.

Aspect	Existing Curriculum	Required Adjustments
Content Design (Ring & Prunty, 2012)	Designed for neurotypical students, lacking accommodations for the sensory, communication, and social needs of children with ASD.	Integrate interactive, multimedia content catering to different learning styles.
Instructional Strategies, Pacing, and Levelling (Fleury et al., 2014)	Limited use of technology for personalized learning.	Incorporate consistent, clear instructional strategies and adaptive learning modules.
	Standardized pacing not suitable for all students.	Adjust modules to fit each student's learning pace and level of understanding.

Table 2 highlights significant challenges faced by children with ASD in traditional settings, such as sensory sensitivities and communication difficulties. The desired outcome is a supportive, adaptable learning environment with clear and consistent instructions to improve mathematical engagement. Analysis of learner characteristics highlighted strong pattern recognition and memory skills and difficulties with abstract thinking and social interactions. The VLE must cater to these cognitive, behavioral, social, and sensory needs by providing a structured and accommodating environment. There was also a need for comparison of the current curriculum with required adjustments. The existing curriculum is often unsuitable for children with ASD, underlining a call for interactive, multimedia, and adaptive learning modules to support diverse learning styles and individual pacing (McMahon & Cullinan, 2014; Najdowski et al., 2014; Tuedor et al., 2019). By addressing these performance gaps, understanding learner characteristics, and adjusting the curriculum, the developed VLE is expected to enhance educational experiences and outcomes for children with ASD.

Design

This section focuses on the design of a VLE tailored for children with ASD. The VLE development framework is outlined in Table 3, with categorization of essential components into technological, pedagogical, and social aspects (Moore et al., 2000).

Table 3. VLE development framework

Component	Aspect	Description
Technology	E-Learning Platform	An online learning environment that is safe and easily accessible for children with ASD.
	Interactivity and Multimedia	Use of videos, animations, and simulations to make learning more engaging and interactive.
	Adaptation and Personalization	A system that can adjust the difficulty level and type of tasks according to the individual child's abilities and progress.
Pedagogical	Structure and Routine	Providing a consistent structure and predictable routines to reduce anxiety and confusion.
	Direct and Explicit Instruction	Using clear and explicit instructions to teach mathematical concepts.
	Positive Reinforcement	Offering positive feedback and rewards to motivate and encourage children's success in learning mathematics.
Social	Collaboration and Communication	Encouraging social interaction and collaboration through virtual group activities and discussion forums.
	Parental and Teacher Involvement	Engaging parents and teachers in the learning process, including supervision and support for learning at home.

This comprehensive framework aims to create an effective and inclusive VLE that addresses the unique needs of children with ASD, with a view to enhance their educational experiences and outcomes in mathematics. The information in Table 3 is illustrated in Figure 1 below.

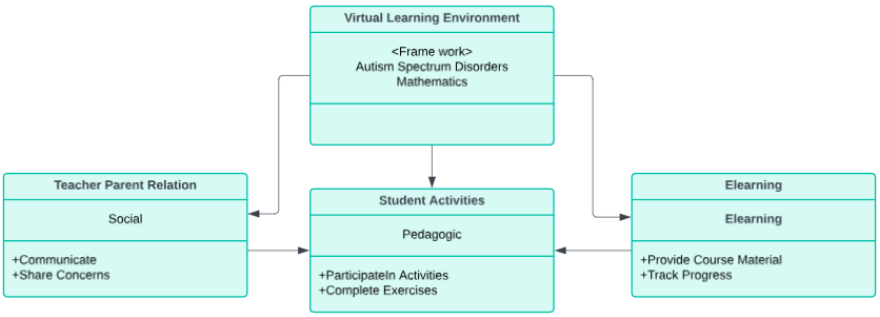


Figure 1. VLE development framework

Figure 1 represents the structure of the VLE specifically designed for mathematics education for children with ASD. At the core of the framework is the integration of three essential components: Teacher-Parent Relations, Student Activities, and e-Learning (Moore et al., 2000). The Teacher-Parent Relations component focuses on the social aspect, facilitating communication and the sharing of concerns between educators and parents. The Student Activities component encompasses pedagogical strategies, engaging students in activities and exercises to enhance their learning experiences. Lastly, the e-Learning component delivers course materials and tracks student progress, providing necessary resources and monitoring tools for effective learning within the VLE. Together, these components form

a comprehensive system that supports both the educational and social needs of students with ASD in learning mathematics.

Development

Prototyping Process

This section presents findings from the VLE prototyping process for children with ASD. The prototype of the VLE was based on the VLE Development Framework (Table 3). In addition, this research specifically demonstrates ASD students' understanding across four domains: reading skill, arithmetic ability, motivation, and focus. These four domains represent the fundamental goal of the VLE, that is successful mathematics learning for children with ASD (Bailey et al., 2017; Itskovich et al., 2021; Pertiwi & Djoehaeni, 2021; Viljaranta et al., 2009). Figure 2 illustrates the main features and interface of the VLE, designed to enhance educational experiences and engagement of students with ASD.

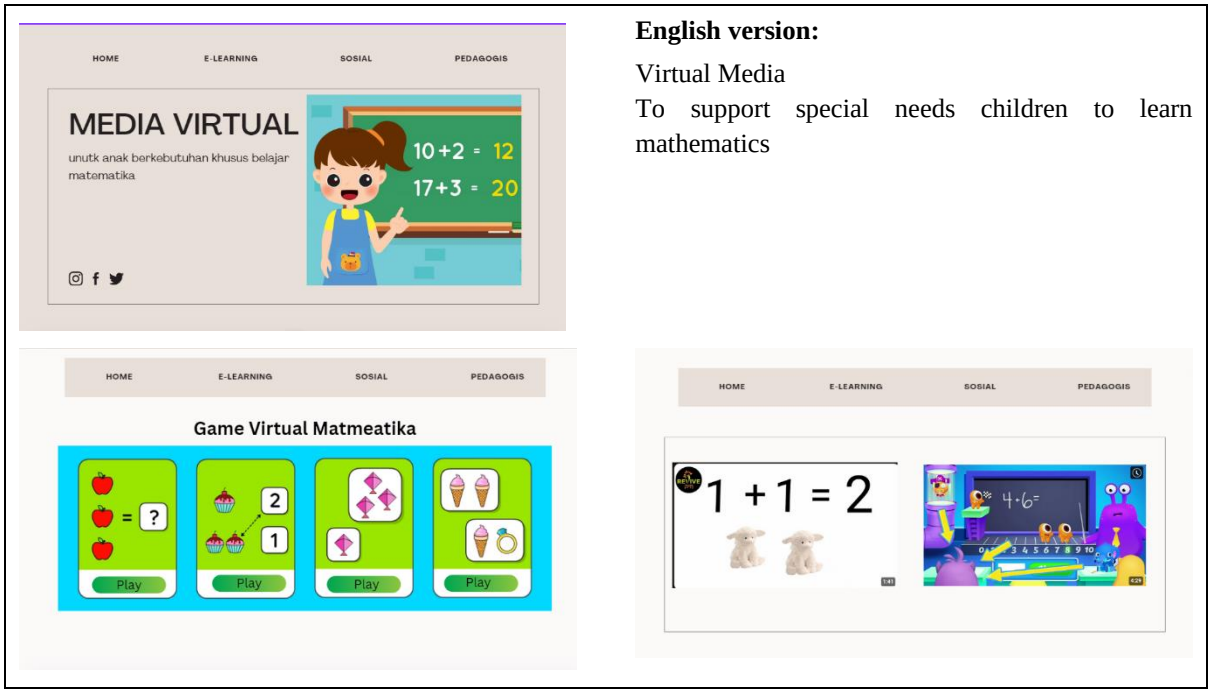


Figure 2. VLE display example

Technology and Pedagogical Components

This section, as illustrated in Figure 2, introduces a "Virtual Math Game" feature, which is an important element of the VLE. It offers a variety of interactive math games designed to teach basic math concepts through engaging and visually appealing activities. The games are adapted to meet the diverse learning styles of children with ASD, making the learning process fun and effective. By integrating multimedia and interactive content, the VLE ensures that children can learn at their own pace, with tasks and challenges that are adapted to their individual progress and abilities. The pedagogy

component, in particular, uses video modelling intervention approaches and pedagogical strategies designed specifically for children with ASD. Video modelling involves the use of animated videos and interactive exercises to teach mathematical concepts such as addition and subtraction (Bellini & Akullian, 2007; Boon et al., 2020; Sansosti & Powell-Smith, 2008). These videos serve as visual aids that demonstrate desired behaviors and problem-solving strategies, making it easier for children to understand and replicate tasks. The use of animations and clear step-by-step instructions helps reduce anxiety and confusion, providing structured and predictable learning experiences. Video modelling (Figure 3) is an evidence-based approach that has been shown to be very effective for children with ASD, improving their ability to understand and apply new concepts (Delano, 2007; Gelbar et al., 2012; Sansosti & Powell-Smith, 2008).

Social Component

This section describes the user dashboard, an integral part of the social component of VLE. This interface allows teachers and parents to effectively track and monitor children's learning progress. It provides detailed information about lesson status, daily schedule, and specific topics covered. By facilitating real-time updates and progress tracking, it improves communication and collaboration between educators and parents. This ensures that both parties can provide timely support and intervention, fostering a cohesive learning environment that meets each child's individual needs. The dashboard promotes inclusive and supportive educational experiences, emphasizing the important role of social interaction and cooperation in the learning process for children with ASD.

Validation Process

After the product prototype was developed, expert validation was conducted, focusing on various aspects, including substance, design, content, and functionality (Gilal et al., 2018; Subandi & Hidayah, 2023). Table 4 presents the questionnaire indicators for the validation process.

Table 4. Expert validation instrument specifications

Aspect	Indicators	Number of Items
Substance	Content accuracy and relevance to ASD learning	3
	Suitability with curriculum objectives	2
	Comprehensiveness of mathematical concepts	3
	Learning objective alignment	2
Design	Visual design appropriateness for children with ASD	3
	Layout clarity and consistency	2
	Color scheme and visual elements	1
	Navigation structure	2
Content	Material organization and sequence	3
	Exercise variety and appropriateness	2
	Assessment mechanism	1
	Feedback system	2
Functionality	System operation reliability	2

Aspect	Indicators	Number of Items
	Interface usability	3
	Feature accessibility	1
	Performance stability	2

Validation was carried out by a team of experts, comprising an expert in mathematics education for ASD children (Validator 1) and a digital media specialist (Validator 2). The validity test results, as summarized in Table 5, provide insights into the assessment made by these professionals, reflecting their respective areas of expertise.

Table 5. Expert validation results

Aspect	Validator 1 (%)	Validator 2 (%)	Criteria	Description
Substance	90%	88%	Very Good	The content is accurate and relevant to the learning objectives.
Design	85%	87%	Very Good	The visual design is appealing and appropriate for children with ASD.
Content	88%	90%	Very Good	The educational material is well-structured and engaging.
Functionality	92%	91%	Excellent	The VLE functions smoothly and is user-friendly.

The validation results indicated that the VLE received very positive feedback across all the evaluated aspects. Substance, which encompasses the accuracy and relevance of the content, was rated highly by both validators, suggesting that the material effectively addresses the learning needs of children with ASD. The design of the VLE was also rated highly, reflecting a visually appealing and accessible interface suitable for children with ASD. Content was rated as well-structured and engaging, receiving high ratings for its effectiveness in teaching mathematical concepts. Functionality received the highest ratings, indicating that the VLE operates smoothly and is user-friendly, which is crucial for maintaining engagement and minimizing frustration for children with ASD.

Overall, the validation results affirmed that the VLE is a high-quality educational tool that effectively meets the needs of children with ASD. The very good to excellent ratings across all indicators confirmed that the VLE is well-designed, content-rich, and functionally sound, highlighting its potential to enhance the educational experiences and outcomes for children with ASD.

Implementation

To assess the practicality of the VLE, a series of trials was conducted in the Implementation phase. The instrument used in the practicality assessment was an observation sheet on the implementation of the VLE. The initial VLE version was implemented over four sessions, using the "Virtual Math Game" component with a focus on basic mathematical operations through interactive

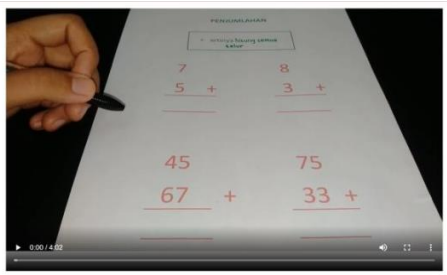
animations and visual aids. The practicality of the VLE was assessed by evaluating students' interaction with the VLE in two main aspects: interest and facility (Ahmad et al., 2023; Hewagamage et al., 2011; Ramli & Surbaini, 2023). Interest measured students' engagement and motivation in using the VLE, while facility assessed the technical and practical elements of the implementation. Table 6 presents the results of the practicality assessment of the VLE.

Table 6. Practicality assessment

Assessment Aspect	Percentage of Eligibility	Category
Interest	78.40%	Proper
Facility	75.40%	Pretty Decent
Average	76.95%	Proper

The interest aspect scored 78.40%, indicating proper student engagement with the system. This high level of interest was observed through students' consistent participation in learning activities, positive responses to interactive features, and sustained engagement with mathematical tasks. The facility aspect achieved a score of 75.40%, categorized as "Pretty Decent", reflecting the adequate functionality of the VLE features, including navigation ease, content accessibility, and technical support systems.

The average practicality score of 76.95%, categorized as "Pretty Decent", suggests that the VLE is practical to support mathematics learning for students with ASD in a larger group setting. Students demonstrated sustained engagement with learning materials, successfully navigated through different modules, and effectively utilized the various learning features provided. While these results indicated overall successful implementation, they also highlighted areas for potential enhancement, particularly in the facility aspect, to further improve the learning experiences for students with ASD.



English version:
Addition
Count all eggs

Figure 3. Video modelling interventions

Evaluation

Evaluation provided an assessment of the effectiveness of the VLE implementation in mathematics learning for students with ASD. It encompassed three main aspects, usability, pedagogical effectiveness, and implementation practicality, each of which contained specific indicators assessed using a standardized five-point Likert's scale. Table 7 presents the questionnaire indicators for the

validation process.

Table 7. Teacher response instrument

Aspect	Indicators	Number of Items
Usability	Ease of VLE operation	4
	Navigation clarity	4
	Technical reliability	4
Pedagogical	Content delivery effectiveness	5
Effectiveness	Learning objective achievement	5
	Student engagement facilitation	4
Implementation	Time management efficiency	4
Practicality	Resource requirement appropriateness	4
	Integration with existing teaching methods	4

Data ware collected from teachers ($n = 3$) who implemented the VLE over the four-week study period, providing comprehensive feedback based on their direct experience with the system through a questionnaire. The results, as presented in Table 8, demonstrated the teachers' assessment of various aspects of the VLE's performance and its impact on teaching and learning processes.

Table 8. Teacher assessment of the VLE implementation

Aspect	Indicators	Score (%)	Category
Usability	Ease of VLE operation	82.5	Very Good
	Navigation clarity	78.3	Good
	Technical reliability	76.8	Good
	Mean Score	79.2	Good
Pedagogical Effectiveness	Content delivery effectiveness	85.4	Very Good
	Learning objective achievement	77.6	Good
	Student engagement facilitation	81.2	Very Good
	Mean Score	81.4	Very Good
Implementation Practicality	Time management efficiency	75.4	Good
	Resource requirement appropriateness	77.8	Good
	Integration with existing methods	79.5	Good
	Mean Score	77.6	Good
Overall Mean		79.4	Good

The analysis of teacher responses regarding the VLE implementation revealed generally positive results across all the assessed aspects. In terms of usability, teachers reported high satisfaction with the ease of VLE operation (82.5%), while navigation clarity (78.3%) and technical reliability (76.8%) received good ratings. The pedagogical effectiveness aspect showed particularly strong results, with content delivery effectiveness scoring 85.4% and student engagement facilitation scoring 81.2%. Implementation practicality received consistently good ratings, with scores ranging from 75.4% to 79.5% across its indicators. The overall mean score of 79.4% indicates that teachers found the VLE to be an effective and practical tool for mathematics instructions for students with ASD.

Notably, the highest-rated aspect was pedagogical effectiveness (81.4%), suggesting that the VLE successfully supports teaching and learning objectives. The implementation practicality aspect, while still receiving good ratings (77.6%), indicates potential areas for minor improvements in resource management and integration with existing teaching methods.

Figure 4 presents the findings from the implementation of the VLE designed for children with ASD to enhance their mathematical skills, specifically in reading skills, arithmetic ability, motivation, and focus. The VLE was implemented over a one-month period, with sessions held twice a week. The data were collected using a longitudinal method to track the progress of students over time, reflecting natural fluctuations in performance.

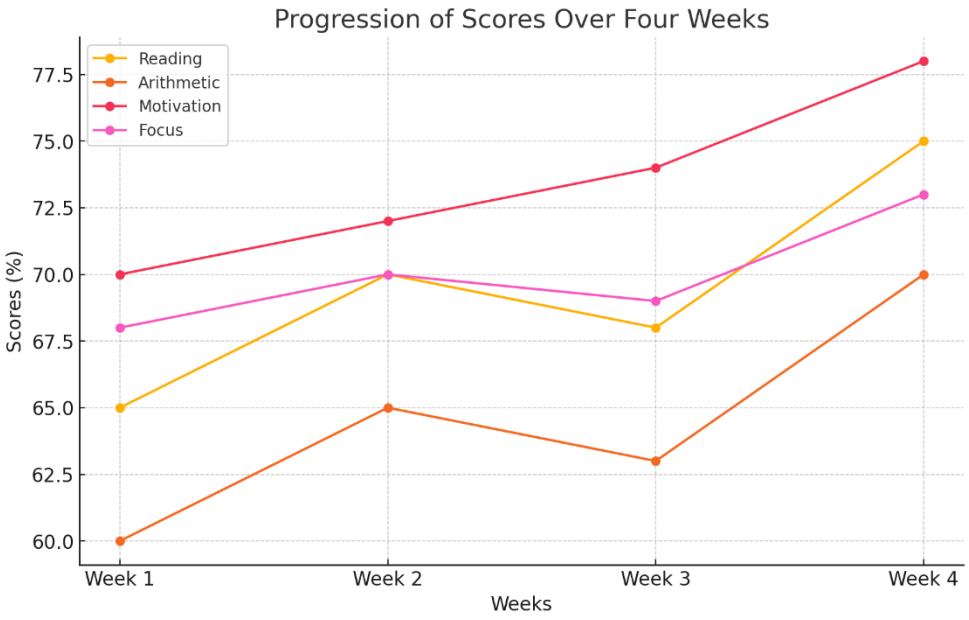


Figure 4. Progression of scores over four weeks

The reading skills of the students showed a gradual improvement over the course of the study. Starting at 65% in the first week, the score increased to 70% in the second week. There was a slight dip to 68% in the third week, followed by a rise to 75% by the fourth week, resulting in an overall 10% increase. This pattern indicated that while students faced minor setbacks, their overall ability to read mathematical problems improved steadily. In arithmetic, students began with an initial score of 60%,

which increased to 65% in the second week. Like reading, there was a slight decline to 63% in the third week, but the score improved to 70% by the fourth week, also marking a 10% overall increase. This trend suggested consistent progress in arithmetic skills, despite natural fluctuations.

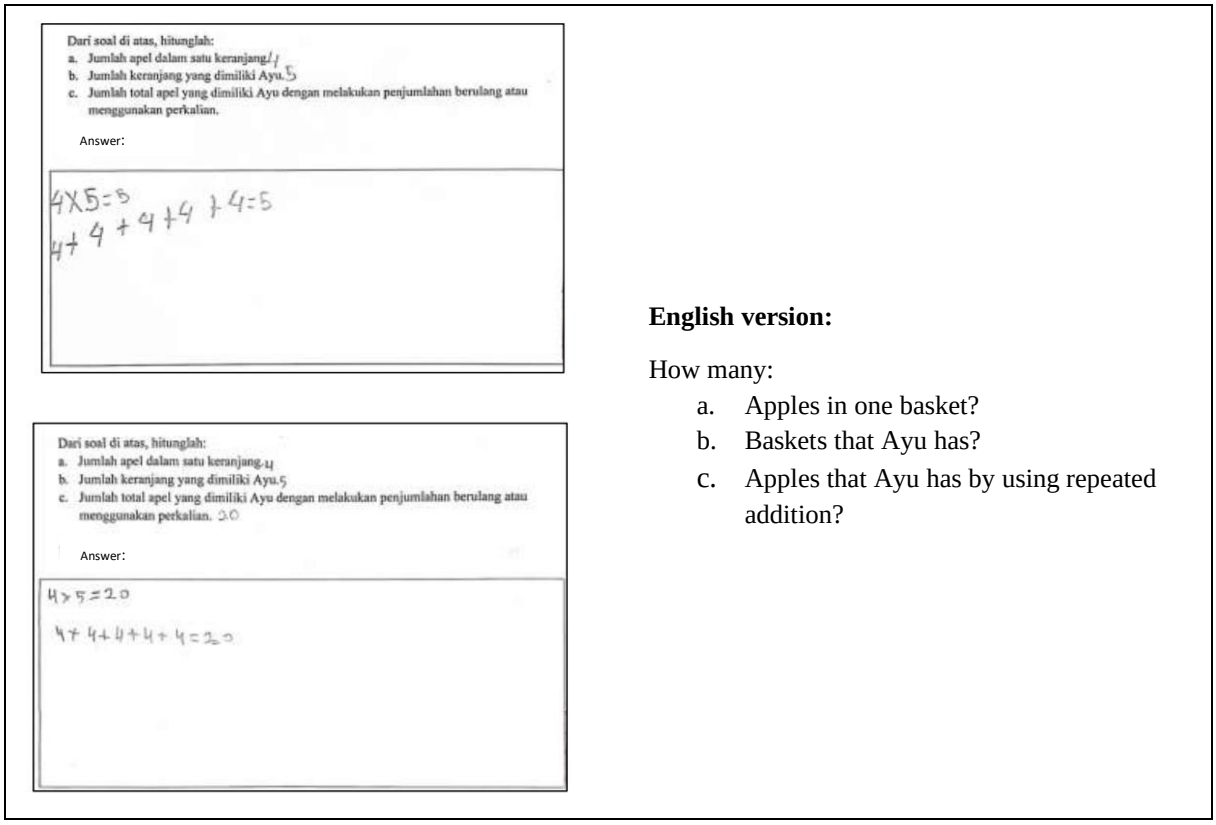


Figure 5. Examples of Student Answers Related to Arithmetic Ability

Figure 5 illustrates the effectiveness of the VLE's pedagogical components in improving students' arithmetic ability. As depicted in the first box (left), before fully adapting to the VLE's visual modelling approach, the student demonstrated computational errors, writing "$4 \times 5 = 9$" and "$4 + 4 + 4 = 5$". This initial response indicated difficulties in understanding multiplication concepts. However, through the VLE's interactive visualization features, particularly those with animated number lines and step-by-step visual representations of multiplication as repeated addition, significant improvement was observed.

The second box (right) illustrates the positive impact of the VLE intervention. After engaging with the visual modelling and interactive practice modules, the student correctly solved "$4 \times 5 = 20$" and showed proper understanding by writing "$4 + 4 + 4 + 4 = 20$". This improvement aligns with the VLE's design principles of providing clear visual supports and immediate feedback, which helped students better grasp the connection between multiplication and repeated addition. The progression from incorrect to correct solutions demonstrated how the VLE's structured approach, combining visual aids with interactive practice, effectively supported the development of arithmetic ability in students with ASD.

Motivation levels demonstrated a positive trend throughout the study. Starting at 70%, motivation slightly increased to 72% in the second week, continued to rise to 74% in the third week, and eventually reached 78% by the fourth week. This overall 8% increase indicated a growing interest and enthusiasm for learning mathematics, with students becoming more engaged over time. Focus showed a more modest improvement, beginning at 68% in the first week. The score increased to 70% in the second week, slightly dipped to 69% in the third week, and reached 73% by the fourth week, resulting in an overall 5% increase. This suggests that while there were minor fluctuations in attention, students generally became more focused during the learning sessions. Overall, the results demonstrated that the VLE has a positive impact on the mathematical skills, motivation, and focus of children with ASD. The gradual and natural improvements over the implementation period highlighted the effectiveness of the VLE in providing an engaging and supportive learning environment tailored to the unique needs of these students. The observed fluctuations indicated realistic learning patterns, emphasizing the importance of continuous support and adaptation in educational interventions.

The results from the implementation of the VLE indicated a positive impact on the reading, arithmetic ability, motivation, and focus of children with ASD. The gradual improvements observed in reading, arithmetic ability, motivation, and focus underscored the effectiveness of the VLE in providing a supportive learning environment tailored to the unique needs of children with ASD. These findings align with previous studies that emphasized the benefits of technology-enhanced learning environments for children with special educational needs (Chen & Bernard-Opitz, 1993; Moore & Calvert, 2000).

The improvements in reading and arithmetic skills observed in this study are consistent with the findings of Bosseler & Massaro (2003), who reported that multimedia and interactive elements significantly enhanced the learning outcomes of children with ASD. Similarly, the increase in motivation and focus is supported by the work of Boon et al. (2020), which found that children with ASD showed greater engagement and sustained attention when using educational technology. The slight fluctuations in weekly performance reflected natural learning patterns, as discussed by Parsons & Cobb (2011), who highlighted the importance of accommodating individual variability in educational interventions.

The findings suggest that VLEs can be an effective tool for improving the educational outcomes of children with ASD. By providing structured and engaging learning environments, VLEs can address the specific sensory, cognitive, and social needs of these students, thereby enhancing their overall learning experiences. This study contributes to the growing body of evidence supporting the use of technology in special education, particularly for children with ASD (Mayer & Sims, 1994; Plass et al., 1998). One of the limitations of this study is the relatively short implementation period of one month. Longer studies are needed to assess the sustained impact of VLEs on the educational outcomes of children with ASD. Additionally, the study sample was limited to a specific group of children, which may not be representative of the broader population of students with ASD. Future research should include larger and more diverse samples to enhance the generalizability of the findings. The positive

outcomes of this study have important implications for educational practice. Educators and policymakers should consider integrating VLEs into the curriculum for children with ASD to support their learning. Training teachers and parents on the effective use of VLEs can also enhance the implementation process and maximize the benefits for students. Moreover, continuous assessment and adaptation of VLEs are crucial to address the evolving needs of children with ASD (Odom et al., 2010; Strickland, 1996).

CONCLUSION

The implementation of the VLE for children with ASD demonstrated significant improvements in mathematical skills, motivation, and focus. The study's findings indicate that VLEs can provide an effective, supportive, and engaging educational environment tailored to the unique needs of children with ASD. The gradual improvements in reading and arithmetic skills, coupled with increased motivation and focus, highlighted the potential of VLEs to enhance learning outcomes. The positive feedback from expert validators further underscored the VLE's substance, design, content, and functionality, confirming its effectiveness and appropriateness for children with ASD. This study contributes to the growing body of evidence supporting the use of technology in special education. The results suggest that integrating VLEs into the curriculum can address the sensory, cognitive, and social needs of children with ASD, thereby improving their educational experiences and outcomes.

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