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Effectiveness of Abacus Hoop© Prototype on Primary School Students' Mathematics Achievement

Shiau Huai Choong[1*], Kien Kheng Foo[2], Hooi Joo Tang[3], Mei Lan Lai[4]
**Corresponding Author*

[1] Faculty of Applied Sciences, Tunku Abdul Rahman University of Management and Technology (TAR UMT), Kuala Lumpur, Malaysia
[2] Mindware PLT, Kuala Lumpur, Malaysia
[3] Jabatan Pendidikan Negeri Sarawak, Kementerian Pendidikan Malaysia, Putrajaya, Malaysia
[4] Jabatan Pendidikan Wilayah Persekutuan Kuala Lumpur, Kementerian Pendidikan Malaysia, Putrajaya, Malaysia

choongsh@tarc.edu.my, kienkheng@yahoo.com, tanghooijoo@moe.gov.my, g-68403052@moe-dl.edu.my
Tel: 03-4145 0123

Abstract
This paper presents a novel mathematics teaching aid designed to enhance primary school pupils' understanding of fundamental arithmetic concepts. Informed by Constructivist Learning Theory, which emphasises active learning through hands-on engagement with instructional materials, the Abacus Hoop© supports children in Year 1 through Year 4 in mastering the Numbers and Operations curriculum. The research utilised a Design and Development methodology based on the ADDIE model. Findings indicate positive feedback from both expert panels and pupils. The paper concludes with recommendations for future research and development to further advance primary mathematics education.

Keywords: Design and development; Mathematics teaching aid; Active learning; Constructivist Learning Theory

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1.0 Introduction

Malaysian mathematics education faces complex, multifaceted challenges at the elementary school level. The challenges include rote learning that hinders critical thinking and competency development. These young age students often feel disinterested in the subject and apprehensive (Anam et al., 2020). According to the Malaysian education system, Mathematics, as a core subject from the earliest stages of the school system, plays a prominent role in shaping students' academic experiences and influencing their attitudes towards mathematics learning. Many elementary school pupils were weak in comprehending mathematical concepts, particularly numeracy, which encompasses fundamental operations such as addition, subtraction, multiplication, and division (King & Purpura, 2021). These pupils need much help and guidance when learning arithmetic operations. This foundational numeracy forms the bedrock upon which further mathematical learning is built.

A common issue students face is difficulty with basic arithmetic operations, such as subtraction and addition. Several factors could be contributing to these difficulties, including the insufficient teaching aids that fail to support conceptual understanding, a lack of personalised feedback on homework and assessment, and limited use of effective instructional methods by teachers (Anam et al., 2020).

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Additionally, the traditional lecture-based teaching approach, which remains widespread across educational levels, including primary and tertiary settings, often neglects the diverse learning preferences of students who may benefit more from interactive and visual learning approaches (Choong et al., 2019; Recabarren et al., 2015).

With the aim of improving and engaging primary students' comprehension of mathematics, particularly in the Numbers and Operations curriculum, designing and developing an innovative teaching manipulative is critical to elevate the learning experience of these young learners. Traditional teaching methods often fail to provide young learners with a practical understanding, highlighting the need for more effective and engaging mathematical instruction. Recognising this challenge, there has been growing research attention on the development of teaching manipulatives, physical objects, and interactive tools to enhance mathematical understanding among schoolchildren. The Abacus Hoop© Prototype is a promising educational tool that promotes deeper conceptual learning through interactive, tactile experiences. Integrating physical manipulation with mathematical operations aims to engage students effectively across various learning styles and abilities (Bartolini & Martignone, 2020). The Abacus Hoop© enhances elementary students' understanding of basic arithmetic concepts, including addition, subtraction, fractions, and decimals, within the Numbers and Operations curriculum. This innovative teaching tool applies traditional abacus place-value principles by moving the beads on rods through a unique modern hoop structure, improving teaching methods in primary mathematics education and offering hands-on tactile learning experiences that foster meaningful learning and develop creativity. The specialty of this teaching tool lies in its versatility, which allows variations not only for the 4:1 Japanese Soroban abaci but also for the 5:2 Chinese Suanpan abaci, employing both visual and tactile learning methods to make abstract mathematical concepts more tangible and accessible for primary students. It serves both as a classroom teaching aid and as a tool for mathematics competitions, catering to students at various proficiency levels.

This paper primarily aims to develop and validate the Abacus Hoop© as an innovative, hands-on teaching-aid for primary mathematics. Specifically, the paper evaluates the tool's practical implementation by assessing its usability and effectiveness among school teachers, while simultaneously measuring its impact on students' understanding and engagement in mathematics lessons.

2.0 Literature Review

Among the challenges faced by primary education in Malaysia are actively promoting a deeper understanding of fundamental arithmetic operations such as addition, subtraction, fractions, and decimals, which are often one of the most important aspects in mathematical calculations, as well as effectively constructing meaningful learning experiences. Traditional teaching methods often fall short of sustaining interest and quality education in understanding these critical aspects of numeracy (King & Purpura, 2021). Guided by Constructivist Learning Theory, this paper introduces the Abacus Hoop© as an innovative teaching aid to enhance student engagement and comprehension of Numbers and Operations from Year 1 to Year 4.

2.1 Theoretical Framework: Integrating Constructivist Learning Theory and Abacus Hoop© Prototype

Followers of Constructivist Learning Theory posit that learners, when given a well-structured active learning framework, will actively interact with hands-on learning materials and develop their comprehension through practical experiences, rather than passively regurgitate information. The Constructivist Learning Theory offers an alternative perspective on how the physical manipulation of the teaching device could improve primary students' understanding of mathematical concepts, especially in the context of the Abacus Hoop© prototype. Past research has consistently demonstrated that interactive teaching aids and teaching manipulatives can deepen students' comprehension and engagement in learning (King & Purpura, 2021). Students render abstract concepts such as addition, subtraction, and place value more concretely and accessibly by envisaging arithmetic operations through physically moving beads on the Abacus Hoop©.

The application of Constructivist Learning Theory to the Abacus Hoop© prototype is consistent with contemporary educational methodologies prioritising experiential and active learning. In their study, Sultan, Woods, and Koo (2011) urge practitioners to focus on the efficacy of constructivist strategies in developing meaningful learning experiences. Part of the benefit of adopting these constructivist strategies is allowing students to build knowledge and facilitate their knowledge construction through hands-on activities. The Abacus Hoop© Prototype combines the traditional abacus principle with the contemporary educational theories, inaugurating the development of a dynamic learning tool that facilitates constructivist learning within the primary mathematics education settings.

The Abacus Hoop© prototype stimulates active collaboration and deeper cognitive processing in acquiring knowledge by engaging students in physical manipulation and visual representation of mathematical operations and their concepts. This approach, besides improving students' cognitive processing and also emphasise their mathematical reasoning abilities and problem-solving skills (Rich, 2021). According to research, students construct their own mathematical knowledge, which contributes to improved academic performance and a positive attitude towards mathematics, as well as to positive interactive dialogues, thereby moving away from teacher-centred learning.

The design and development of the Abacus Hoop© align with the Constructivist Learning Theory and offer substantial potential to revolutionise primary mathematics education. Its integration promotes active student engagement in constructing meaningful mathematical knowledge by allowing students to reflect on their learning, besides, aligning with educational advancements and improving learning outcomes. This prototype is a significant tool for enhancing long-term success by preparing students for future academic and subsequent professional challenges.

2.2 Hands-on Learning and Mathematics Education

While past research consistently shows that hands-on learning has a positive impact on academic performance and develops a positive attitude towards learning mathematics (León et al., 2021), a significant tension exists in the literature regarding the risk of over-dependence on physical tools at the expense of conceptual mastery. Some scholars caution that manipulatives may lack efficacy if not grounded in a cohesive instructional framework. The Abacus Hoop© responds to this limitation methodologically by integrating traditional place-value principles within a structured ADDIE-based development model. Unlike generic manipulatives, this prototype is designed to bridge the gap between concrete interaction and abstract reasoning through its unique hoop structure, which facilitates both visual and tactile learning modes simultaneously.

This investigation of the Abacus Hoop© as a novel teaching aid for primary mathematics education finds that the rationale for its integration remains compelling despite the apprehensions expressed by Hidayah (2021) regarding manipulatives. The existing literature reveals four primary justifications: Pedagogical alignment, Variability in efficacy, Supporting conceptual understanding, and Enhanced engagement and understanding. Hands-on activities using manipulatives such as the Abacus Hoop© consistently promote a positive attitude towards mathematics and enhance academic performance (Rich, 2021). Teaching aids like Abacus Hoop©, which enable students to physically manipulate the beads, do provide tangible representations that significantly aid in grasping abstract mathematical concepts, such as addition, subtraction, and place value. Although the efficacy of a manipulative depends on the instructional materials and student preferences (Choong et al., 2020), the Abacus Hoop©'s interactive nature provides a structured, engaging learning environment that mitigates these concerns (King & Purpura, 2021). It can potentially increase its utility in various educational environments by accommodating various learning approaches. Furthermore, the Abacus Hoop© facilitates a deeper conceptual understanding of mathematics by bridging the gap between concrete experiences and abstract concepts (Zulyusri et al., 2023). Notwithstanding this, some other advantages of using the Abacus Hoop© in the mathematics classroom are that it can confidently leverage the pedagogical value by ensuring its implementation effectively within a well-structured and cohesive instructional framework, thereby mitigating the possible risks of associating with an over-dependence on teaching manipulatives, as cautioned by the past literature (Jarrah et al., 2022). Consequently, the Abacus Hoop© is valid for this paper despite the arguments Jarrah et al. (2022) raised regarding the efficacy of manipulatives, particularly in the context of instructional design and student preferences. Its integration aligns with the objectives of this research, which aim to enhance primary mathematics education through innovative teaching aids. This implementation reinforces the value and relevance of the teaching aid Abacus Hoop©.

2.3 The Abacus and Mathematics Learning

Historically, the abacus has proven effective in improving mathematical abilities, particularly arithmetic understanding and mental calculation skills, and in enabling fast, paperless arithmetic calculations (Ravichandran et al., 2024; Wang et al., 2015). Recent meta-analyses further validate these findings, showing the significant benefits of abacus training across diverse educational settings. However, a significant tension exists in current literature regarding the long-term applicability and sustainability of abacus-based interventions. Contrary to this, there were scholars who argued that the ability to acquire transferable skills from learning the abacus to modern computational tools and applications (Wang et al., 2015). This questioning of the abacus's relevance in a digital age presents a conceptual limitation that this paper seeks to address.

In this paper, the Abacus Hoop© is designed and developed as an innovative tool for primary mathematics education that responds to these concerns by modernising foundational abacus techniques to bridge the gap between historical effectiveness and modern educational needs (Zuhroh, 2023). While some research suggests that the integration of digital technology is the primary solution for modernising mathematics, this paper identifies a practical tension: many schools in rural and less developed areas lack the digital infrastructure required for such technologies.

Historically, the abacus has consistently demonstrated positive outcomes, especially on the effectiveness in enhancing mental calculation skills and arithmetic comprehension. This positive outcome is supported by empirical research and meta-analyses (Li et al., 2020). Its adaptation in the Abacus Hoop© responds to modern educational needs by integrating digital platforms and technologies, and should be able to bridge the traditional benefits with current educational technology demands. This pedagogical approach, combining physical hands-on manipulation with digital interfaces, can cater to tech-savvy students while promoting cognitive development (Sukma & Priatna, 2021). This innovative hybrid pedagogy supports personalised learning environments and prepares students for future challenges, emphasising the mastery learning of essential mathematical competencies. However, many schools, especially in rural areas and less developed areas, are still not equipped with digital classrooms and computational technologies. The integration of physical manipulation and digital technology can be challenging in some contexts; one must be cautious. In spite of the above, while acknowledging the concerns raised by Wang et al. (2015) regarding the transferability of traditional abacus skills, the Abacus Hoop© is justified in this paper for its ability to innovate upon these foundational techniques, integrating them with modern educational needs and enhancing the learning experience in primary mathematics education.

The Abacus Hoop© methodologically responds to this disparity by offering a low-cost, tactile alternative that mirrors the cognitive benefits of digital interfaces without the requirement for expensive hardware. By innovating upon the traditional 4:1 and 5:2 abaci models within a unique hoop structure, this research justifies the tool's necessity as a means to enhance primary mathematics education while directly addressing the limitations of digital accessibility and the transferability of abstract numeracy skills.

3.0 Methodology

This study uses a Design and Development Research (DDR) methodology proposed by Richey and Klein (2014) that aligns with the ADDIE model. DDR involves three main phases: Analysis, Design, and Development. The ADDIE model framework shown in Figure 1

comprises five phases: Analysis, Design, Development, Implementation, and Evaluation. During the analysis phase, the researcher conducted a comprehensive literature review focusing on students' difficulties in mastering arithmetic operations to identify the need to develop the Abacus Hoop© prototype. The review indicated that students had a poor understanding of arithmetic and made mistakes in interpreting arithmetic operations (Na et al., 2015; Sukor et al., 2022). Following that, in the second phase, the design phase, the researcher produced a paper prototype, a paper drawing sketch, during the product design process. This paper prototype was developed to provide a clear picture of the product design (Miller, 2021), which has been widely adopted by many engineering designers. The paper prototype process helped the researcher to determine the dimensions, materials, and cost calculations involved in constructing the actual tangible prototype. The development phase involves constructing and developing the physical Abacus Hoop© prototype. The researcher built the Abacus Hoop© using a round wooden hoop, bamboo sticks, and craft beads. During the implementation and evaluation phase of the pilot testing, Abacus Hoop© was distributed to 5 primary schools purposively in the Sarawak area. Five teachers (users) used the Abacus Hoop© prototype to teach arithmetic and mathematics to 54 pupils. These five mathematics school teachers, with over 10 years of teaching experience in elementary schools, were appointed to validate the Abacus Hoop© using the Expert Validation Form. The data obtained during the validation process were analysed using the Percentage Agreement method to assess the product's usability and efficacy. Feedback data from the school teachers (users) and pupils (users) were collected and analysed. The research related to human use has been compiled in accordance with all relevant national regulations and institutional policies, in accordance with the tenets of the Helsinki Declaration, and has been approved by the Tunku Abdul Rahman University of Management and Technology (TAR UMT) institutional review board.

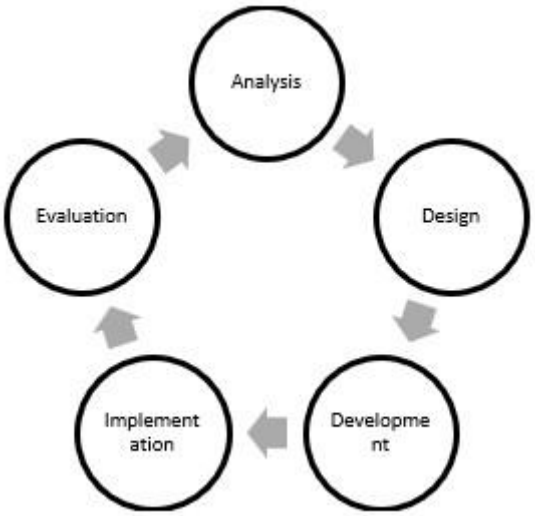

Figure 1: The ADDIE Instructional Design Framework applied to the development of the Abacus Hoop©

4.0 Findings

The Abacus Hoop© has successfully blended unique tactile and visual learning methods, and it has emerged as a valuable resource in primary mathematics education. This pilot study's results indicate that students' engagement and comprehension of arithmetic concepts have increased when using the Abacus Hoop© in the mathematics classroom. This positive outcome aligns with previous literature that emphasises the benefits of hands-on manipulatives for enhancing students' academic performance in mathematics (Shurr et al., 2021) and for fostering a more positive attitude towards learning arithmetic operations. The observed increase in students' engagement is consistent with past research demonstrating the effectiveness of tactile and visual learning methods, such as those used by the Abacus Hoop©, in making abstract mathematical concepts more tangible and accessible to young learners (Small-Bailey, 2021; Wang, 2020).

Using the Percentage Agreement Method, the panel of experts endorsed the usability and efficacy of the Abacus Hoop© during the expert validation phase with an average agreement score of 87.5%. This high validation agreement score undermines the significance of integrating innovative teaching aids together with a well-structured learning framework can enhance learning experiences in educational practices (Li et al., 2020). The acknowledgement by school teachers in the expert pool of the practical applicability and intuitive design of the Abacus Hoop© Prototype is consistent with previous literature, which suggests that a well-designed instructional aid improves student engagement and teaching effectiveness (Fisher et al., 2021). In addition to the above positive feedback from the expert panels, this study also collected feedback from students. The received reviews from the students further substantiate the effectiveness of this Abacus Hoop© manipulatives. Students' feedback was positive, and they also reported a genuinely enjoyable experience with the tool, noting its engaging learning process. This aligns with previous research highlighting the motivational advantages of interactive and personalised learning manipulatives in primary mathematics education, especially in the arithmetic curriculum (Wang, 2020). Through these insights, the potential of Abacus Hoop© is not only to complement traditional instructional methods but also to bridge educational gaps in mathematics instruction, despite acknowledging its limitations, such as its suitability primarily for in-class activities rather than standardised tests (Miller, 2021).

5.0 Discussion

Through deliberate planning in executing the Abacus Hoop© Prototype research in this paper, the Constructivist Learning Theory posited that learners actively construct their understanding of the world through experiencing and reflecting on those experiences through deep learning. The Abacus Hoop© with its tactile design, has been shown to improve student engagement and learning experiences. The results are consistent with the Constructivist Learning Theory's emphasis on active learning strategies and hands-on exploration (Choong et al., 2020). The Abacus Hoop© enables students to interact directly with mathematical concepts, particularly the arithmetic addition and subtraction operations, thereby facilitating the construction of abstract mathematical knowledge through the physical manipulation of beads up or down on the hoop, mimicking the place value in arithmetic learning. With this approach, Abacus Hoop© improves conceptual comprehension, encourages meaningful engagement and deeper retention of learning outcomes, thereby fostering meaningful learning experiences and sharpening critical thinking skills in mathematics (León et al., 2021; Ravichandran et al., 2024).

The Abacus Hoop©'s tactile and visual features unequivocally support Constructivist Learning principles by providing students with hands-on learning experiences that bridge the gap between abstract mathematical concepts and real-world applications. By physically manipulating the beads, students can use the Abacus Hoop© to visualise numerical relationships and experiment with different mathematical problem-solving strategies, enhancing their problem-solving and critical thinking abilities.

By applying the Constructivist Learning Theory to evaluating the Abacus Hoop© yields significant educational implications are yielded. Subsequently, educators can optimise the design and implementation of this teaching aid to accommodate a wider range of learning contexts and requirements (Zuhroh, 2023). Following this, the present research strongly encourages the continual development of more innovative educational technologies to enhance students' learning experiences in mathematics and/or other STEM subjects. In summary, the Abacus Hoop© leverages the educational framework of Constructivist Learning Theory, blends modern design with the traditional abacus principle, and thus enhances active and personalised learning engagement and deepens understanding of mathematical concepts. This Abacus Hoop© teaching aid addresses various instructional gaps and underscores the role of Constructivist principles in improving educational outcomes. This paper contributes to the growing body of literature advocating the validation of more innovative teaching aids,s especially for primary mathematics education, and aligning with current pedagogical trends.

6.0 Conclusion and Recommendations

The paper confirms the great promise of Abacus Hoop© by aligning with the Constructivist Learning Theory framework and enhancing student learning experiences through hands-on interaction with the teaching aid, thereby transforming the primary mathematics education landscape. The research not only emphasises the benefits of tactile and visual learning methods for students, but also fosters academic performance and positive attitudes towards mathematics. Combining traditional abacus principles with contemporary design, the Abacus Hoop© effectively supports the fundamental learning of mathematical concepts for students in Years 1 to 4. Pilot testing and expert validation emphasise its pedagogical value, with an 87.5% validation score from mathematics experts, validating its usability and effectiveness as an instructional tool and manipulatives. Besides, the feedback from the primary students was generally positive, with most satisfied with its use and functionality.

Acknowledging the shortfall of this research, which is the small scale of pilot testing, in the future, the researcher urges conducting larger-scale studies so that a more comprehensive understanding of the Abacus Hoop©'s effectiveness can be obtained across diverse classroom settings. Suggested future studies include exploring how the Abacus Hoop© can help bridge educational disparities and promote effective teaching practices, as well as designing a well-structured learning module that incorporates the Abacus Hoop© in primary mathematics education. By expanding this research to other educational contexts, more researchers and practitioners can further explore the vast potential of the Abacus Hoop© in advancing mathematics education. This will align with the ongoing initiatives to integrate innovative educational tools that enhance student learning and promote 21st-century skills.

In conclusion, the preliminary research on Abacus Hoop© sheds light on the primary mathematics education. Rooted in the Constructivist Learning Theory framework, the hands-on manipulatives like Abacus Hoop© boost student engagement and facilitate active learning among primary students. This paper makes a valuable contribution to the evolving field of mathematics educational research. Subsequently, it enhances the teaching practices and improves student learning experiences in mathematics.

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Paper Contribution to the Related Field of Study

This paper not only contributes to the Constructivist Learning Theory but also to the growing body of literature advocating the validation of more innovative teaching aids, especially for primary mathematics education, and aligning with current pedagogical trends. Subsequently, it enhances the teaching practices and improves student learning experiences in mathematics.

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